MANAGING THE FLOW OF SCIENTIFIC AND TECHNOLOGICAL INFORMATION

by

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B.S., Physics, Upsala College (1954)
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Signature of Author
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Thesis Supervisor

Accepted by ....
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Submitted to the Alfred P. Sloan School of Management on August 22, 1966 in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

Over the past ten years, behavioral scientists have become increasingly interested in the flow of technical information among scientists and engineers. This thesis summarizes many of the results attained over this period and presents new evidence gained from the study of sets of parallel R&D projects.

Data were gathered by means of time allocation forms submitted by individual engineers, tape recorded periodic progress reports by the project managers, Solution Development Records -- a form which provides a weekly estimate of the probability of adoption of the approaches under consideration as possible solutions to a technical problem -- and post-project interviews with the engineers responsible for each of the project's subproblems.

The parallel nature (two or more R&D teams assigned the same set of problems) of the projects studied comparisons can be made between the information gathering patterns of the teams, holding the substance of the problems constant. In addition, since evaluations of relative performance were obtained, the information patterns are compared on the basis of their relation to performance.

Scientists are found to rely more heavily upon written than oral sources of information, while for technologists the pattern is reversed.

For technologists, the organization to which they belong imposes rather severe barriers to communication. Communication across organizational bounds is relatively ineffective, and intramural communication, while relatively effective, is little used.

The flow of technical information to a member of an industrial organization follows a multi-step pattern, with certain individuals serving as key links to the outside world, through either the literature or oral contacts outside of their own laboratories.

Thesis Advisor: Donald G. Marquis

Title: Professor of Organizational
Psychology and Management

Professor William C. Greene
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Professor Greene:

In accordance with the requirements for graduation, I herewith submit a thesis entitled, "Managing the Flow of Scientific and Technological Information."

Sincerely yours,

Thomas John Allen

Acknowledgements

As the contents of this thesis testify, scientific work is seldom, if ever, accomplished in a vacuum. Contributions come from far and wide, and as a result the acknowledgement page in most dissertations is a long and often tedious accounting of services received. If the present page is an exception, it is only because the list will be longer than usual. The contributors to the present work have been many, and to be complete, a listing of them would have to include all of my students in course 15.04, "Psychology and Human Organization" upon whom many of the ideas were first attempted.

My intellectual debt to Donald G. Marquis is indeed profound. It was he who first aroused my interest in behavioral research and overcame my first love, engineering. Ever since, he has been generous with his ideas, time and friendship, and without his encouragement and assistance the research would never have been possible.

To Edward B. Roberts, Irwin M. Rubin, and Richard B. Maffei, whose influence was instrumental in my decision to pursue the doctorate at an already advanced age, I can only say that I will do my very best to warrant their confidence.

Professors Edward B. Roberts, Richard S. Morse and William F. Pounds -- the members of my committee -- have all aided me in many ways, and I am especially grateful for their recommendations and aid in clarifying the presentation.

As for the research itself, first acknowledgements must go to the National Aeronautics and Space Administration which provided initial support under grant NaNsg 235-62 and to the National Science Foundation which has provided support for the past two and one half years under grants GN 233 and GN 353. In addition, I must gratefully acknowledge the aid of Maurice P. Andrien, Jr., Richard J. Bjelland, Stephen I. Cohen, Richard H. Frank, Daniel S. Frischmuth, Peter G. Gerstberger, Arthur Gerstenfeld, Milton L. Lavin, and William D. Putt who served as research assistants during various phases of the project and who contributed many of the methodological twists, and express my appreciation to the cooperating companies, project managers and engineers who must remain anonymous, but without whose help the study could not have been conducted.

For the manuscript, I must thank Katherine Blakeslee who typed the rough drafts and helped edit Part II and Virginia Stupak who typed the final draft. My friend of many years, John A. Wright, edited Part I and provided many valuable comments which have helped to greatly clarify the presentation.

Finally, I wish to express my very deepest thanks to my wife, Joan, who alone knows the many lonely hours which she invested in the preparation of this thesis. It was Joan, who motivated me to enter graduate school at M.I.T., and without her continuing support, I would never have reached the position of writing this list of acknowledgements.

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For the several employments and offices of our fellows, we have twelve that sail into foreign countries under the names of other nations (for our own we conceal), who bring us the books and abstracts, and patterns of experiments of all other parts. These we call Merchants of Light.

We have three that collect the experiments which are in all books. These we call Depredators.

We have three that collect the experiments of all mechanical arts, and also of liberal sciences, and also of practices which are not brought into arts. These we call Mystery-men.

We have three that try new experiments, such as themselves think good. These we call Pioneers or Miners.

We have three that draw the experiments of the former four into titles and tables, to give the better light for the drawing of observations and axioms out of them. These we call Compilers.

We have three that bend themselves, looking into the experiments of their fellows, and cast about how to draw out of them things of use and practice for man's life and knowledge, as well for works as for plain demonstration of causes, means of natural divinations, and the easy and clear discovery of the virtues and parts of bodies. These we call Dowry-men or Benefactors.

Then after divers meetings and consults of our whole number to consider of the former labours and collections, we have three that take care out of them to direct new experiments, of a higher light, more penetrating into Nature than the former. These we call Lamps.

We have three others that do execute the experiments so directed and report them. These we call Inoculators.

Lastly, we have three that raise the former discoveries by experiments into greater observations, axioms, and aphorisms. These we call Interpretators of Nature.

We have also, as you must think, novices and apprentices, that the succession of the former employed men do not fail; beside a great number of servants and attandants, men and women. And This we do also: We have consultations, which of the inventions and experiences which we have discovered shall be published, and which not: and take all an oath of secrecy for the concealing of those which we think fit to keep secret: though, some of those we do reveal sometimes to the State, and some not.

Bacon (in describing his proposed research laboratory, Salomon's House), in The New Atlantis, (Johnson 1965).

CHAPTER 1

INTRODUCTION

Merchants of Light, Depredators, Mystery-men, Miners, Compilers, Benefactors, Lamps and Inoculators, they all share a common concern and responsibility for the processing of information. Information processing is now and always has been the basis of scientific activity. As physical systems consume and transform energy, so does the system of science consume, transform, produce and exchange information. Technology, too, is an ardent consumer of information. But as in most physical systems consuming energy, technology produces transformed information primarily as a by-product. The principal output in the system of technology is, of course, physical "hardware." Even though it is a by-product, information does not occupy a position of sufficient importance for it to have become to some degree a commodity of exchange within the system.

Information processing in science is thus different in nature from information processing in technology. This distinction between the processes and products of science and technology should be borne in mind in reading the following pages. It is a distinction which lies at the heart of, and is responsible for many of the differences in behavior between the two communities of science and technology.

Information in science retains its verbal form throughout the process; as a result it is readily contained and stored in a written form. In the case of technology, information is used to direct and mold the energic inputs which become the final product. And excepting the extent to which transformed information is produced as a by-product, it loses its form and becomes coded in the structure of physical output.[1] True enough, this structure can very often be decoded as is done, for example, in the analysis by U.S. aircraft experts of the technological information contained in captured Soviet Mig fighters, or in the analysis by commercial R&D laboratories of competing firms' products. But coded in this way it is much less accessible, and is certainly much more difficult to physically exchange. Decoding from physical structure is then resorted to only when, for some reason as the unwillingness on the part of one party to the exchange, the by-product information is unavailable. But even when it is readily available, the fact that this information is a by-product of the technological process introduces certain factors which not only distinguish the technological situation from the scientific, but also in many ways impede the flow of technological information.

Both science and technology consume information and by somewhat different processes transform it into either new information or use it to modulate the flow of physical and energic inputs to structure a physical product. Both are then highly information dependent systems. The quality of their products is to a very large degree dependent upon the quality of their information intake. And as activity in science and technology increases in magnitude, the problem of insuring quality becomes both more important and more difficult to accomplish. The quality of the output is, of course, highly dependent upon the quality of the input to either system. And since an important part of the inputs is in the form of information, it becomes quite important to ensure quality inputs of information.

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[1] This is one reason, by the way, that historians of technology confront a much more difficult task than do historians of science.

We know that historically one of the principal contributors to the economic growth and well-being of the United States has been the ability to draw upon the world's fund of scientific knowledge and to transmute that information into technological substance. Furthermore, since World War II, the U.S. has become the world's foremost source of scientific as well as technological knowledge. The generation of scientific information has grown into a key industry whose output is a major national resource. As such it can be as important to the future of the nation as any other resource, provided that it is wisely exploited. As with other resources, its usefulness will be highly dependent upon the effectiveness and efficiency with which it is put to use.

Unlike most physical assets, science is not a dormant body of material which can be drawn upon as needed. It is, rather, a dynamic quantity, integral with, and absolutely essential to the process by which it is generated. Research is a process which feeds upon itself, and the communication of the products of research is of paramount importance to the proper nurturing of the process. Research and development cannot be envisaged without communication of results. The tremendous increases in recent years in the amount of research and development performed in this country has resulted in a concomitant increase in the amount of information to be communicated, presenting the user with the difficult problem of plowing through a morass of available information to reach that which is pertinent to his problem.

Studies (Price, 1961) showing an exponential growth rate of scientific journal articles and manpower are too well known to require explication here, but they provide the stimulus for much of the concern displayed during the last few years. The now famous report of the President's Science Advisory Committee (1963) noting this trend warns of the impending danger that science may fragment into a "... mass of repetitious findings, or worse, into conflicting specialties that are not recognized as being mutually inconsistent."[2]

The response of these forebodings has for the most part taken the form of research aimed at improving existing information systems or developing new ones. This end is being accomplished through studies of both hardware[3] and software[4] techniques. The key problem in this response has been well stated by Saul Herner (1959):

> Perhaps the most important and least considered factor in the design of information storage and retrieval systems is the user of such systems. Regardless of what other parameters are considered in the development of a storage and retrieval mechanism it is necessary to consider its potential use and mode of use by the persons or groups for whom it is intended; it is necessary either to fashion the system to suit the user's needs, habits, and preferences, or to fashion the user to meet the needs, habits, and preferences of the system. Both approaches are possible, but the second one, involving education and re-education of the user, is evolutionary and futuristic. A system designed for now should at least be able to serve the present user.

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[2]For a dissenting voice, Cf. Bar-Hillel (1963).

[3]See, Kuipers, et. al., 1957; Nelson, 1958; Ware, 1960; Fasana, 1963; Bauman, 1962.

[4]Borko, 1956; Buckland, 1965; Casey et. al., 1958: Freeman, 1965; Hillman, 1965a, 1965b; Kessler, 1965; Johnson, 1963; Kessler and Ivie, 1964; Jennings, 1964; Melton, 1965; Mooers, 1956; Simonton, 1963; Salton, 1965; Wilson, 1964.

User Studies

Concurrent with these efforts, which hope to actually improve the flow of scientific information, a number of studies were initiated whose purpose is to determine empirically the manner in which the existing communication system functions.[5] These studies of scientific communication in process have come to be known as "user studies," and have the following three general goals (Menzel, 1962):

1. to distinguish the types of informational needs which scientists have, and to determine in what respects they remain unsatisfied.

2. to examine the means and occasions of scientific information exchange, in order to single out the features which make them more or less able to meet the scientists' several needs.

3. to analyze characteristics of the scientists' specialty, his institution, and his outlook as possible conditions which influence his needs for information, his opportunities for satisfying them, and hence, his information-gathering habits and felt satisfactions.

In sum, the purpose of user studies is to define the problem as it exists and thereby provide direction not only to those who are designing improved systems and techniques of communication, but to those policy-makers whose task it is to determine the relative emphasis and direction that such improvement programs should take.

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[5] See, Menzel, 1962; Ackoff and Halbert, 1958; Halbert and Ackoff, 1960; Bernal, 1959; Cole, 1958; Fishenden, 1959; Glass, 1959; Herner, 1954; 1959; Hogg and Smith, 1959; Mote and Angel, 1962; Martin, 1962; McLaughlin, et. al.,1965; Scott and Wilkins, 1957; Tornudd, 1959; Voight, 1959; Allen, 1964; 1966b; 1966c; Allen, Andrien and Gerstenfeld, 1966; Berul, 1965; American Psychological Association, 1963; 1965.

Brownson (1960) describes some 30 user studies which had been completed to that date; at least ten additional major projects have been initiated since then. Menzel (1960), in reviewing completed studies, voiced the criticism that all too often they are content "... to report descriptive distributions, or simple cross-tabulations, with few attempts at interpretations based on more than one ...'fact'."

The first purpose of the present volume is to report and interpret the results of a major study of user requirements which has been conducted in the M.I.T. Sloan School of Management over the past three years. A second purpose is to relate these findings to those of other "user studies" showing where conclusions are strengthened by several pieces of evidence and attempting to interpret the reasons underlying contradictions, apparent or otherwise, as they occur. In this way, it is hoped to knit together a coherent statement of the manner in which both the scientific and technological communities in the United States presently maintain themselves abreast of the "research front" or "state-of-the-art."

The Plan of the Study

For the past three years, a team of researchers at the M.I.T. Sloan School of Management has been engaged in the study of information use over the course of active R&D projects. Data concerning information sources used have been gathered "live" during the actual R&D process. This approach limits the errors of memory which are a necessary concomitant of survey research. Since the sample comprises a respectable number of projects (19), the results are generalizable (within certain sample limitation

The research strategy has been to combine the advantages of both the sample survey method, and of the intensive single case method, while, hopefully, avoiding the drawbacks of both these approaches.

In addition, we have stolen a cue from biological scientists (Cf. Beveridge, 1950) and psychologists, who control a large component of the sample variance by comparing matched pairs of subjects (twins), and have located a number of instances of "twin" research projects. The use of matched pairs controls for that variance which results from the substantial nature of the R&D problem studied. It also eases the criterion problem, since relative evaluations of problem solutions are much easier to make and are more accurate than absolute evaluations.

The volume will center its attention upon an analysis and interpretation of the data gathered during the study of parallel R&D projects. The evidence is quite extensive and comprises not only data in several forms, but also covers a wide variety of user behavior. Throughout the analysis, information gathering behavior will be observed and related to actual problem solving performance. Although there are a number of areas in which this goal has been impossible to achieve, for the most part the study is focused upon this all-important relation between information inputs and the quality of the output from the R&D process.

Working outward from this focus, the study will compare and contrast the results of a number of other user studies, and in several important areas it will be extended through consideration of other studies into areas in which the evidence from the parallel projects is incomplete or non-existent.

The volume will be divided into two principal parts. Part I is devoted to an analysis of the information system in science; Part II is concerned with the information system in technology. The two systems, it will be seen, differ in many ways, and it is on the basis of an analysis and comparison of the observed behavior of scientists and technologists in the several studies considered in this volume that an ex post facto division was made. Many early studies of information use failed to differentiate among the various types of work performed by scientists and engineers, and thereby failed to discover the variance in information gathering behavior which is displayed. Recent studies, notably Mote (1962) have demonstrated the error which results from ignoring this inter-category variance, and divide their samples on the basis, usually, of the position in the spectrum from basic research to development and test of the work performed by the subjects. At this point in the development of our knowledge, the most usual such division is simply dichotomous: a division into science and technology. The present study follows this scheme, dividing on the basis of the conceptualization presented at the beginning of the chapter. Those projects whose principal and only product is new information will be included in the category of "science"; those whose principal product is physical hardware of some sort, a study report devoted to the techniques for incorporation of information in a physical structure will be considered "technology."

Applying these definitions, one set of parallel projects quite clearly fits the science definition; the remainder are equally clearly technological in nature. A problem arises, however, as we turn to the classification of other user studies. Seldom does a research report provide sufficient information for the application of the above criteria. We will, accordingly, have to judge from the information provided whether the work was scientific or technological, generally relying upon the authors' judgment as to whether the work was basic research, applied research, development or any of a number of other categories which have been used. In each case cited, we will clearly state the authors' description of the subject population, and the reader may then agree or disagree with our placement into the present category system.

Each of the two sections is divided into a number of separate and somewhat parallel chapters. Each chapter is in turn devoted to the consideration of a specific problem, or the operation of a specific set of information channels. Each cluster of channels will be considered with respect to functions performed and to both their mutual interaction and their relation to channels outside of the set. This consideration of channels, functions, and interactions will take into account, where possible, the effects which policies to promote specific channel performance, or to improve the manner in which certain functions are provided, will have on the operation of other channels. This will be done to provide the system designer with warning of the possible detrimental side effects of some forms of channel enhancement. Menzel (1965) cites as an extreme example the case where retrieval systems are developed to such a degree that they eliminate browsing and thereby put an end to occasions where a scientist's attention is called to information which he has not foreseen as pertinent to his own work.

CHAPTER 2

RESEARCH METHODS

In all user studies to date, the judgment of the researcher has been the only criterion of the value of the information. No objective, external evaluation of solutions has been developed to relate to information handling and utilization. In order to accomplish this goal, one must first overcome a fundamental difficulty which arises in the study of almost any aspect of science or technology and which stems from the obvious fact that each research problem is unique. There is ordinarily no opportunity to repeat your observations, because two projects, two groups or two individuals do not undertake to perform the same research. If it has been done before, it is no longer research.

The Parallel Projects

The Performance Criterion

To surmount this basic problem and to properly evaluate the performance of the various information sources leading to specific solutions, we have sought out instances in which two or more R&D groups attempt the same problem. This matched case approach is analogous to the research strategy employed by experimental psychologists in the study of human problem solving behavior. By assigning the same problem to large numbers of college students, the substance of the problem is controlled and a comparison of of subjects' approaches is made possible.

While social scientists have not reached such a level of affluence that they can hire a number of engineers and assign them the same problem, there are organizations (e.g., in the United States, the National Aeronautics and Space Administration, and the Department of Defense) who can, and do make a fairly regular practice of this. For that reason the matched cases presented in the present volume are all ones in which two or more R&D laboratories are awarded a contract to perform the same design study or investigation.

Once a parallel project of this type has been located, the contractual work statement is obtained and analyzed and factored into a reasonable number of subproblem areas (generally subsystems). This breakdown is checked with the technical person who prepared the work statement. Forms for the collection of data from the project teams are then designed. Data are gathered by four means: (1) time allocation forms, indicating the amount of time each engineer spends on the job in several categories; (2) before and after interviews with individual engineers; (3) periodic tape recorded progress reports by the project manager, and (4) a special form which we have christened the Solution Development Record. Upon completion of the project, relative evaluations are obtained from responsible technical personnel in the government laboratory, of the subsystem solutions submitted by the two or more R&D teams.

Time Allocation Forms

An example of a time allocation form is presented in Figure 2-1. Respondents are asked simply to record each day's activity in four categories: time spent in literature search; time spent in consultation with technical experts within the laboratory, but not assigned to the project; time spent

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Time Allocation Form

Name ______________________ Date ______________

Activity \ Day	Sun.	Mon. DATE	Tues.	Wed.	Thurs.	Fri.	Sat.
Analytic Design							
Literature Search							
Consultation with Specialists within the Company (but not on the research team)							
Consultation with Experts outside of the Company (paid or unpaid, formal or informal)							
Total time on the Problem							

FIGURE 2-1 TIME ALLOCATION FORM

in consulting with experts outside the laboratory; and time spent in analytic design.

Progress Reports

Several of the project managers agreed to provide a tape recorded resume of each week's (or in some case, month's) activity in each subproblem area. The format for the reports was left quite unstructured but each project manager was provided a list of subject areas (subproblems or subsystems) on which his comments were desired. The data from these reports are used principally to aid in interpretation of data obtained by other mechanisms from the engineers or scientists, and will not appear separately anywhere in the discussion of results.

The Solution Development Record

The Solution Development Record, which is the source of many of the data presented in this volume, is a research tool which provides a record over time of the progress of an individual engineer or group of engineers (or scientists) toward the solution of a technical problem. The individual engineer, or in the case of a group,[1] the lead engineer responsible for each subproblem is asked to provide a weekly estimate, for each alternative approach under consideration, of the probability that it will be finally chosen as the solution to that subproblem (Figure 2-2).

If at some point in the design the respondent were considering two technical approaches to providing electrical power for the space vehicle,

[1]Groups, when they existed seldom comprised more than two men.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Solution Development Record
Manned Uranus Landing in an Early Time Period Study
General United Aerospace Corporation

Name________________ Date______________

Subproblem #1: Design of the electrical power supply subsystem for the space vehicle

a. Alternative approaches:

Alternative approaches	Estimate of Probability that Alternative will be Employed										
hydrogen-oxygen fuel cell	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
KOH fuel cell	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0,9	1.0
Rankine cycle thermal reactor	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Brayton cycle reactor	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
____________	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
____________	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

b. Alternative approaches:

Alternative approaches	Estimate of the Likelihood that Alternative Will Satisfactorily Perform (meet or exceed specification)					
hydrogen-oxygen fuel cell	certain	very likely	rather likely	tossup	somewhat unlikely	quite unlikely
KOH fuel cell	certain	very likely	rather likely	tossup	somewhat unlikely	quite unlikely
Rankine cycle thermal reactor	certain	very likely	rather likely	tossup	somewhat unlikely	quite unlikely
Brayton cycle reactor	certain	very likely	rather likely	tossup	somewhat unlikely	quite unlikely
____________	certain	very likely	rather likely	tossup	somewhat unlikely	quite unlikely
____________	certain	very likely	rather likely	tossup	somewhat unlikely	quite unlikely

c. If information which had a serious impact upon your visualization of the problem or any of its potential solutions was received at any time during the past week, please circle the source(s) of that information on the line below. Sources are defined on the reverse side.

Information Source: L V C ES TS CR PE E

comments (if any):______________________________

____

d. Please estimate the percentage technical completion of the portion of the project with which you are concerned ____%. (This need not be a monotonically increasing function of time. Since it is a subjective estimate and since R&D is characterized by the continual discovery of new problem areas, this estimate may decrease as well as increase from week to week).

Figure 2-2. The Solution Development Record and he were completely uncommitted between the two, he would circle 0.5 for each. If more than two approaches are under consideration, probabilities would of course be distributed differently, but in all cases would sum to one. Eventually, as the solution progresses, one alternative will attain a 1.0 probability and the others will become zero. By plotting the probabilities over time we obtain a graphic record of the solution history. Alternative approaches are identified from the contract work statement, when so specified, or from the responsible engineer when he is interviewed prior to beginning the task. Blank spaces are always provided so that new approaches may be reported as they arise. In cases where a respondent believes there is some probability of choosing an approach which he cannot clearly specify at the time, he is instructed to assign a probability to an approach which he may call "other."

In addition to the probability estimates the respondent is also asked to indicate for each alternative his certainty over the likelihood that it will satisfactorily perform its intended mission. This dimension is quite independent of probability and is best described by considering situations in which a probability of 0.5 is assigned to each of two alternatives. This could result from either of two situations. First, would be the case in which both alternatives are equally satisfactory and it makes little difference which is chosen; either one will work. A quite different circumstance arises when both alternatives are equally unsatisfactory but one must be chosen, since nothing else presents itself. The engineer or scientist's information gathering behavior can be expected to differ quite drastically in these two cases.

A third section of the form allows the respondent to report the source of any important messages, which he received during the previous week. These data are used to aid in interpreting the probability plots and in aiding the respondent's memory during the post-project interview. The code used for channels is shown in Table 2-1.

Table 2-1

Information Sources

L = literature:	books, professional, technical and trade journals and other publicly accessible written material.
V = vendors:	representatives of, or documentation generated by suppliers or potential suppliers of design components.
C = customer:	representatives of, or documentation generated by the government agency for which the project is performed.
ES = external sources:	sources outside the laboratory which do not fall into any of the above three categories. These include paid and unpaid consultants and representatives of government agencies other than the customer agency.
TS = technical staff:	engineers and scientists in the laboratory who are not assigned directly to the project being considered.
CR = company research:	any other project performed previously or simultaneously in the lab regardless of its source of funding.
PE = personal experience:	ideas which were used previously by the engineer for similar problems and are recalled directly from memory.
E = experimentation:	ideas which are the result of test or experiment with no immediate input of information from any other source.

The final request is for an estimate of the percentage technical completion of the portion of the project with which the respondent is concerned. Since progress is usually independent of calendar time, this affords a perhaps more realistic time base against which to compare information gathering behavior.

Over the course of a project, a copy of the form is mailed every week to each respondent. The forms are sufficiently flexible so that new alternatives may be incorporated, old ones dropped, and in instances in which an early solution is reached and "frozen," subproblems at the next level may be substituted.

The Solution Development Record, by economizing on the respondent's time, provides a quite efficient record of a project history. When the project is completed, each respondent is presented with a time-plot of his probability estimates, and is interviewed at some length to determine causes and effects of design changes reflected in this record. The plot thus provides a stimulus to the man's memory and assists the investigator in gathering a detailed record of each project.

Interview Data

Cooperating engineers and scientists are interviewed prior to the initiation of a project in order to determine the alternative solution candidates that they are considering at that point and to obtain a feeling for the manner in which the man's previous experience relates to the project at hand.

Following completion of the project, each respondent is presented with the time plot of his Solution Development Record estimates and interviewed in depth to determine the causes of changes in the probability levels assigned to each alternative; the reasons for discarding alternatives; and the information sources which were used throughout the study for such functions as the generation of alternatives, generation of critical dimensions of the problem, test of alternatives against critical dimensions, etc. The length of interview ranges from a half hour to an hour per man, but a few have run for several hours.

The interviews are tape-recorded and are later coded to determine the information sources used for each of the various R&D functions as shown in Figure 2-3. Figure 2-3 is an empirically derived model of the R&D problem solving process (Frischmuth, 1966), and is used by the coders to assist in categorizing the various functions for which information is sought and used. Inter-coder reliabilities have ranged from 80 to 90 percent.

An Example

To further illustrate the research method and the nature of the data obtained, a single subproblem has been selected from one of the projects studied, and the solution process for the subproblem will be described in some detail. The plot of Solution Development Record points over time provides a rather interesting perspective on the history of this solution process (Figure 2-4), and illustrates the intimate relation between technical information inputs and the form of problem solving that we generally call engineering design.

We can see here the approaches followed by two engineering groups, Lab A and Lab B, in the design of the reflector surface for the antenna. While both teams ultimately decided upon the same general approach, they

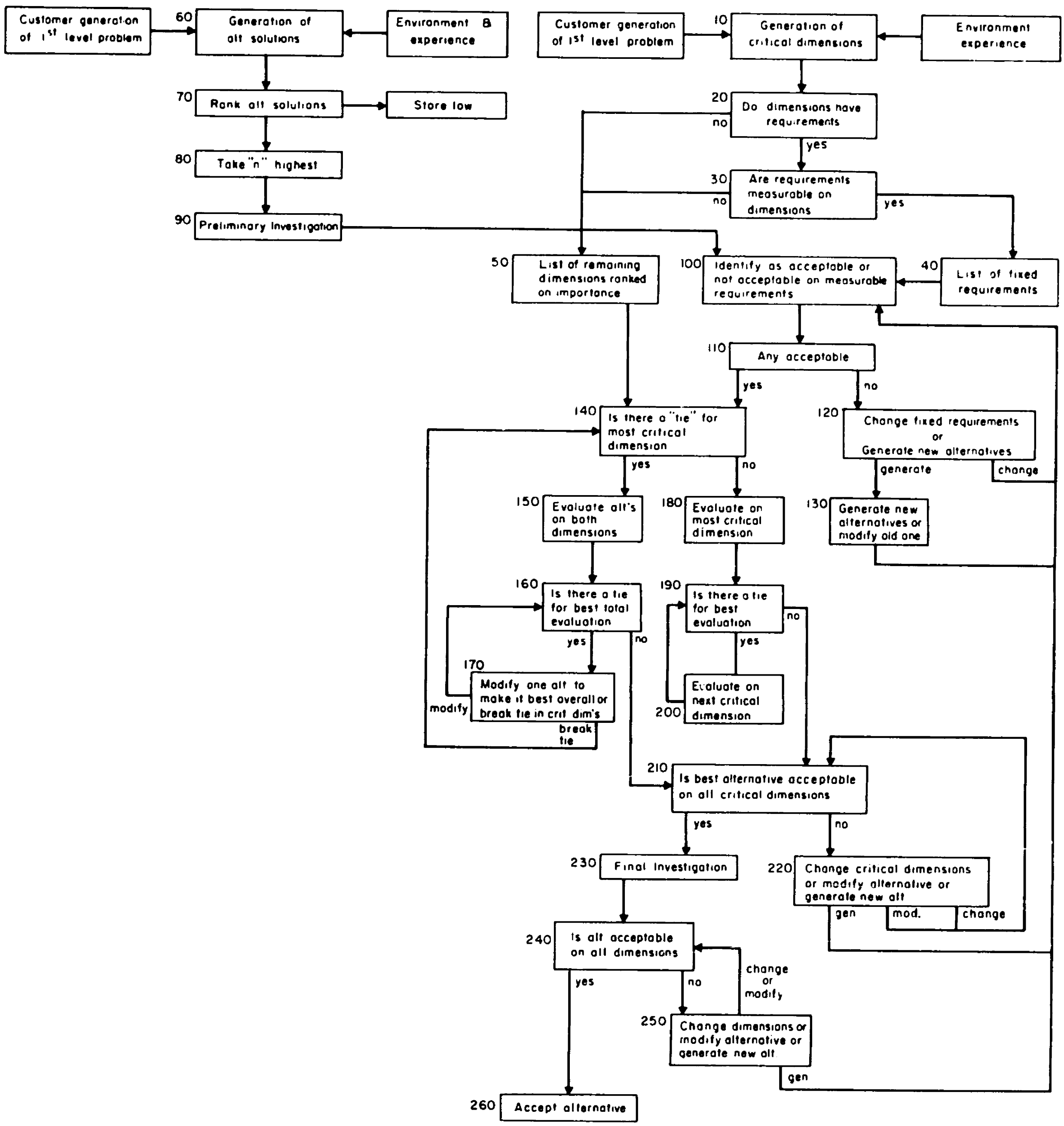

Customer generation of 1st level problem
60
Generation of alt solutions
Environment & experience
70
Rank alt solutions
Store low
80
Take "n" highest
90
Preliminary Investigation
Customer generation of 1st level problem
10
Generation of critical dimensions
Environment experience
20
Do dimensions have requirements
no
yes
30
Are requirements measurable on dimensions
no
yes
50
List of remaining dimensions ranked on importance
100
Identify as acceptable or not acceptable on measurable requirements
40
List of fixed requirements
110
Any acceptable
yes
no
140
Is there a "tie" for most critical dimension
120
Change fixed requirements or Generate new alternatives
yes
no
generate
change
150
Evaluate alt's on both dimensions
180
Evaluate on most critical dimension
130
Generate new alternatives or modify old one
160
Is there a tie for best total evaluation
190
Is there a tie for best evaluation
no
yes
no
yes
170
Modify one alt to make it best overall or break tie in crit dim's
modify
break tie
Evaluate on next critical dimension
200
210
Is best alternative acceptable on all critical dimensions
yes
no
230
Final Investigation
220
Change critical dimensions or modify alternative or generate new alt
gen
mod.
change
240
Is alt acceptable on all dimensions
yes
no
change or modify
250
Change dimensions or modify alternative or generate new alt
gen
260
Accept alternative

Figure 2-3

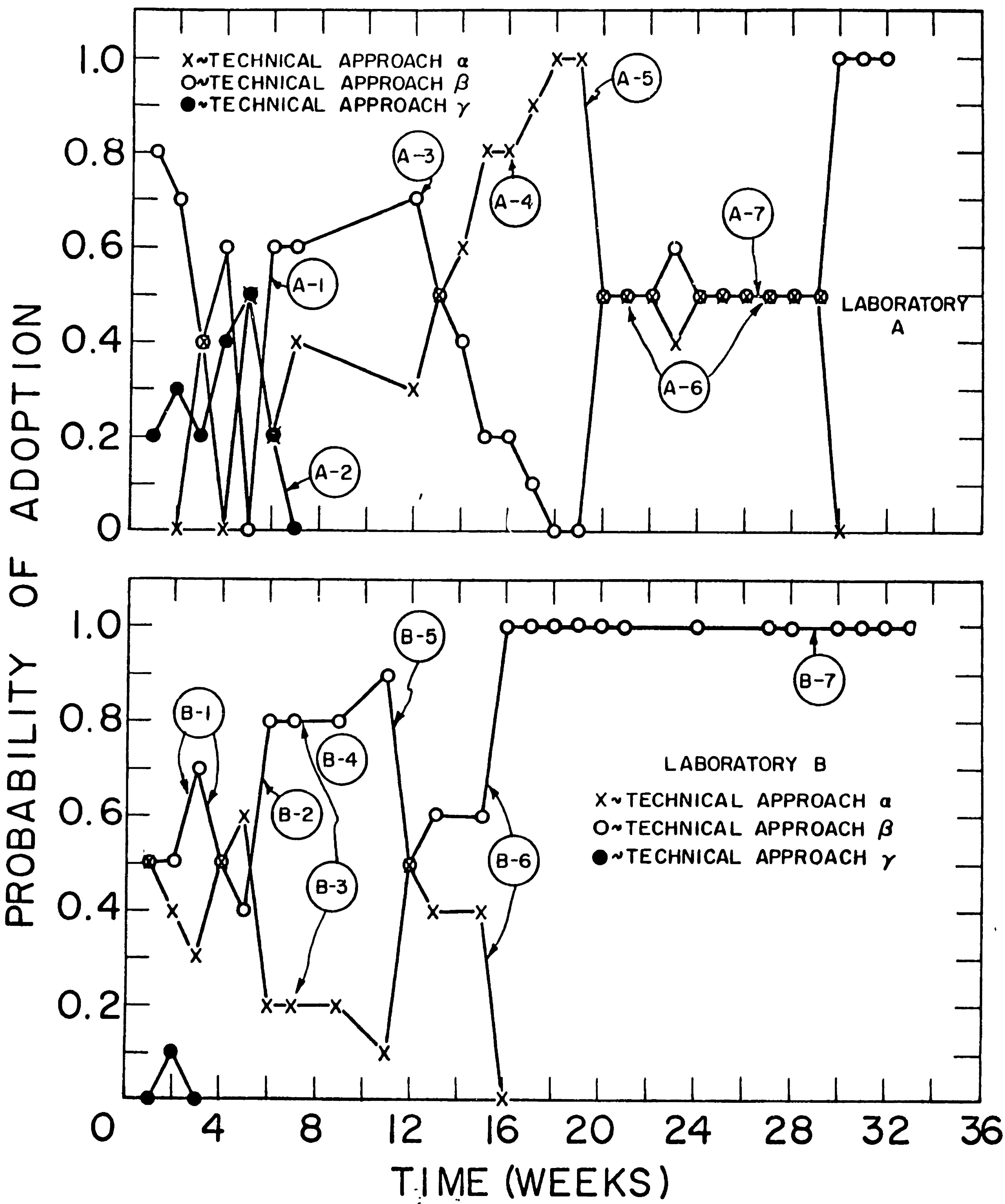


FIGURE 2-4

DESIGN OF ANTENNA RADIATION SUBSYSTEM

arrived there by quite different routes. A brief look at specific intakes of technical information (indicates in the figure by flagnotes) will explain much of this difference.

For example, rather early in the study, as indicated by flagnotes A-1 and B-2, the customer supplied both contractors with the results of an experiment to determine the wind loadings which would be experienced by the antenna. As a result, approach β rose in favor at both labs. Prior to this time, Lab A showed considerable vacillation among the three alternatives; Lab B, during this early period, conducted an intensive literature search, but failed to uncover any evidence of empirical or analytical work having been done with flat aerodynamic shapes at the low air speeds under consideration.

At A-2 Lab A's aerodynamic staff reported wind load moments for approach γ to be about twice that for α or β. At the same time, the electromagnetic staff reported that approaches α and β satisfactorily met electrical requirements up to 3 gigacycles.

An electromagnetic analysis by Lab B shows that approach α fails to perform as well as β electrically. This is indicated by flagnote B-3. During the same period (B-4), this laboratory attempted to extrapolate from previously acquired data (an earlier antenna) to estimate wind loads.

About the twelfth week (A-3) Lab A conducted a wind tunnel study, which showed that approach β resulted in a wind torque considerably larger than that predicted by the customer's data (A-1). Since approach α did not perform as well as β electrically, one of three things now had to be done. Either the electrical or aerodynamic specification had to be relaxed or a new alternative meeting both the aerodynamic specification and the electrical performance level of approach α had to be generated. The latter possibility did not present itself, so negotiations with the customer over specifications were pursued.

The customer subsequently allowed a relaxation of the electrical specification (A-4) and approach α rose in favor. The change in specification was provided to Lab B as well, but there was no consequent change in the probability level of approach α. This undoubtedly resulted from the fact that B did not have as complete information as A regarding approach β. The brief drop in β's position at Lab B (B-5) was a result of some doubts which this lab had concerning the feasibility of the approach, but as far as can be determined this was not based upon hard data. Following this brief period of skepticism, β rose rapidly to a 1.0 level (B-6) and was further established there when, as indicated by B-7, information concerning special fabricating machinery became available.

At Lab A, meanwhile, approach α encountered some difficulty with the cost analysts, with a resulting dropoff at note A-5. Lab A remained indifferent between α and β for quite some time while tradeoff studies were pursued (A-6). Numerous contacts were made with vendors to determine the costs associated with various elaborations of the two approaches.

Finally, at A-7, information was obtained from the Weather Bureau which allowed a 20% reduction in wind loading specification. This information was instrumental in Lab A's decision to adopt approach β.

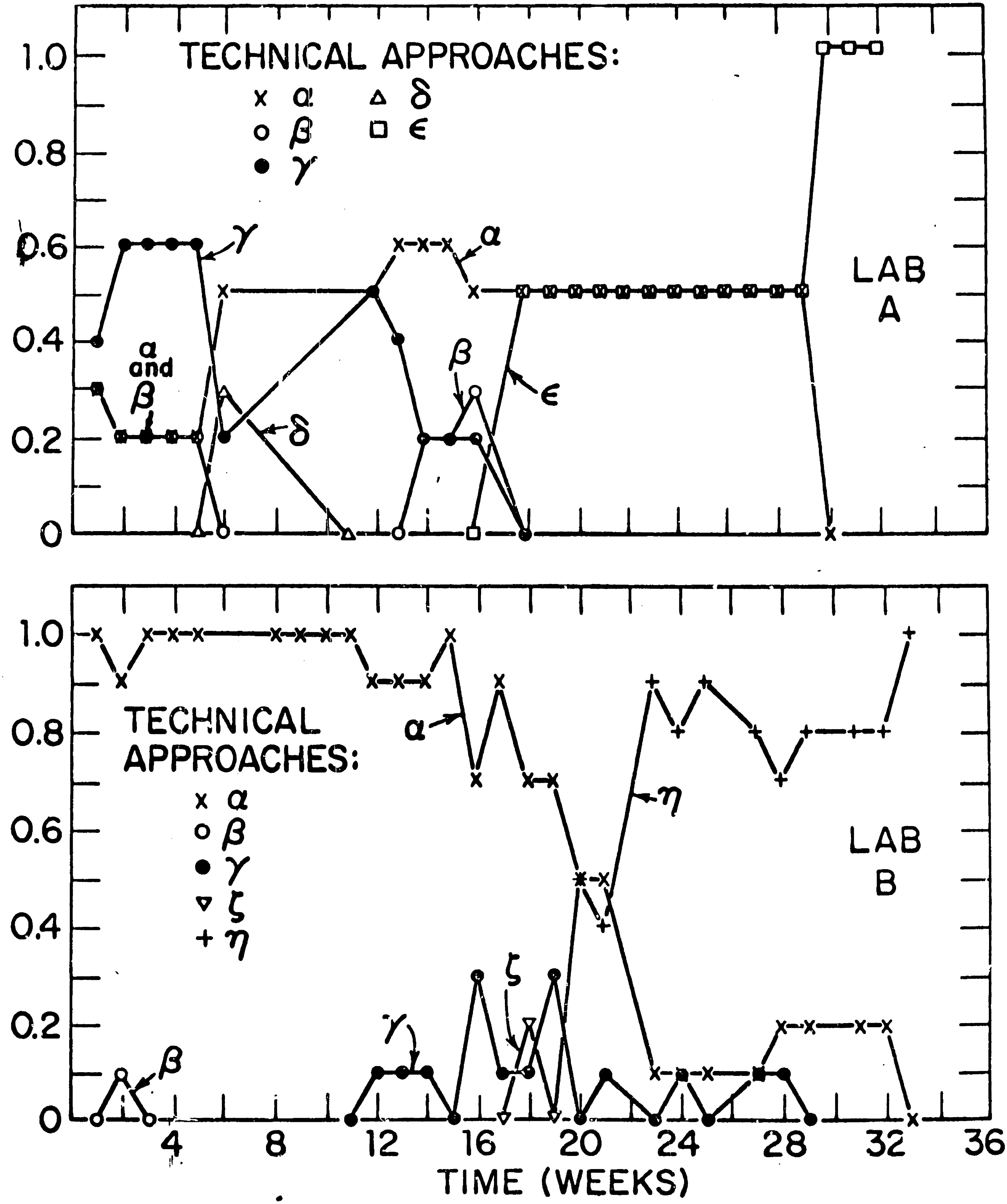
The work statement for the subsystem under consideration suggested three technical approaches, and these were the only ones considered by the two teams. But this is not always the case. Look at another of the antenna subsystems (Figure 2-5).

In this instance, each group considered five alternative approaches to the problem. Three of these (α, β and γ) were specified by the customer at the start of the contract. Two were generated by each team during the course of the project. In team A approach δ had been previously used by the engineer on problems of a similar nature, and the association of this problem with the former ones brought the idea out of memory. Approach ϵ was suggested by a paper which a colleague had heard presented at a SAE meeting. Further details on this approach were obtained through the trade literature and vendors.

In team B an engineer, thumbing through a colleague's reference file of clippings from trade journals, ran across an item which suggested approach ζ to him. He had employed this approach before, but it had not occurred to him as a possibility for this particular application until his memory was jolted by the trade journal clipping. Fortuitous contact with the representative of a vendor firm suggested approach η. This representative happened to visit a man in another department who knew of the engineer's problem and suggested that the vendor contact him. In a similar manner, alternatives considered in other subproblems are attributed to the information channels whence they originated.

Units of Analysis

The two units of analysis employed in the main body of the study are man-hours devoted to use of an information channel and messages received



TECHNICAL APPROACHES:
x α
o β
● γ
△ δ
□ ε
1.0
0.8
0.6
0.4
0.2
0
α and β
γ
α
β
δ
ε
LAB A
TECHNICAL APPROACHES:
x α
o β
● γ
▽ ζ
+ η
α
η
γ
ζ
β
LAB B
4
8
12
16
20
24
28
32
36
TIME (WEEKS)

FIGURE 2-5

via each information channel.[2]

Man-hours. Since engineering man-hours expended is quite closely correlated with cost on projects such as these, this 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.

Messages Received. By "message" is meant some kind of unit of information transmitted or received. Menzel (1960) in his methodological review describes this measure in the following way:

> ... (another) way of delineating the units of observation or recording uses as the basic unit a "message" -- i.e., some kind of unit of information transmitted or of communication achieved -- instead of focussing on some piece of scientist's behavior and then, perhaps, asking what information it yielded, it singles out pieces of information and asks whether and through what behavior they were obtained. The neatest embodiment of this approach would be actual studies of the diffusion of a message ...

In our case, the suggestion of a potential solution to the problem or the suggestion of a reason for discarding a solution is considered a message received. Quite often a single solution alternative will result from messages received from several channels; for example, reference in the trade literature might lead the engineer to a vendor who provides more complete information on the alternative. In such a situation, where several channels contribute to a single alternative, credit is given to each source. Sources of alternatives were sought out in the post-project interviews, and the

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[2] See Menzel (1960) for a discussion of units of analysis which have been and might be employed in user studies with a critical examination of each possibility.

tape-recorded transcriptions of these interviews were coded to indicate channels through which information was obtained for each function performed in Figure 2-3.

Channels

When using the unit of analysis, "man-hours expended," three broad classes of information channel are considered and a measurement of time spent with literature, time spent with oral sources outside the lab, and oral sources within the lab is made.

With "messages received," a finer division is performed and interview tapes are coded to determine which of eight possible channels is responsible for each message (Table 2-2).

Characteristics of the Sample

There are several sample limitations which must be kept in mind while considering the data to be presented in subsequent chapters. Paramount among these are the size of the laboratories in which the R&D project teams were embedded; the nature of the principal industries in which the laboratories are themselves situated; and the general nature of the work performed.

The outstanding characteristic of the laboratories represented in the sample is their size. They are all very large, ranging from several hundred professional technical employees to a few thousand. Any current listing of the fifty leading corporations in terms of sales to the Department of Defense or the National Aeronautics and Space Agency will include all of the laboratories in the sample of parallel studies. In a sense, this

Table 2-2

Information Channels Considered in the Study

literature:	books, professional, technical and trade journals, and other publicly accessible written material.
vendors:	representatives of, or documentation generated by suppliers or potential suppliers of design components.
customer:	representatives of, or documentation generated by the government agency for which the project is performed.
external sources:	sources outside the laboratory which do not fall into any of the above three categories. These include paid and unpaid consultants and representatives of government agencies other than the customer agency.
technical staff:	engineers and scientists in the laboratory who are not assigned directly to the project being considered.
company research:	any other project performed previously or simultaneously in the lab regardless of its source of funding.
personal experience:	ideas which were used previously by the engineer for similar problems and are recalled directly from memory.
analysis and experimentation:	ideas which are the result of an engineering analysis, test or experiment with no immediate input of information from any other source.

is not a serious limitation. It is in fact an important attribute of the sample. A strong trend to perform more research and development work within large organizations has been underway for several years, and is showing little sign of abating. The problems which such a large scale organization imposes are becoming more and more the problems of technology and to some degree of science. In other words, as science and technology came to be performed more and more in large organizations, the unique problems which this imposes will become more typical of scientific and technological work itself. The sample limitation, in this light, is in fact a distinct advantage, since it will allow us to focus upon the problems which organization presents to communication, and they are many. This is not to say that the individual research will be neglected, but merely that the nature of the sample and the nature of current trends in science and technology lead us to emphasize our consideration of organized science and, to an even greater extent, organized technology.

Because all of the parallel projects studied were financed by the U.S. government, the sample is necessarily biased toward firms whose business interests are slanted toward this type of customer. In a word, the sample was drawn from the aerospace industry. This, of course, is a serious limitation. It would be much nicer if we were able to include commercial chemical, data processing equipment and pharmaceutical laboratories, for example, in the studies. But until recently, the only instances of parallelism which could be found were government-financed, and so we are forced to live with this limitation. The author feels that many of the results to be presented are clearly generalizable to these other industries. This is a matter which can only be finally resolved through further research, so the reader will be left to draw his own conclusions on the validity of extending each of the findings beyond the aerospace industry.

The projects themselves will be described in the specific sections of the volume in which data from each project are presented. Suffice it to say, at this point, that they are for the most part studies: either preliminary design studies, feasibility studies, or the study of some phenomenon having possible long range potential. Never was their final product more than a prototype piece of hardware. They were never intended to lead directly to production contracts, but were several phases earlier and were sometimes, but not always followed up by further study or development contracts awarded to one or more of the laboratories. The technological projects, in other words, represent a very early conceptual phase in the technological process and were to a great degree devoid of the real life "nuts and bolts" type of hardware problem. This is not to say that they were not hardware-oriented at all. All but two which were feasibility studies were intended to result eventually in some hardware development, and hardware constraints were therefore accorded their due importance. But actual fabrication was not involved and the unique problems which arise only when this point has been reached are noticeably absent.

Factors Other Than Communication

There are, naturally, very many factors which may affect the performance outcome of a research and development project. The use of parallel instances controls some but, obviously, not all of these factors. Several of the more salient possibilities, however, were measured to determine whether any differences existed between the competing teams.[3] On the basis of this check, it can be said that no significant differences were found to exist between competing teams in the level of effort (measured in dollars) which they expended on the projects; in the previous managerial experience of the project managers; in the degree of general company experience in the technical area[4]; or in the level of education or experience of the team members.

[3]The questionnaire which was completed by the project managers may be found in the Appendix.

[4]With but one exception, and in this case the team with less experience turned in the better performance.

The Sociometric Study[5]

In Chapter 11 are presented the results of a sociometric analysis of communication flow within a single R&D laboratory. The data in this section were gathered by means of questionnaires and personal interviews (Appendix) with each professional employee in the organization.

In order to perform this type of analysis, the sociometric choices for each question were laid out in the format of an N x N matrix where N equals the number of persons in the laboratory (34). An entry "1" at a_{ij} indicates that there is a direct connection from person i to person j. An entry "0" indicates that no connection exists. The rows are subscripted i and the columns are subscripted j. In examining the matrices it can be seen that the number of times the j^{th} person was chosen is indicated by number of 1's in the j^{th} column.

In order to determine the relationships between any two matrices for the sociometric choices, a count is made of the number of times $a_{ij} = b_{ij} = 1$, $a_{ij} = b_{ij} = 0$, $a_{ij} = 1$ and $b_{ij} = 0$, and $a_{ij} = 0$ and $b_{ij} = 1$. These numbers are inserted in a 2 x 2 table and tested for significance with the chi-square statistic. Some hypothetical results from this procedure are illustrated in Table 2-3. The number 27 is the number of times that the two matrices agree on choice of person. Seventeen persons who were chosen for socialization were not chosen for technical discussion. Seventy-one persons were selected for technical discussion and not selected for socialization. Eight hundred and thirty-seven is the number of times that the

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[5] A more complete description of the methodology for this study is provided in Cohen (1966).

Table 2-3

Sample Contingency Table Resulting from the Sociometric Analysis

		technical discussion Yes	technical discussion No	
socialization	Yes	27	17	$\chi^2 = 125$
	No	71	837	p 0.001

two matrices have a corresponding absence of choice. In other words, there were 837 possible choices which do not appear in either matrix. The value of chi squared for these data is equal to 125 which is statistically significant at less than the 0.001 level. In other words, out of the 44 socialization choices made by the entire laboratory, 27 choices involved the same people with whom the choosers also have technical discussion. Forty-four is the sum of the numbers in the Yes row.

Other Studies

To set the results of our central study into its proper context and perspective, the results of several other user studies will be drawn together and their results compared. While an attempt will be made to integrate these results, the focus will be on a comparison of the data from the parallel projects with the evidence from previous research.

Since the number of user studies has grown quite large and since those completed prior to 1960 have been quite satisfactorily integrated in Menzel's

(1960) review, we will be quite selective in choosing the studies to be included in our analysis. Specifically excluded, except where it is felt that they have something special to add to the interpretation of another finding, are those studies in which scientists were asked (usually by questionnaire or interview) their opinion concerning the value of an information channel or their satisfaction over the use of an information chennel. Another, and perhaps more exclusive limitation results from the strategy of focusing upon the results of the parallel projects study and working outward, bringing in the results of other studies only where they contradict or support the evidence from the central study. This automatically limits our consideration to those points on which the central study provides data. The limitation appears quite necessary, however, in view of the extensive data which have been generated during our study of parallel R&D projects. Instead, however, we have chosen to go just a bit further and bring in some other results to set the proper context and aid in interpretation and generalization.

Table 2-4 details the studies from which data have been abstracted, and the particular segments of their samples which are considered.

Table 2-4

Other Studies from Which Data Are Used and the Characteristics of Their Samples

Study	Sample	
	scientists	technologists
Berul, et.al. (1965) U.S. Department of Defense Laboratories	156 individuals belonging to the conjunctive set whose "kind of activity" was classified as "research" and for whom the task in which information was used was classified as being of a "research" nature	2,999 individuals belonging to the conjunctive set whose "kind of activity" was classified as "exploratory development," "advanced development," or "engineering development," and for whom the task in which information was used was classified as fitting into one of the same three categories
Halbert & Ackoff (1959) 5 university and 45 industrial laboratories	15,000 chemists	
Fishenden (1959) Atomic Energy Establishment Laboratory, Harwell, Eng.	19 "pure" research workers	34 "applied" research workers
Shaw (1956) Forest Products Laboratory U.S. Forest Service	54 chemists, physicists, and botanical scientists	51 engineers
Herner (1954) Johns Hopkins University	370 workers in "pure" science	336 workers in "applied" science
Mitchell (1964) M.I.T. Physics Dept.	6 Ph.D. dissertation students	
American Psychological Association (1965)	438 psychologists reporting "research" as their most information demanding activity	
McLaughlin, et.al. (1965) 5 divisions of a "large decentralized company"		
Scott & Wilkins (1959) British electrical and electronics industry		technologists "in grades from foreman upwards"
Shilling & Bernard (1964) university laboratories industry laboratories government laboratories private research institute laboratories in the biological sciences	biological scientists	
Hagstrom (1965) university departments	researchers in the "formal, physical and biological sciences"	

PART I

THE COMMUNICATION SYSTEM IN SCIENCE

To the present time, the attention of researchers concerned with information flow has largely focussed upon the behavior of scientists in the several disciplines. The substantial body of evidence concerning scientists' information gathering behavior and the relative lack of information concerning the behavior of technologists provides but one reason for the separate treatment of science and technology. A more overpowering argument for this division appears in the data themselves. Scientists in all cases (and there is a considerable degree of consensus among the studies) exhibit behavior which is strikingly different from that displayed by the technologists. To deal with the two populations together would cloak these important differences.

Part I will address itself to the task of drawing together this expanding body of evidence in a coherent picture of the system of scientific communication, presenting the results of a detailed study of one set of parallel physics projects, and then expanding from this base by comparing, contrasting and extending the results through reference to other user studies which have been recently reported.

Chapter 3

WRITTEN vs. ORAL INFORMATION CHANNELS: THEIR RELATIVE IMPORTANCE TO SCIENCE

General opinion has followed at least one complete swing of the pendulum in attempting to assess the relative performance of written and oral communication in science. For many years, the less formal interpersonal channels were overlooked and it was assumed that the way in which information changed hands was through formal publication. As problems arose with the written form as a result of the proliferation of scientific journals, analysts gradually awakened to the existence of alternate channels which were informal in their operation, and which were largely oral in their mode. So for the last few years an increasing degree of attention has been focused upon oral media. So much so in fact, that if one listens in on the discussion at almost any gathering of information scientists today, he would be drawn toward the conclusion that these were the only mechanisms of any import in the transfer of information. Any such extreme emphasis should lead one to expect that the pendulum has perhaps swung a bit too far, so before we treat either of the two classes of communication media in any detail, let us first look at the evidence which exists concerning their relative importance.

The Scientist as a Consumer

The scientist can be considered an information processor. Clearly his most important product is in the form of organized information about our physical or social environment. But in order to produce such an output, the scientist must first consume large amounts of information in a wide variety of forms. Much of this information appears in the form of measurements, computer printout, or simple physical observation, but a second very important component stems from the output of other scientists. In other words, a large part of the information input to any scientist results from the output of other scientists. It is this connection between output and input with which we are concerned in studying the flow of information.

With the exception of some necessary diagrams and pictures the information transfer occurs in a verbal mode. The verbal information is then transmitted either orally or in writing. It is a comparison of the two methods of transmitting verbal information with which we are presently concerned.

A number of user studies have in various ways measured and compared oral and written communication, and these will be presented a bit later in the chapter. Before getting to them, however, let us look, in some detail, at a pair of parallel research projects, and compare the relative value of the literature and oral sources over their course.

The Modulation Transfer Project

This project had as its goal the discovery of a mechanism to allow the transfer of modulation (intelligence) from one coherent light beam to another, by passive means. In other words, modulation was to be transferred without the addition of energy, aside from that supplied by the two light beams themselves. While the attainment of such a process has obvious communications applications, few will argue that the physics involved was indeed (in 1963) of a fundamental nature, and that there is justification for including such a project in our consideration of "scientific" as opposed to technological activity. Basic research labs of two major aerospace contractors were chosen by a U.S. government laboratory to perform this study, each in parallel with the other, hopefully pursuing divergent approaches. Lab A assigned one full-time and one part-time Ph.D. physicist to the project, while Lab B used one part-time and two full-time Ph.D. physicists.

Data were gathered by the means described in the preceding chapter. These included the use of Solution Development Records, Time Allocation Forms, tape recorded progress reports by the project leaders, and extensive interviews with the scientists and with a technical monitor in the government laboratory which oversaw the projects.

Time Devoted to Channels

Time Allocation Forms provided detailed information on the total amount of time spent by each scientist on the project, and a breakdown of this time among four activity categories. The forms were collected over a period of approximately eight months. While one team was four times as faithful in submitting time forms (Table 3-1), the degree to which the two agree in their manner of allocating time among information sources is certainly remarkable. They devoted about 20 percent of their total time to the literature and ten percent to oral communication.

Figure 3-1 shows, plotted over time, the relative exposure to literature and informal oral information sources. Written sources maintain their primacy throughout the project, being challenged for only a brief time near the midpoint.

Table 3-1

Allocation of Time Among Three Activities as a Percent of Total Time Report by Scientists on Twin Fundamental Research Projects (Modulation Transfer Project)

	Lab A	Lab B	Average	p*
analysis and experimentation	68.2%	69.6%	69.3%	0.30
literature use	22.2	17.0	18.2	0.02
total oral communication	9.7	10.4	10.3	0.36
total time in communication	31.8	27.3	28.6	0.06
total time reported (man-hours)	311	1269		

* p = probability of a difference in proportions, as large as that which is observed.

So we see that the death knell which some have sounded for the literature's role as a communication medium in science is a bit premature. Certainly, it is not the only means used, but it does receive twice as much attention in terms of time allocated to it. Well, all right, one might say, literature does receive more time, but being a uni-directional channel it is less efficient and probably delivers less useful information per unit of time than do two-way channels. This is certainly a valid criticism of the data shown thus far, so let's look at the same project from another point of view.

After project completion, the scientists were interviewed at some length to explain the solution plots based on the data they had submitted

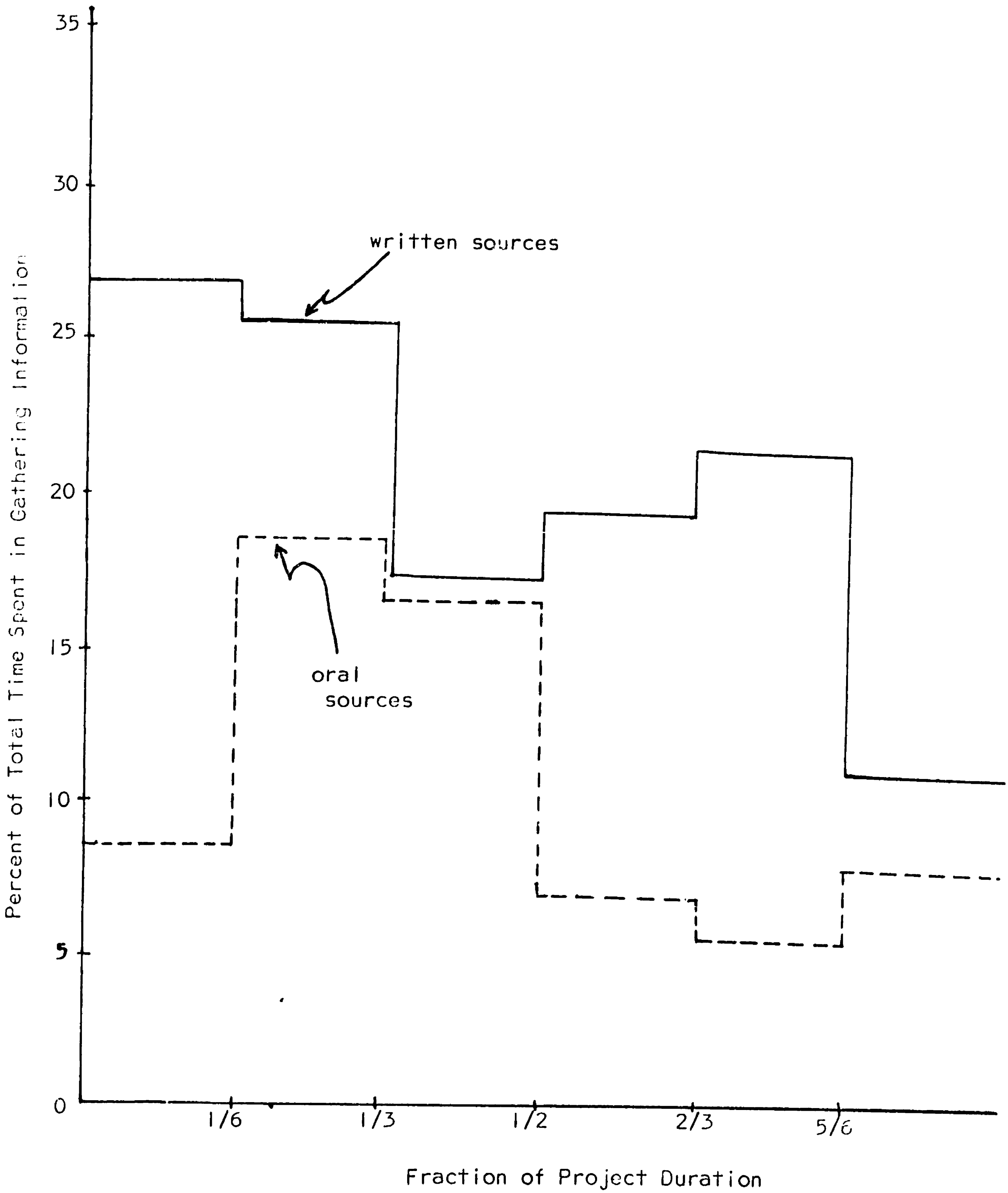

Figure 3-1. Allocation of Communication Time Between Written and Interpresonal Information Sources as a Function of Project Life Span. (averaged for a pair of twin fundamental research projects).

on Solution Development Records. They were asked for the sources of each idea considered and the reasons for (in terms of information sources) each major change in the probability level of an alternative. The interviews were tape recorded and employing "messages received" (Menzel, 1960) as a unit of analysis were coded for the sources of each item of information indicated. Tape recorded progress reports submitted periodically by the lead scientists provide a supplementary source of data to amplify and clarify that obtained through the Solution Development Record.

Literature again stands out in its importance, being responsible for 41 percent of all messages received (Table 3-2). In terms of specific functions, it is especially useful for generating ideas and for determining the manner in which these ideas will be assessed. Interpersonal sources account for only about 10 percent of the messages received, showing a rather close agreement with percent of time spent. Realizing the dangers in relating two such remotely connected data points, it remains that the literature was twice as effective in generating messages for the scientists on this project as were interpersonal channels. Can this be true? After all, studies in the social psychological laboratory (see, for example, Leavitt, 1964) consistently show two-way communication to be more effective in terms of accuracy than one-way. The difference is obvious; the social psychologists compare two forms of oral communication. Here we are dealing with reading versus oral communication; people can read much faster than they can speak and are able to consume a much larger amount of information per unit of time through reading. Furthermore, as we shall see later, scientists do not spend very much time in searching for information. If it is

Table 3-2

Relation of Problem Solving Function to Information Channel
on Twin Fundamental Research Projects
(Modulation Transfer Project)

Function	Information Channel			
	written sources	oral sources	customer	previous experience or analysis & experimentation
generate alternative approach to subproblem or expand existing approach	58.2% (18)*	3.2% (1)	0	48.7% (12)
reject alternative approach	12.5 (2)	6.3 (1)	0	31.2 (13)
generate criteria against which competing approaches are to be measured	53.8 (7)	7.7 (1)	7.7 (1)	30.8 (4)
set limits of acceptability for each criterion or modify existing limits	53.3 (8)	6.7 (1)	6.7 (1)	33.3 (5)
decide whether to modify criteria or generate new alternatives	0	0	100 (1)	0
test alternative approach against criterial dimensions	27.2 (9)	9.1 (3)	0	63.7 (21)
total	40.4% (44)	6.4% (7)	2.8% (3)	50.5% (55)

* Numbers in parentheses indicate actual message count.

not immediately available, they seldom go very far in search of it. The time recorded under the category "literature search" is then primarily reading time, with search time being but a small component.

Comparison with Other Studies

Comparing the results from the modulation transfer project with two previous studies (Table 3-3), we find rather close agreement in terms of the relative use of written and oral communication. This occurs in spite of rather widely varying units of analysis, populations studied, and definitions of communication activity. Written channels appear to dominate by a factor of about two whether the analysis is in terms of time spent or messages received.

The three studies show that oral channels have not completely supplanted written means of communication, in their importance to scientists. It would appear that written channels are still the principal means by which scientists acquire information. This is not to say that oral channels are unimportant and we will consider them in detail in Chapter 5. Meanwhile, let us turn briefly to a more detailed consideration of the manner in which written information is transferred and used.

Table 3-3

A Comparison of Emphasis on Written and Oral Communication by Scientists

Study	written communication	oral communication
Modulation transfer project		
(percent of time receiving)	18.2	10.4
(percent of messages received)	40.7	9.3
Halbert & Ackoff (1959)[1] (percent of time receiving)	7.2	3.8
Berul, et. al. (1965)[2] (percent of all information "chunks" received)	52	24

[1] 1500 chemists in five university and 45 industrial laboratories in the United States. Based on percentage of time observed. (random observations)

[2] 156 members of U.S. government laboratories who belong to the conjunctive set of those whose "kind of activity" was classified as "research" (as opposed to "exploratory development," "advanced development," etc.), and for whom the task in which the information was used was classified as "being of a 'research' nature." Oral contacts include those with vendors, consultants and colleagues; written sources include journals, preprints, texts, handbooks, directives, manuals, proposals and reports. Based on number of "chunks" of information (critical incident interviews).

Chapter 4

WRITTEN INFORMATION CHANNELS: THEIR FUNCTIONS AND PERFORMANCE IN SCIENCE

Preceding chapters have demonstrated rather clearly the importance of the literature in transferring information among scientists. In the present chapter, we will explore in much greater detail the peculiar characteristics of this important channel, but first let us turn back briefly in time and set our analysis of the contemporary performance of the scientific paper into its proper historical perspective.

Origins of the Scientific Paper

As science emerged from the Middle Ages and an emphasis on the observations of nature became its abiding aim, the need for rapid communication among scientists rose in importance. During what Kuhn (1962) has described as the pre-paradigm[1] phase of science, there is little need for communicative activity; the research which exists is uncoordinated and practitioners make little attempt to relate isolated findings. Only with the crystallization of a research paradigm -- a corpus of scientific knowledge or belief, the validity of which is accepted by the great bulk of investigators

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[1]Kuhn's pre-paradigm phase of science can be described as the period prior to establishment of a consensual body of theory, during which a number of competing theories may exist, all vying for general recognition. The establishment of a paradigm involves the accomplishment of one or more scientific achievements, "that some particular scientific community acknowledges for a time as supplying the foundation for its further practice." Such achievements must be "sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity" and simultaneously it must be sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve.

-- does science begin to build upon itself. Only then there arises a true need for the universal communication of findings which extend, elaborate, or contradict elements of the paradigm. In Butterfield's (1957) words:

> It would appear that experimentation and even technological progress are insufficient by themselves to provide the basis for the establishment of what we would call a 'modern science.' Their results need to be related to an adequate intellectual framework which on the one hand embraces the observed data and on the other hand helps to decide at any moment the direction of the next enquiry.

Such an intellectual framework and the relation of findings to it, can only be accomplished through rapid and effective communication among those at the forefront of scientific knowledge. While such paradigms certainly existed for certain areas of mathematics and astronomy from pre-historic times, the sixteenth and seventeenth centuries stand out as an era of intense activity in paradigm formation, and thereby in the intensification of the need for communication in what was becoming the scientific community.

The progress of science at that time would have been severely impeded were it not for the introduction of two innovations, the printing press and the postal system, which solved for that period, the crisis in communication. Medieval science largely involved the rediscovery and interpretation of the teachings of the sages of ancient Greece and Rome, a process which Butterfield describes as "literary transmission" rather than scientific investigation. This was largely a solitary endeavor with little need for active communication among scholars. Subsequent to the time of Galileo western science began to develop a tradition of its own, with major discoveries transmitted via the printed book and woodcut or engraving. Still the audience which was reached was largely local, and discoveries were propagated on a relatively universal basis only through generations of students. By the end of the sixteenth century the volume of scientific communication, especially among astronomers who found the need to compare celestial observations from several terrestrial points, had reached rather extensive proportions.

While the introduction of printing afforded the scientist a mechanism for reaching a wider and wider public with his work, it was not until the establishment of postal systems permitted the rapid dissemination of this work that scientists began to employ this channel for communication with their peers. Courier services exist from antiquity, and scientists to some extent made use of them, but organized postal services in Europe are usually dated from the sixteenth century. The postal service undoubtedly led to the increase in scholarly correspondence which, in turn, prompted the introduction of the first scientific journals.

> The improved postal services doubtlessly played a role in the increase of scholarly correspondence which preceded the introduction of the learned journal and as we shall see later was an important element in the distribution system for journals. From its very origins the post was closely bound up with the distribution of news and in the early history of the newspaper the postmaster is as frequently the printer as the purveyor of news. (Kronick, 1962)

The erudite letter served the functions of exchanging ideas and news of the learned world, and of priority establishment, functions which, as we will see, have persisted to the present day. McKie (1948) summarizes the functions and limitations of the erudite letter quite clearly:

> Before the foundation of the scientific academies in the middle of the seventeenth century, there were no scientific periodicals; and "natural philosophers" conveyed their ideas and accounts of their work and experiments to one another by means of letters,

> which from their scope and length, might be more appropriately described as dissertations. Much of this voluminous correspondence has survived; and in it is to be found the give-and-take, and sometimes the cut-and-thrust, of scientific argument and debate ...
>
> But the epistolary dissertation was not an ideal method for the communication of scientific fact and theory, even when it transcended frontiers. It was too personal. Men write to their friends, and not always, or not so often, to those who dispute their facts and reject their theories. Questions of priority were so easily raised; and ciphers were used for secrecy. Moreover, the method could not spread new knowledge and new ideas either rapidly or widely: it was too slow and too limited within narrow personal circles.

Similarly, Kronick (1962) points out the fact that, in addition to their function of communicating, they were often written "for the record":

> That (the letters) were written with an eye on posterity rather than solely for the information or entertainment of their recipients is shown by the number of them which were published during the lifetimes of their writers, although many of them remained buried in official archives and family papers until they were resurrected by editors of the 19th and 20 centuries. Thus the Danish scholar and physician, Thomas Bartholin, who was responsible for one of the earliest medical and scientific periodicals, published five volumes of his correspondence and would have published three more except for the fact that his manuscripts were accidentally burned in 1670.

That letters performed the service of priority establishment as well as communication is further attested to by the fact that they were often encrypted to <u>prevent</u> actual communication and sent to frien .s who could then preserve them and reveal their contents only after the scientist had sufficiently exhausted the potential for further exploration of the information which they contained.

It is interesting to note that in performing its function of priority establishment, the erudite letter assisted at the birth of the modern scientific society. It became customary during the sixteenth century for interested groups of people to meet periodically to read and discuss letters received from correspondents abroad. Many of these groups later formed the nuclei of the more formal scientific academies. We thus see a desire for staking individual claims for scientific discovery leading to the use of correspondence for that purpose; the latter, in turn, leading to the development of scientific societies. We are left with the question of what initiated the whole process. That is quite easily answered. The need for establishing priority in scientific discovery is an artifact of the rise of empirical science. Medieval science essentially relinquished all priority rights to the ancients[2]; once men began to rely upon their own observations of the world, bitter disputes, over who saw something first, were bound to arise.

So we find the scientific literature, at its introduction, embodying at least two important functions. First it serves as a medium for communication among those at the research front and, second, as a mechanism for establishing priority. Both of these functions were actually inherited from its predecessor, the erudite letter. These functions have continued with it down to the present time, and we find the importance of one or the other stressed in the writings of such current analysts as Merton, Price, Storer and Menzel.

Returning to the actual origins of the scientific journal, we find the first scientific periodical, de Sallo's Journal des Scavans issued

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[2]Sarton (1952) even tells us that "modest medieval authors would try to pass off their own compositions under the name of an illustrious author of an earlier time." (quoted in Merton, 1962)

first on January 5, 1665. The Royal Society was not long in following with the first issue of its Philosophical Transactions produced a scant two months (March 6) later. These two publications provided models for what was to follow. While it would be oversimplification to say that the Transactions was devoted to the reporting of empirical results and the Journal to digesting the state of scientific knowledge, it is probably true that the former became the prototype for publications of scientific societies, and the latter the model for magazines intended for the more general reader. Both of these journals, however, shortly after their introduction did begin to publish original papers. Roller (1946) provides us with the following brief chronology surrounding the formation of scientific societies and the initiation of the first scientific periodicals.

1600 (ca)	First informal scientific societies, Italy.
1646	First annotated book catalogs.
1657	First organized scientific society, Accademia del Cimento.
1662	Charter granted to the Royal Society of London.
1663	Royal Society plans an official society periodical.
1665	First real periodical, Journal des Scavans.
1665	First society periodical, Philosophical Transactions.
1681	Single issue of the Journal devoted to one topic, comets.
1682	Acta Eruditorum founded in Leipzig.
1682	Lay periodicals begin to publish original articles.
1691	First literary periodical, Works of the Learned.
1702	Journal institutes a board of editors.
1709	First essay periodical, the Tatler.

The Journal des Scavans was soon to be imitated by, among others, the Giornale de Litterati di Roma, founded in 1668. The Philosophical Transactions, in turn, appears to have been the model for the Acta Eruditorum, published monthly at Leipzig from the year 1682 (Ornstein, 1928). The latter became instrumental in linking the developing German scientific thought with that of the rest of the continent and England.

And so it all began. Journals started quite rapidly to proliferate as interest rose in the "new philosophy," and as groups of scientists fractionated into specialized areas of interest, the world's stable of scientific publications was soon on its exponential ascent.

Performance of the Literature as a Communication Device

Historically. Historically, as we have seen, scientists came to record the results of their investigations in various forms and for manifold purposes. The purpose of communication has been to varying degrees, however, always present in these communication forms. The scientific journals arose as the need for communication became more pressing and when the existing written communication forms, the book and the erudite letter, were not performing their functions efficiently enough. As Price (1963) has shown, the papers in these journals did not reach their present form of cumulating one upon the other, until the middle of the last century. This may be taken as evidence, not that the communication function wasn't being performed, but that the state of most areas of science had still not reached the critical stage at which "... each paper is built upon a foundation of previous papers, then in turn is one of several points of departure for the next." In other words, not until the nineteenth century did the major portion of scientific investigation reach a point where with active research paradigms the need for complete communication became manifest.

The Era of Big Science. As science has followed its exponential growth pattern over the years, its output in the form of scientific papers has grown accordingly. As a result, the number of journals publishing scientific papers is rapidly approaching the fifth order of magnitude, and the scientist's dilemma in maintaining himself abreast of his field is increasing at an even greater rate. For this reason, there has been a great deal of discussion in recent years about the development of new mechanisms to fulfill the communication need of science and of the declining importance of the literature. The discussion of alternate modes of communication has progressed to the point where we must ask the question, "Is the literature any longer of value as a communication medium among scientists?" and, provided it is still of some finite value, "How does it perform this function, and what specific information needs does it meet?"

A Detailed Look at the Written Channels

What sort of literature is it that scientists now spend 20 percent of their time in reading? About one-third of the way through the modulation transfer study, the time allocation forms were modified to obtain more detailed information of just this sort; scientists were asked to indicate specific literature references and to record, in code, the means by which the literature was acquired and the function to which it was put. Analysis of records shows that advanced textbooks are consulted most frequently, followed by scientific journals and reviews (Table 4-1). When the same references are viewed with respect to the amount of time devoted to each, the order between texts and journals is reversed. A greater amount of time is spent in reading scientific journals.

This results from the fact that average time per instance of use is considerably higher for journals (and reviews) than for texts. Texts are consulted for answers to specific questions, requiring less time; journals

Table 4-1

Relative Use of Literature Sources by Scientists
on Twin Fundamental Research Projects
(Modulation Transfer Project)

	number of instances	total man-hours	average man-hours per instance	principal functions
advanced textbooks	39	56	1.4	1
scientific journals	32	79	2.5	2
engineering journals	1	2	2.0	2
Revews of Modern Physics	3	3.5	1.2	1,3,5,6,9
Philosophical Society Reviews	1	1	1.0	2,1
handbooks	7	7	1.0	1

Function Code:

1. Aid in direct solution of a problem (e.g., handbook-type information).
2. Determination of results of related work performed by others.
3. Determination of procedures (e.g., testing procedures, fabrication procedures).
4. Learning new specialty -- broadening areas of attention (to include brushing up on an old specialty).
5. Browsing of technical literature, resulting in significant discovery.
6. Verifying reliability of an answer.
7. Keeping abreast of developments in one's own particular field.
8. Keeping abreast of developments on related or competing systems.
9. Aid in definition of operational environment.

are consulted for more general information. This is not to say that they are used principally for keeping abreast, while that is true to some extent, this is not the meaning of the category, "determination of results of related work performed by others." This category implies a somewhat more specific "How did someone else do this?" sort of information which is related to the specific problem at hand. Reviews of Modern Physics is used for a wide variety of functions and are probably underrepresented in the table, since one of the scientists admittedly referred to two specific issues quite frequently, but only once reported their use. As seen in the row entitled "handbooks" there is probably a lower threshold effect in the data, since respondents show a tendency toward rounding off periods less than one hour and reporting each as an hour spent.

The most-used journal is Physical Review with 19 citations; the Journal of Chemical Physics follows with six citations, and the remaining seven citations are scattered among five domestic and one foreign science journals, with one reference to the Proceedings of the Institute of Radio Engineers. The 39 references to advanced textbooks are spread over 16 titles with one central reference receiving 13 citations and the rest one or two each.

This, of course, is but one project. But it is not an unusual finding. Several other studies have shown a similar emphasis (Table 4-2). Scientific journals are used most frequently, followed by textbooks and then such secondary publications as abstracts and reviews. Unpublished reports are usually found to be little used. We will see later (Part II) that this situation contrasts sharply with that which is found in technology. Fishenden (1959) reports a similar finding thus:

> In particular the (pure research workers) make practically no use of the report literature over 70% of their reading being in journals, whereas the (applied research workers) make roughly equal use of the report literature and journals. This difference is reflected in relative use made of different sources of information. The "pure" group make noticeably more use of references in other papers, but surprisingly little use of abstract journals. The "applied" group make greater use of library services.

Table 4-2

Literature Sources Used by Scientists
(Ranking of Degree of Exposure or Use)

	research journals	books	abstracts	reviews	books	theses	unpublished reports
modulation transfer project	1	2	*	3	4	*	*
Amer. Psychol. Assoc. (1965)[2]	1	2	-	-	-	-	3
Berul, et.al. (1965)[3]	1[a]	2	-	-	4	-	3
Mitchell (1964)[4]	1	2	4	5	-	3	6
Fishenden (1959)[5]	1	2	-	3	-	-	4
Ackoff & Halbert (1958)[6]	1	2	4[b]		5	-	3[c]
Shaw (1956)[7]	1	3	4	-	5	*	2
Herner (1954)[8]	2	1	-	4	3	6	5

[*] no indicated use of this source

[a] includes preprints and reprints

[b] abstracts and reviews

[c] "bulletins, pamphlets and proceedings"

[1] includes monographs and textbooks

[2] 438 psychologists reporting research as being their most information demanding activity. Based on percent reporting each channel as "important" to that activity (questionnaire)

[3] 156 members of U.S. government laboratories who belong to the conjunctive set of those whose "kind of activity" was classified as "research" (as opposed to "exploratory development," "advanced development,"etc. and whose most recently completed task was classified as being of a "research nature." Based on number of "chunks" of information from each source (critical incident interviews).

[4] Six Ph.D. students in Chemistry at M.I.T. Based on number of sources reportedly used in decision making during dissertation research (critical incident interviews).

[5] Nineteen "pure" research workers at Atomic Energy Establishment, Harwell, England. Based on percent of useful items of information obtained over two-month period (diary record).

[6] 938 observations of reading acts by chemists in 45 industrial and 5 university laboratories. Based on percent of total observation (random observations).

[7] 54 chemists, physicists and botanical scientists at Forest Products Laboratory, U.S. Forest Service. Based on number of reading acts performed over period (diary record).

[8] 370 workers in "pure" science at Johns Hopkins University. Based on number

Unpublished reports are generally produced for the restricted use of some organization or controlled set of organizations. This practice, quite obviously, flies directly in the face of one of the strongest norms of scientific community. This norm variously called communism (Merton) or communality (Barber) requires that the ownership of intellectual property be assigned to the community at large of scholars, and any attempts to restrict knowledge to an individual or organization directly violate this norm. Hence unpublished reports are not an acceptable vehicle for recording or transmitting scientific findings. Such information must be recorded in the public literature.

Note the absence of abstracts from the sources used in the modulation transfer project. This is due most likely to the discipline involved; several studies have shown that American physicists seldom use abstracts, in contrast with chemists who rely upon them quite heavily. Fishenden, in the quotation above corroborates this finding for his "pure" research workers who were probably physicists, although he never identifies their discipline other than to say that they were employed by the British Atomic Energy Research Establishment.

Although the degree of concordance concerning the third, fourth and fifth positions is rather low, the studies cited in Table 4-2, with but one exception, found journals to be the most used source with books second. The one exception merely reversed this ordering but agreed that these were the two most important channels.

Method of Acquisition

Before it can be put to any useful purpose, the message which is contained in the literature must physically reach the scientist. How does this come about? In addition to listing literature sources and the functions for which they were used, scientists in the modulation transfer project were asked to indicate by code the method whereby they acquired each article. Codes were provided for five acquisition methods. The most important finding in this part of the study is simply that literature which is not available in the scientist's immediate work area just doesn't reach him. Two-thirds of the scientist's literature acquisitions take place because the (Table 4-3) literature is immediately available (desk or file) or can be borrowed from a colleague. The remaining one-third are accomplished through personal library search. In no instance during this study did a scientist resort to an abstract or research librarian, although both were available in the two labs.

Comparing the methods employed for acquiring books with those used for periodical literature, we find (Table 4-4)that for both of the modulation transfer groups, at least, journals are acquired through library search, while textbooks are obtained locally (i.e., on desk, in file or borrowed from colleague). This tendency was somewhat stronger in one team but both show trends in the same direction. Obviously, such a situation might be a result of conditions in the two laboratories studied, and generalization should be pursued with caution. But disregarding for the moment the possibility of a unique situation, what appears to be happening is this. The books that were used are of a type which would be owned by

Table 4-3

Method of Literature Acquisition Employed by Scientists on Twin Fundamental Research Projects (Modulation Transfer Project)

Method of acquisition	Number of instances in which a publication was thus acquired	Percent
Personal library search	28	30.8
Search by library assistant	0	0
Discovered through use of technical abstract	0	0
On desk or in personal file	52	57.1
Borrowed from colleague	11	12.1
Total	91	100

a large proportion of the scientists working in a given field. There is then a high probability that the scientist himself owns the half-dozen or so necessary books or at least has a colleague who owns those that he himself does not have. In addition, the scientist acquires other necessary texts at the outset of the project and retains them in his work area, referring to the same texts frequently during the course of a project. As for journals, some of these are undoubtedly obtained through personal subscription, but specific papers in back issues are more readily obtained through library search. The median age of 11 of the papers[3] to which the scientists referred is 10 years and for two it was more than 30 years.

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[3] Publication date was obtained for only 11 of the 32 journal citations.

Table 4-4

Methods by Which Texts and Journals were Acquired by Scientists Working on Twin Fundamental Research Projects (Modulation Transfer Project)

	Number of Publications Acquired*			
Method of Acquisition	texts and handbooks		journals and reviews**	
personal library search	10		18	
search by library assistant	0		0	
technical abstract	0		0	
total formal		10		18
on desk or in personal file	36		16	
borrowed from colleague	6		5	
total informal		42		21

For total formal vs. informal, $X^2 = 7.58$, $p < 0.01$.

*Includes six double counts for books and two for journals. Double counts result when more than one method of acquisition is cited by the scientist.

**Reviews are included with journals as periodical publications since three of four citations were to Reviews of Modern Physics, a quarterly publication of the American Institute of Physics.

Other Functions of the Scientific Literature

Priority Establishment. Since, as Merton (1962) and Storer (1966) have so cogently pointed out, recognition is the coin of the realm in science and as Storer further delineates, the act of creativity is not complete without some feedback from others, some device is obviously necessary to make these others aware of a scientist's accomplishments. As we have seen this function was performed in a not too satisfactory manner, prior to the birth of the scientific journal, by the sometimes encrypted letter to a friend. The difficulty in validly determining priorities under such a system can most certainly be listed with the multitude of causes which presage the birth of the scientific paper as we presently know it. The function of properly establishing credit for scientific discovery has remained with the scientific paper down to the present day, and is evinced by the practice of many journals, which print the date of first receipt for each manuscript.

An Archival Repository. The scientist, in publishing, presents his ideas for the scrutiny and potential acclaim not only of his colleagues, but of future generations as well. This potential certainly supplies a major component of the motivation which brings a scientist to share his ideas through publication. The scientists' humanitarian brethren, the historians of science, surely welcome this as a boon, making their study of science, post 1665, much less difficult and more precise.

We need delve no further into these auxiliary functions of the literature, since they lie outside our central concern with communication. Our purpose is to merely remind the reader of both their existence, and the potential which they have of effecting any proposal to modify or replace the scientific paper.

Biography of a Scientific Paper

While we have seen that the scientific literature retains much of its importance as a communication device, there has been much discussion (Price, 1961; 1963) and some evidence (American Psychological Association, 1963; Garvey and Griffith, 1964; American Psychological Association, 1963; 1965) which show the existence of a rather significant amount of communication of a paper's contents in parallel with and somewhat prior to actual publication of the paper. Garvey and Griffith provide an excellent description of the events leading up to, and surrounding the publication of a paper in one of the journals of the American Psychological Association.

Garvey and Griffith find that actual research precedes publication by 30 to 36 months, on the average. This is, of course, a function of the nature of the field as well as of the professional association's editorial system, with some journals or sets of journals having longer publication delays than others. In physics, for example, the lag before publication in Physical Review Letters can be very short. Other types of research can have a long lead time on results. The nature of the communication events prior to publication in an archival journal will certainly depend upon both of these lags, but, with the possible exception of psychology, little is known about this relation in any scientific field.

In psychology, we find that about 18 months after initiation of a research project, the work reaches a stage at which some report of results can be made. The first reports are very informal and are given at seminars or colloquia within the scientist's parent institution. At about the same time, a more formal, but still oral, report may be made before a meeting of a small special-interest group (local chapter of a section or sub-section of a scientific society). During this time, the scientist is also probably preparing a draft of a more formal written report. About 21 months after project initiation he may present a formal oral report to a reasonably large audience at a regional or national meeting. In psychology, one out of every five articles is presented at a national meeting; one in ten to regional meetings. The reader is, of course, reminded that while the total attendance at a national meeting of a professional society may be in the order of thousands, individual papers are seldom heard by more than one hundred people.

Shortly after the convention, copies of the presentation may be distributed informally to individuals requesting copies. Garvey and Griffith find, in psychology, "few requests for any single presentation." The first written reports of the work are found in the form of "Formal Progress Reports" which appear 12 to 15 months prior to journal publication. This is an artifact of the system which has developed for support of scientific research. Grants from supporting agencies (National Science Foundation; National Institutes of Health; Department of Defense; the private foundations, etc.) are generally made on a relatively short-term basis (1 to 3 years), especially with new projects. This means that about two years after the initiation of a project, the principal investigator must produce some evidence of success in order to obtain the funds required to complete the job. In psychology, it was found that about 10 percent of the published studies are reported in this form with accompanying requests for further support. The audience reached directly by this mechanism is probably very small, consisting only of the members of a reviewing "panel" and their immediate colleagues. But it is highly select, since it should make up the very core of the invisible college's informal communication network, thus rapidly informing all of those at the research front of the report's contents.

About the same time, first dissemination is made of a rather complete written report. This may be an early draft of the manuscript which is to be submitted for publication. In psychology, about 60 percent of all manuscripts are distributed in this manner. The number of copies distributed is generally rather small and is limited, usually, to local colleagues. Following receipt of comments on his draft, the author may submit to a journal and, depending upon the extent of the journal's publication lag, will distribute preprints anywhere up to a year prior to journal publication. Garvey and Griffith find that 40 percent of authors follow this practice, with the number of copies sometimes exceeding 200. This convention may vary widely with scientific field, since Bernard et. al. (1963) found that less than three percent of 673 bioscientists queried distributed preprints. The median number distributed by bioscientists was about eight. This probably includes all of the author's invisible college and substantiates Price's hypotheses with rather strong empirical evidence. Interestingly, certain divisions of the National Science Foundation have institutionalized this practice to a degree, by providing each grant recipient with a list of the names of scientists who are working in the same or related areas and suggesting that reports and preprints be disseminated to this distribution list. Practices in distributing preprints vary with author; some distributing just before the manuscript is submitted; others waiting until the paper has been accepted by the editors.

Authors meanwhile continue to disseminate the paper's contents orally, through colloquia, etc. during visits about the country. Following publication, "up to 20 percent of the membership of the American Psychological Association will at least expose themselves to the title of a paper appearing in a psychology journal. Figures are unavailable for other disciplines, but probably are comparable. The immediate audience for any single paper is, no doubt, very restricted in size.

What about the audience which develops later in time: Is the paper ever referred to again once it enters the archive? As we have seen, the median age of the articles read by the four scientists on the modulation transfer project was ten years. This certainly indicates that archival papers serve some function beyond their first audience. Cole (1963) employing articles citing as an index of the extent to which papers are read with time (a not too satisfactory index, since many classical papers are undoubtedly referenced without being read, and thereby bias the time distribution toward older papers) shows that (for what appear to be engineering rather than scientific journals) the time distribution of use is exponential following the equation:

$$N(t) = N_T e^{-\lambda t}$$

where:

N = the number of references older than t years

N_T = the total number of references

λ = a constant

Cole reports that the half life (τ) for the journals he studied varies between 1.3 and 5.9 years. In other words, if $\tau = 2.5$ years (the mean for Cole's data), 50 percent of all references to a paper will have been made within three and one-half years of publication, 86 percent within seven years about 95 percent within ten years, and so on following the exponential distribution. Similarly, Kessler (1961) has disclosed data for which the half-life varies from 3.5 years for Physical Review to about five years for Journal of the Acoustical Society of America. Burton and Kebler (1960) find half-lives varying from 4.6 years for physics to 10.5 for mathematics and 11.8 for geology.

The point is simply this: once a paper appears in the scientific literature, its probability of ever being cited is first of all quite low, and this probability is subject to a rather rapid exponential decline with age. The principal value of studies such as those cited lies in the planning of library journal holdings, where determining the probability of a potential user desiring a particular publication becomes of great importance. This form of analysis and its potential is summarized in an excellent paper by Bourne (1965). For our present purposes, it will suffice to note eventual fate, with regard to subsequent use, of a scientific paper once it achieves formal publication.

Publication Lags

The delay between submission of a manuscript and distribution of the journal containing it, of course, varies from journal to journal. The increase in the amount of information submitted for publication has, however, in recent years resulted in an increase in this publication delay time for most journals. A number of physical innovations have been attempted to speed the process of publication. Looking at these innovations from a systems view, an improvement similar to that expected from the supersonic transport, they will drastically reduce a portion of the total delay while completely ignoring the major component, in the case of the SST the delays between city centers and airports, in the case of the scientific paper the delays imposed by the referee system. A thorough job of refereeing a paper cannot be performed rapidly, and the people best qualified are almost by definition extremely busy with other work. In the absence of suitable alternatives to the system, the delay it imposes appears to be something with which we must live.

Such express journals as Physical Review Letters and Science provide some relief as a supplement to the normal journals, but they cannot supplant the function of the regular journals, and by their nature, in bypassing much of the referee process, they lose much of the protection inherent in publication by carefully refereed journals.

In a recent experiment, based upon the findings of Garvey and Griffith (American Psychological Association, 1963; 1965) that over 80 percent of the papers presented at the American Psychological Association's annual meeting are eventually published in APA journals (and virtually all achieve publication somewhere), the association requested formal papers from all speakers prior to the conference. The papers were reviewed by conference committees and published in a single volume for communication and archival purposes. None of these papers were then eligible for publication in an APA journal without the incorporation of additional data. Such a scheme, of course, acknowledges and to some degree formalizes the process of preprint exchange which normally takes place informally under invisible college auspices, and has the eventual goal of reducing the number of papers in APA journals which report what are by themselves relatively unimportant experiments (cf. Dunnette, 1966). This policy aims at delaying journal publication until the results of a number of experiments can be integrated into a more substantial contribution.

Just what the long term consequences of such an experiment will be is difficult to predict. But, in the short run, it appears to have reduced attendance at the sessions in which papers are presented to a hard core of scientists who are more than peripherally interested in the substance of the paper. It has also expedited the process of announcing through abstracts the existence of research results. The delay between conference presentation and publication of abstracts has been reduced by about six months.

Secondary Publication

The development of secondary publication, rather than being a direct result of the growth of the number and scope of journals, was contemporary with, if not antecedent to, the growth of journals. Many of the journals themselves began their existence as review publications, providing excerpts from current books.

Since information generated at the research front has come now to be published almost entirely in scientific journals, what we refer to here as secondary publication is the process of taking information from the journals, processing it in some way (or even simply taking it verbatim) and incorporating it in a new publication. The category of secondary publications would then include, but not necessarily be limited to, abstracts, review journals, collections of readings and textbooks.

Abstracts. Abstract journals were soon to appear after the initial growth spurt of scientific publication. They were thought at the time to be the answer to the then-existing "information explosion." As with most innovations the point of origin of this type of journal is rather obscure, but appears to be somewhere around 1670 (Kronick, 1962). Price (1961), using perhaps tighter definitions, dates the first abstract journals from about 1830. Whatever the date of the first abstract journal, the fact remains that it appeared in response to a demand on the part of scientists who could no longer keep abreast of the proliferating literature in their fields. And since the middle of the nineteenth century, the number of abstract journals has followed an exponential growth path parallel to and lagging by about 130 years the path of journal growth. There are currently published in the world more than 300 scientific abstract journals. The number of abstracts published in chemistry, biology and physics appear now to be growing at a stable rate in which the cumulative total number of abstracts in each of these fields is doubling every fifteen years. There are now about 65,000 physics abstracts, 330,000 biological abstracts, and 650,000 chemical abstracts added to the world's store each year.

Urquhart (1965) in a survey of the sources of references to publications requested from the National Lending Library for Science and Technology (England) found 38 percent of the physicists and 49 percent of the chemists queried, located the reference in an abstract journal. For the total sample of scientists, abstract journals were the most important single source of referrals (Table 4-5). However, when compared with all

Table 4-5

Abstract Journals Compared with Other Sources of Reference (National Lending Library Study)

	Percentage of References Produced
Abstracting journal	43%
Periodical article	25
Non-periodical publication	14
Private or library index	9
Verbal recommendation	9

sources of referral, they occupy a minority position. Urquhart concludes that:

> References come from a wide variety of sources and, with the exception of Chemical Abstracts, abstracting journals when regarded as individual sources, may be relatively insignificant. In total they provided only 43 percent of the loan demand on the NLL during May 1963. It is possible then that whilst many scientists say they use abstracts as a means of keeping up to date this is in fact a not very productive occupation in terms of the numbers of originals they eventually consult. Alternatively it is equally possible that in general scientists are happy with the amount of information that they are able to extract from conventional abstracts.

Martin and Ackoff (1963) find that, "There is strong evidence ... that abstracts do not serve this function (of searching and selecting relevant articles): they appear to be used as a substitute for articles rather than a guide to them." Urquhart's reference to scientists' saying that they use abstracts is based upon the results of a number of studies which asked simply what methods were used for keeping up to date, or whether "you use abstract journals" (Flowers, 1965; Gray, 1950; Glass, 1955).

An interesting plan for future development of an abstracting service has been proposed by Garvey and Griffith (American Psychological Association, 1965). This plan, first of all differentiates between literature which is central to the field and that which is peripheral. Only the former is abstracted. From the peripheral literature, current awareness lists will be compiled and it will then be catalogued and filed. When its relevance to the field has been increased usually through cumulation of additional literature, the several articles will form the basis of a summary abstract.

In addition, provisions are planned for a rather complex feedback system to maintain the form and content of the abstract journal abreast of changing requirements.

Reviews, Collections and Textbooks. We saw in the modulation transfer project (Table 4-1) the many uses to which reviews are put. Flowers (1965) found that 90 percent of the scientists he polled claim to have read or consulted a review article during the month prior to his survey. The general feeling at the present seems to be greatly in favor of expanding the publication of scientific reviews (see, for example, Bernal, 1965). It appears a logical way to aid the scientist in keeping abreast, but this conclusion is based upon little hard data. Garvey and Griffith (American Psychological Association, 1963) who studied the compilation of one of the Annual Reviews of Psychology have this caveat to offer:

> Possibly this most evident feature of the findings of this study is the dependence of the contents of the review on some rather arbitrary decisions of the reviewer who delimits the field and the pattern and extensiveness of his search, and who may further limit the topics of contributions reviewed. His option to be evaluative and critical is generally exercised, and for most reviewers provides one of the more rewarding aspects of their experience as reviewers. As some reviewers recognized, a review is idiosyncratic, and a balanced picture is only obtained through many reviews that cancel and augment one another.

Collections of papers appear little used, except perhaps in the social sciences, and there largely as pedagogical tools. Textbooks, as we have seen are used quite heavily. Once again we turn to Garvey and Griffith for additional support (American Psychological Association, 1965). They administered a questionnaire survey of book use to a ten percent sample of the American Psychological Association membership and conclude:

> Those aspects of the information contained in books which proved to be most frequently indicated as useful were theory and data; however, the work activity to which the information was relevant often determined which aspect would be most useful or applicable. A comparison of the useful aspects of information derived from books, journal articles, and convention presentations suggested that these three communication media satisfy different types of information needs or are utilized for different purposes by psychologists ...
>
> The subjective descriptions of the use and influence of books on the work and thinking of respondents suggest the impact of information presented in book form to be great. These comments also reinforce and make more evident the difficulties (apparent throughout this study) of assessing the role of books in the dissemination of scientific information and of comparing the effectiveness of this manner of presentation of information with that of other media. If separates are multitudinous and

> elusive, so also are the uses to which they are put and the types of effects which they generate. At the other extreme, the scope of influence of any one book is apt to be minute and the likelihood of two psychologists --even within the same area of interest or responsibility -- citing the same book, very slight.

Again we see books used for direct problem-oriented information (cf. Table 4-1). Fishenden (1959) also found books to be used more for information "directly applicable to job" than for background reading.

Secondary publications then clearly have an important role in scientific communication. Unfortunately, we still know little about this role other than the fact that it varies considerably with type of publication and with the type of scientific discipline in which it is used.

Chapter 5

ORAL INFORMATION CHANNELS: THE SOCIAL SYSTEM OF SCIENCE AS A COMMUNICATION MECHANISM

Much has been written in recent years about the informal communication system in science, about the operation of the social system of science by means of the "affluent scientific commuter," and the exchange of information informally through the "invisible colleges." Before we attempt an attack upon a system so formidable as this one appears to be, let us examine once again the original "invisible college," and its contemporaries which protected and nurtured science in its infancy.

Origins of the Scientific Society

With the rise of the empirical approach to science in the late sixteenth and seventeenth centuries, the practitioners of this new and somewhat suspect approach to expanding knowledge often found it expedient to band together in small communities. One of the very first of these, the Accademia dei Lincei (Drake, 1966), developed in 1603 out of the interest of four non-scientists in "... the study of nature and especially (of) mathematics ..." while not neglecting" ... the ornaments of elegant literature and philology, which like graceful garments adorn the whole body of science ...". This early attempt at social organization lasted long enough to shelter Galileo during his tribulations and to publish several of his books. Later attempts at organization by scientists followed with the establishment in England, shortly after Charles II's restoration, of the Royal Society and slightly later of similar societies in France and Germany.

The universities, primarily because they were generally the bastions of the established order (which science threatened) were not very comfortable dwelling places for sixteenth century scientists. One exception, Gresham College in London, provided employment and shelter for a number of men interested in the new science, who later formed the nucleus of a luncheon club, dubbed by Robert Boyle,"the invisible college" (Stimson, 1948). After meeting on an informal basis for a number of years, with a portion of the membership moving to Oxford and establishing a similar organization there, the members applied for and received a royal charter in 1662. Their stated purpose was to "... meet together weekly ... to consult and debate concerning the promoting of experimental learning." There were established, in several other countries during the next few years, similar communities.

The purpose behind the founding of such societies was two-fold. First, in a period in which science found itself under counterattack from many points, there must have appeared greater safety in the formation of cohesive groups. More important for our purposes is the implicit recognition by these gentlemen of the need for interaction and communication among colleagues. This is witnessed by the many discussion meetings dealing solely with technical matters and the extended correspondence maintained with members on trips or in the case of the Lincei (the first international body) between members residing in several countries.

Thus we see that a social system one of whose principal concerns is the maintenance of communication among its members comes gradually into formal existence. The social system of science has evolved to date into a rather clearly defined and much-studied entity. The characteristics which it has developed are the subject of a number of sociological investigators (Merton, 1957; Parsons, 1951; Barber, 1952; Storer, 1966). Rather than deal with this system in a direct sociological sense, we will concern ourselves at this point with only those functions and characteristics of the system which facilitate or impede its principal task, the communication of scientific ideas.

As we have seen, scientists have long exchanged their ideas by means which are social in nature. They visit and discuss common problems or interests; they maintain correspondence with one another; and they pass along second and third hand information about "what this person or that is doing now." These operations are the principal function of what Price has immortalized as the "invisible college." He describes an "invisible college" as comprising about 100 men, each group being organized around a particular rather specialized bit of subject matter. He goes on to trace their rise in importance in recent times:

> Probably during World War II, pressure of circumstances forced us to form such knots of men and keep them locked away in interacting seclusion. We gave them a foretaste of urgent collaboration in nuclear physics, and again in radar. These groups are still with us in the few hundred people who meet in the "Rochester Conference" for fundamental particles studies, and in the similar number who congregate by invitation to discuss various aspects of solid state physics. (Price, 1963)

The prototypical pattern for this phenomenon is found, probably, in nuclear physics, where the number of research installations in the country is severely limited by the capital investment required. The scarcity of research facilities has necessitated the grouping together of physicists conducting experimental research. Eyring (1965) has conducted a very interesting study of the organization of teams of nuclear physicists. He selected research teams by drawing physicists' names and years of publication at random and searching Physical Review Letters for the first paper co-authored by the scientist selected. The scientist and his co-authors were then defined to constitute a team. Of 26 teams so selected, ten turned out to be multi-institutional in nature. In other words, the members came from more than one university or other research organization. In addition, Eyring finds the constitution of these teams to be relatively unstable, new co-authors appearing and old ones dropping out with rather high frequency on several successive papers.

The implications for communication are rather obvious. The formation of multi-institutional groups provides a direct mechanism for mediating the flow of information among the physics departments of the major universities. Scientists come together at, say Brookhaven, and perform a series of experiments, all the while remaining in close touch with their colleagues back in the home departments, and relaying not only their own results but all of the latest information about what is going on in other universities, obtained from team members.

In addition to this phenomenon which may well be relatively restricted, there exist the widely used mechanisms of visiting professorships, invitational seminars, etc., increasing in scope to the Gordon Conference and professional symposia and conventions.

The Extent of Interpersonal Communication

Returning to the modulation transfer project, it will be recalled that about 10 percent of the total time spent by both research teams was in interpersonal communication of one sort or another. Furthermore less time was spent in this form of communication than in literature use throughout the project, with literature exceeding oral communication by an overall factor of two. Does this then mean that all that has been said about the importance of person to person contact is untrue, and that it plays a minor role in scientific investigation? Obviously, any activity which accounts for 10 percent of a scientist's time, and provides a corresponding percentage of his ideas (Table 3-4) is far from trivial in its role.

Interpersonal Channels, Their Functions and Performance

Viewing the three studies in a bit more detail, let us pursue the question of the exact nature of this oral communication. First, in the modulation transfer project the data allow a breakdown only into man-hours devoted to originating within the home laboratory of those entering from without (Table 5-1)[1]; one team relied principally upon sources within its own lab, while the other preferred outside sources.

The exact reasons for such a sharp difference in this aspect of the communication behavior of the two teams is rather difficult to determine (especially since they agree so remarkably in all other aspects). Both labs had other personnel engaged in similar and related research; lab A

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[1]Unfortunately, the total number of messages received through oral channels is too small (10) to afford a reliable breakdown into sub-categories.

Table 5-1

Allocation of Time Between Two Classes of Oral Communication Channel as a Percent of Total Time Reported by Scientists on Twin Fundamental Research Projects (Modulation Transfer Project)

	Lab A	Lab B	mean	level of statistical significance*
oral sources within the laboratory				
percent of total time	2.6	8.5	7.4	0.002
oral sources outside of the laboratory				
percent of total time	7.1	1.8	2.9	0.001
total oral communication				
percent of total time	9.7	10.3	10.3	0.36
total time reported (man-hours)	311	1269		

* probability of occurrence of a difference in proportions as large as that which is found.

reported having only one man acting as internal consultant to the project while lab B assigned two. This could well account for team B spending more time with internal channels, but why does A apparently compensate by going outside? It would almost appear that a given amount of oral communication was necessary to accomplish the project, and that when information which had to be obtained in an oral form was unavailable within the lab it had to be obtained outside. A sample of two, such as we are here dealing with, is far too small to allow more than speculation, were it not for the existence of a considerable body of independent data pointing in the same direction and, additionally, displaying a rather definite relation between research performance and the extent to which sources on one or the other side of this organizational boundary are used. Shilling and Bernard (1964), for example, find consistently inverse correlations (all significant at the 0.05 level or beyond) between the use of "paid consultants" by bioscientists and eight measures of laboratory "productivity and efficiency." It appears that outside sources may be approached only when the necessary talent is unavailable in one's own laboratory, and that they are then usually incapable of filling the need. That this phenomenon may be limited to industrial laboratories is pointed out by Shilling and Bernard since they found only the industrial labs in their sample ever used paid consultants. The bounds of the "laboratory organization" are much less determinate for academic scientists, so in that case it is difficult to ascertain the precise meaning of "outside sources." If, however, the organization is defined as an academic department we find opposing evidence for the value of outside sources. Hagstrom (1965), who studied 179 prominent researchers in the formal (mathematics, statistics and logic), physical and biological sciences, found a rather strong positive correlation ($Q = 0.85$)[2] between extra-departmental communication and productivity in terms of papers published. The correlation between productivity and intra-departmental communication is considerably lower ($Q = 0.42$). Indications such as these point toward the

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[2] Yule's Q correlation for dichotomous data. No significance level is given.

possibility that the entire social system in a particular discipline may function as the academic scientists' laboratory, while the industrial scientist is prevented, through artificial organizational bounds imposed by his employer from reaping the full advantage of communication within this community.

The industrial laboratory with its inherent orientation toward the eventual marketplace no matter how basic the research, requires of its scientists an identification with the organization that is generally absent in the university. This organizational identification works in two directions to exclude the scientist from informal communication channels. First, there are the usual requirements that the scientist work only on problems which are of interest to his employer, and that he refrain from publishing results, to prevent the employer's competitors from profiting by this research. Both of these constraints violate rather strong norms of the scientific community. The first violates the norm that science be free to choose its own problems and that the community of colleagues be the only determinant of the relative importance of areas of investigation. The second breaches a norm which we discussed earlier with respect to unpublished reports, the norm of communism. This norm requires that the substantive findings of science be assigned to the community. The requirement by the organization, that the scientist assign his first loyalty to it, engenders on the part of science, a reaction tantamount to partial excommunication of industrial scientists from the community. This partial excommunication entails a certain loss of prestige and recognition and results in an increased impedance to the transfer of information through informal channels. Denied access to informal channels, the industrial scientist must rely largely upon formal written ones. And where these fall short through either lack of competence on the part of the user or inadequacy of the literature, he attempts to formalize normally informal channels by hiring a paid consultant. The evidence available indicates that this attempt at formalization of the unavailable informal channels has for the most part been unsuccessful. It would appear that the industrial scientist is restricted to the use of those informal channels which are available within his own organization.

We will have much more to say about the relative merits of internal and external oral channels in Part II. There, when we deal with the consumption of information in technology, there will be much more evidence and rather strong conclusions may be reached concerning the impact of organizational factors on informal communication.

Looking to other studies, we find that unfortunately the data from the study by Berul et. al. are not in a form which allows any breakdown into sub-categories of oral communication. Contacts with vendors, consultants and colleagues are pooled and treated as a single channel.

The Halbert and Ackoff study does treat oral communication as something more multiplex than a unitary class of behavior. Here, we find communication activity analyzed in terms of time spent in discussion and in sending or receiving (Table 5-2), but no indication of the organizational affiliations of the second parties to the communication. The study does give some indication of the relative magnitude of inter- and intra-disciplinary communication. Chemists are found on the average to spend 21.4 percent of their time in communicating with other chemists. They

Table 5-2

Allocation of Time Among Oral Communication Activities as a Percent of Total Time Recorded for Chemists in 50 Laboratories (Halbert and Ackoff, 1959)

Form of oral communication	minimum	percent of time average	maximum
general discussion	0	10.3	35.3
non-discussion	0	9.2	28.0
sending	0	4.5	17.7
receiving	0	3.8	19.4
total	-	19.5	-
total scientific communication	15.7	33.4	61.4

spend only 2.7 percent of their time communicating with scientists other than chemists. Unfortunately, these percentages include written communication, and Halbert and Ackoff do not present a separate breakdown for oral communication.

Intradisciplinary

Many new ideas, and much of the knowledge of colleagues' recent results are most certainly conveyed through the informal oral system, with individuals shifting among research teams, assuming visiting professorships and meeting their colleagues at conventions and summer studies. But a distinction must be made between information which is specifically sought by the scientist and that which is obtained adventitiously. The informal network of the "invisible college" is far more likely to supply the latter. While many important needs will be satisfied in this way, there remains the requirement to fulfill those needs of which the scientist is consciously aware, and which the informal grapevine may not be capable of immediately supplying. Two problems exist with the informal system.

First of all, it sometimes exhibits a long response time. As a result of the possible unavailability or difficulty in finding the proper person, response times can become quite long. In addition, the stochastic nature of the system is such that a passive strategy with respect to specific information needs will almost necessarily result in a low probability of fulfillment. Facing such a situation, a scientist would be more inclined to turn to the literature to meet his problem-instigated information needs. Lest we appear to be suggesting the literature as a substitute for interpersonal contact, let it be said here that the evidence (Table 5-2) shows the literature to be clearly the dominant channel for such directly problem related searches. The distinction is between directed and non-directed search. The "invisible college" provides information which is for the most part not directly sought. This does not of course mean that this information might not have been sought at a later time, and it is impossible to determine the extent to which such information does obviate later searches, but it certainly cannot foresee all such needs. It is the browsing function, the keeping abreast of the state-of-the-art function which has been largely assumed by informal communication. The direct problem-dictated information searches remain the province of the literature. This, perhaps is the explanation underlying the rather surprising importance of textbooks for the scientist.

Supporting evidence may be found in a study of medical scientists by Herner (1959), in which he found that when an "answer or solution to a recent problem or question" was sought, the scientist referred to personal contacts in only 24 percent of the instances reported. Journals were reported as the source 33 percent of the time, books 14 percent, and abstracts or indexes 15 percent of the time.

Further elaboration is provided by the evidence of Menzel (1958). This shows that in the majority of cases where the scientist referred to non-literature sources for a problem-instigated information need, the information desired was of a type not normally found in the literature. When procedural details such as the use of techniques or a method of setting up apparatus are sought, the literature is usually incapable of providing the answer and the scientist must seek out an individual who has performed the procedure previously.

Interdisciplinary

When information must cross disciplinary lines, special problems are presented to the informal communication system. The "invisible college," almost by its very definition, cannot be assumed to function in this instance. Only in those rare instances in which a scientist regularly interacts with colleagues in several other disciplines can the functioning of the "invisible college" be approached. These instances, though undoubtedly rare provide rather interesting possibilities, for the scientific process. Pelz (1956), for example, has shown that scientists who interact frequently with colleagues who have dissimilar interests (provided the "most important" colleague shares their own interest) are higher in productivity than scientists who restrict their contacts to similar colleagues.[3] So in forming their own interdisciplinary colleges some scientists enhance the probability of obtaining useful information unavailable to their more homogeneously-oriented colleagues.

Again it might appear that the informal system is more suited to undirected information search, that problem-directed search must lie in the province of the literature. In other words, while the scientist may receive quite useful information from colleagues in other disciplines, the probability of finding answers to specific questions must be low among a necessarily limited set of colleagues in differing disciplines, and the information-seeker must fall back on the literature of other disciplies in his quest for specific information.

What scant evidence there is, however, seems to point in the other direction. One should be wary about conclusions drawn from these data since, as will be pointed out there are several weaknesses in the studies from which they are derived.

First, a re-analysis of data from the Auerbach Study (Berul et. al., 1965) shows that when the field of an information "chunk" sought differs from the field of the task for which it is sought the scientists (and engineers in the instance) tended to first approach colleagues and consultants, with the library and librarians rather low on the list of first

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[3] Maizell (1960) shows that stimulating ideas can cross disciplinary bounds in a similar manner through the literature. He found that more creative chemists consult the literature outside their own field more frequently than do their less creative counterparts.

sources. Unfortunately there are two rather severe limitations to this finding. First, the question on which these data are based was poorly designed and excluded the possibility of direct reference to any written source; even the use of libraries is probably underestimated, since the wording would lead the respondent to indicate such use only when he actually asked for help from the library. We have already seen that this is seldom done. A more important limitation lies in the impossibility of separating scientists from engineers as the data are reported. We will see that the two differ considerably in their information seeking behavior and since the sample studied by Berul and his associates for the most part comprised engineers, the finding would probably be quite different were the scientists separated out.

Other than this there exists no direct evidence to show preference for literature or personal contact when disciplinary bounds are crossed. Indirectly, however, Halbert and Ackoff (1958) show that 25 percent of chemists' journal reading time is spent with non-chemical scientific journals; Shaw's (1956) data (re-analyzed) indicates that more than 50 percent of the reading acts performed by chemists in the U.S. Forest Products Laboratory were outside of their principal discipline! The fact that this laboratory is oriented toward applied research may account for the breadth of the scientists' reading habits. The botanists in this study provide an even more extreme example but the reason is clear since most of their reading acts involve forestry publications (applied) with only 11 percent of the total given to botany.

Chapter 6

FORMAL AND INFORMAL CHANNELS: A SYNTHESIS

Until recent times, the normal vehicle for scientific communication has been assumed to be the formally edited scientific paper published in a specialized journal. Recent evidence shows that the journal system has been replaced in part, by a less formal interchange of information among members of invisible colleges, each operating at a research front of knowledge. That this is true can scarcely be denied, yet there remains a rather substantial dependence for information upon not only journals but, of all things, upon textbooks: How does one reconcile the functioning of the invisible college, which disseminates new ideas and findings so much more rapidly than the journal with its editorial and publication delays, with the reliance upon textbooks which necessarily lag the research front by several years? To answer this question, we must look a bit more closely at the nature of science.

The Process of Normal Science

Kuhn (1962) describes three classes of problems which are normally undertaken in science.

1. The determination of significant facts that the research paradigm has shown to be particularly revealing of the nature of things.

2. The determination of facts, which (in contrast with problems of the first class) may, themselves, be of little interest, but which can be compared directly with predictions made by the research paradigm.

3. Empirical work undertaken to articulate with paradigm theory.

The first two of these, namely, the precise determination and extension to other situations of facts and constants which the paradigm specially values (e.g., stellar position and magnitude; specific gravities; wave length; boiling points) since they have been used in solving paradigmatic problems, and the test of hypotheses derived from the central body of theory, will not concern us here. These are the normally accepted concerns of science, but the third-listed function is probably the most important and it is to this that we shall address ourselves. This category of activity comprises empirical work undertaken to extend and complete the central body of theory. It may, itself, be subdivided into three classes of activity:

1. The determination of physical constants (gravitational constants; Avogadro's Number; Joule's Coefficient; etc.).
2. The development of quantitative laws. (Boyle's, Coulomb's and Ohm's laws).
3. Experiments designed to choose among alternative ways of applying the paradigm to new areas of interest.

Within the third class lie problems that have resulted from difficulties encountered during the course of scientific research or during the process of technological advance.

Recent research has been unable to find support for the age old myth of a direct progression in the projects from basic research through engineering development. It is becoming generally accepted that technology builds upon itself and advances quite independently of any link with the scientific frontier, and often without any necessity for an understanding of the basic science which underlies it. Derek Price, a strong advocate of the latter position cites (Price, 1965b) Toynbee's position that:

> Physical science and industrialism may be conceived as a pair of dancers, both of whom know their steps and have an ear for

> the rhythm of the music. If the partner who has been leading chooses to change parts and to follow instead, there is perhaps no reason to expect that he will dance less correctly than before.

and goes on to marshall evidence refuting the idea of technology as something "growing out of" science, and to make the claim that communication between the two is restricted almost completely to that which takes place during the education process.

According to Price, the results of work at the research front are passed along to technologists only after having been packed down into textbook form. The process, of course, involves two rather long delay periods. The first one, during which original research is published in primary journals to await extraction into textbooks, may require several years; the second one, the period between education and the utilization of knowledge, is variable and one of the major causes of the technical obsolescence problem which we presently face.

> ... Interactions between science and technology provide the dramatic paradigm-breaking exceptions rather than the rule, and it is particularly evident on analysis that in no clear sense can technology be regarded as 'applied science'; it does not happen that technology is a sort of fruit hanging from twigs of a scientific tree. Technology is another tree of a different sort, but both trees are necessary if either is to grow, and the delicate symbiosis that keeps the growths in step appears to derive from the educational process that supplies scientists with a feeling for the ambient technology, and technologists with a feeling for the ambient science of their student days. (Price, 1965a)

Price's hypothesis certainly appears valid in light of what data exist. There is little evidence for direct communication between science and technology. The two do advance quite independently and much of technology develops without a complete understanding of the science upon which it is built. Occasionally, however, technology encounters a problem blocking its advance, the removal of which requires a fundamental understanding of the scientific basis of the phenomena involved. In this way, science discovers voids in areas which have been by-passed by the research front. Quite frequently, too, difficulties encountered during the research process in a seemingly unrelated area will reveal a gap in the understanding of a basic segment of science. Here again, in a sense, application helps to determine the direction or priorities in scientific investigation. Science must, so to speak, backtrack a bit and increase its understanding of an area previously passed over or neglected.

Several examples in which technology has defined important problems for scientific investigation are described by Morton (1965). He points out that progress in electron tube technology at one time appeared to have reached an upper limit of a few megacycles in frequency response. With the rapidly increasing amount of radio frequency communication, it was clearly desirable to extend the range of usable frequencies even higher. Use of the higher frequency ranges not only would increase the number of "channels" available to communicators, but would allow the use of larger bandwidths and thereby increase the amount of information per unit time which could be transmitted. This difficulty forced the realization that electron tube technology had advanced without a real understanding of the principles which were involved. It did this largely by "cut and dry" methods, manipulating the geometry and number of elements, without any real understanding of the fundamental physics underlying the observed phenomena. This block to the advance of a burgeoning technology forced a return to basic classical physics and a more detailed study of the interactions of free electrons and electromagnetic waves.

Returning to basic physics permitted the subsequent innovation of microwave amplifiers such as the magnetron, klystron and traveling wave tube. To quote Morton:

> ... the important lesson to be learned from the vigorous past of electronics is not that it was always close to the new frontiers of basic science. Rather, it was the conscious or unconscious recognition of relevant physical phenomenon and materials, old or new which could fulfill a critical need or break an anticipated technological barrier (1965, p. 64).

Additional support for this idea is provided by the results to date of the Defense Department's Project Hindsight (Sherwin, 1966). Working backward from recognized advances in the performance of a number of recent technological systems, expert teams attempt to trace the origins of these advances. In most cases, it has been impossible to pursue the search directly back to any specific scientific advance. The trail seemingly runs cold long before this point is reached. Paraphrasing R.S. Isenson, the project director, "It would appear that most advances in the technological state of the art are based upon no more recent scientific advances than Ohm's Law or Maxwell's equations." It is the exception to this discontinuity between science and technology, that chiefly concerns us at this point. Isenson reports[1] that he has discovered exceptions to his general finding and that these exceptions are usually characterized by a situation in which, similar to Morton, technology has advanced to a limit at which an understanding is required of the basic physical science involved. Thus technology defines a problem for science. When this problem is attacked and resolved by scientists, its solution is passed immediately into technology. A close coupling

[1] Private communication, April 22, 1966.

thus exists for at least an isolated point in time, and the researchers of Project Hindsight are able to trace the record back from an improved system in the utilization stream, through an advance in the technological state-of-the-art to the closure of a gap in the body of scientific knowledge. To distinguish this latter form of research from "frontier science," we would propose to call it "gap-filling science."

Gap-filling science is by its nature directly responsive to technological need. The advance of technology is contingent upon the pursuit of gap-filling science. So when the connection between science and technology is of this nature, little delay is encountered in the transfer of information. Communication is rapid and direct, and the long delays of the normal transfer process are circumvented. The transfer process from gap-filling science can be further accelerated by the inclusion of former scientists or individuals whose training was in science in the technological development team. The advantages of such a strategy were clearly demonstrated during World War II when many scientists became, at least temporarily, engineers and were very effective in implementing the results of fundamental research.

The point to be made is that much of basic science is not conducted at what is called the "frontier" of knowledge. Technology and oftentimes investigation in other scientific areas raise problems which attract investigators, to an area which has been trodden before. The investigation then proceeds, looking perhaps for items which had not been deemed important phenomena from a somewhat different vantage. The mere fact that such investigations are searching in what had been considered secure territory makes them no less fundamental in their nature. To draw upon the National

Science Foundation's definition of basic research, the fact that these researches are directed back over old ground does not mean that their primary aim cannot be "... a fuller knowledge or understanding of the subject under study, rather than a practical application." (National Science Foundation, 1965)

It is axiomatic that such investigations, at least at their outset, have no invisible college to aid in the dissemination of new findings. Researchers attracted to the area must begin from scratch, so to speak. They must search through the results of previous investigations, brush up on new specialties, and develop research techniques. In the absence of knowledgeable colleagues, most of this information must be obtained through the literature. Our belief that much of scientific activity involves the pursuit of knowledge in these non-frontier areas, is supported in some sense by the surprisingly heavy use by scientists of advanced textbooks, and the fact as we have seen (Table 4-1) that textbooks find their primary use in what has been labelled "direct solution of the problem." In other words, their information is used not in areas peripheral to the line of investigation, but rather, as a compact source of that knowledge which has been previously acquired.

The Need for Both Formal and Informal Flow

Thus, we see both the more formal written channels exemplified by journals and textbooks, and the informal, somewhat random, exchange of information through visits, seminars and meetings exist side by side in science and are really complementary. Each excels in servicing a type of research to which its particular idiosyncratic characteristics are best suited, at a given time. While the degree to which science in general will tend to rely on one or the other will vary with the general nature of scientific inquiry, and with the changing environment in which science must operate, neither can be said to be supplanting the other. Relative emphasis may change, but the nature of science requires that something like both these systems must exist to fully meet scientists' needs.

Chapter 7

OVERVIEW OF THE SCIENTIFIC COMMUNICATION SYSTEM

In the analysis of data, it has been necessary to break the scientific communication system down into its component parts and to view the use and value of each channel independently of other components. That channels do not operate in such an independent manner should be, of course, obvious. Nevertheless, the reader must be reminded at this point that although necessary for our analysis, this type of thinking would be disastrous if carried over to the design of new components or improvements for the communication system of science.

The interdependence of communication channels and the truly systemic nature of the scientific information complex should be readily apparent from the brief review of the findings of Garvey and Griffith in Chapter 4. In a similar manner, Orr and his associates (1964) have developed a systems model of the information complex of bio-medical research. Among their proposed uses for the model is included in the following:

> To determine where innovations may be advantageous and to predict their effects on other parts of the system. The model helps to predict the probable gross effects of an innovation on preceding or subsequent operations in the given processing sequence, or an operations in parallel chains. For example, the model calls attention to a major difficulty that arises when some, but not all, of the operations in the reference retrieval chain are automated. Greatly increased capacity for preparing reference search tools, such as printed indexes, will not result in commensurate improvement in the service provided by the entire chain unless the capacity for document analysis is correspondingly increased. ... The first operation has proved to be much more readily automated than the latter. Subject analysis of documents will remain, at least for the near future, an intellectual operation -- one for which the present acute shortage of qualified personnel is unlikely to be remedied quickly unless new approaches are adopted, e.g., author indexing.

This is the key argument for the systems approach. Menzel (1964) states the case quite clearly with his example of the introduction of an automatic retrieval system that operates so efficiently that it eliminates browsing. And yet, such an outcome is clearly possible under the strategies which have been followed by most information technologists up to the present time. A single system component is viewed in isolation, and innovations and modifications to improve its operation are formulated without any regard for the consequences which such changes hold for the remainder of the system.

Such studies as that of the modulation transfer project and the initial Garvey and Griffith work allow us to fill in the many components of this system much more completely than would be otherwise possible. They also provide knowledge of the relative importance of each channel in terms of performance or extent of use. These studies, however, make the necessary assumption of a static system. In view of this, even given the results of these studies, the accuracy with which we can predict the effects of innovations or changes in the system must necessarily be low.

In order to improve this accuracy the next step in our research efforts must involve the testing of the effects of system changes under controlled field experimental conditions. This, Garvey and Griffith have begun to do. During the 1965 convention of the American Psychological Association several changes were made in the information processing and dissemination system of that conference. The effects of the system will be measured and should be reported in the very near future.

In many ways, an even more ideal experimental situation is presented in the occurrence of parallel research projects. Modifications can be introduced to the communication systems of one team in each of several pairs and the behavior and performance of the teams may then be compared. Since a performance evaluation of the parallel projects can be obtained, the impact on research performance of system modifications can be measured. This method, then, provides empirically-based measures of effectiveness for incorporation in cost/effectiveness tradeoff studies of competing information systems.

PART II

THE COMMUNICATION SYSTEM IN TECHNOLOGY

Engineers are not scientists. While few will contest such a statement, it expresses a condition which has largely been ignored by researchers performing studies of information use. With few notable exceptions (Scott and Wilkins, 1959; Burton, 1959a; 1959b; 1959c), engineers have not been treated as a separate category of user. This has been due, in part, to the initial emphasis on scientific information with little explicit regard for technology. As a result, when engineers enter a sample they usually do so because they were either physically co-located with a sample of scientists or they are readily available and can be employed in a study of "scientific" information use.

Several recent studies[1] have shown the degree to which engineers differ from scientists. The differences lie not only in the type of work they perform, but also and more basically in their values and attitudes as well. We will show in this section that equally strong differences in their information gathering behavior.

The treatment will be somewhat different from Part I, since a new organizational entity presents itself when we consider technology. True enough, the laboratory organization exists as an organizational reality for many scientists, especially those in government or industrial employ. But it reaches its true actualization when we enter the realm of technology. Engineers do not usually form invisible colleges, nor do they generally exist as independent practitioners; they are almost totally employed in one form or another of laboratory organization. This, as we shall see is a critical distinction.

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[1]See for example: Pelz, 1966; Ritti, 1966.

Again we begin with a consideration of the relative importance of written and oral sources; from that point the treatment will move on to a consideration of each of these forms in greater detail. It is with the investigation of oral channels that the laboratory organization enters the picture. For this reason, Chapter 10 will be divided into two parts, the first dealing with channels which originate outside of the laboratory, the second with internal channels.

The data in Part II have been gathered from 22 development projects. All three types of data (messages received, time allocated, and specific literature references) were obtained on only seven projects.[2] The remaining 15 provided one or two types, but not all three. For example, on some projects data in the form of messages received and time allocated were obtained, but specific literature references were not. For this reason the sample size discussed will vary from section to section in Part II, but will always be noted in the tables presenting results. The number of projects supplying each form of data is indicated below:

1. Messages received: 17 projects in 8 parallel sets. Of the remaining five projects, two supplied data of too poor a quality for inclusion, and three were operations research projects, and supplied data of a nature which was not really comparable with other projects in the sample.

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[2] This is primarily due to the necessity of enlisting the cooperation of each project manager and his engineers on a voluntary basis. The nature and degree of cooperation varied among project sets. Only between members of a single project set did we exert effort to keep the nature of the cooperation constant. Some projects were more cooperative in submitting Time Allocation Forms; some in submitting Solution Development Records. In addition, some data requirements (e.g., specific literature references) were added over the course of the research, so these data are not available from the earliest projects.

2. Time allocation: 12 projects, 8 in four parallel sets; 4 single projects resulting from instances in which time data were not obtained in usable form from the other project in the parallel set. On the remaining 9 projects, time data either were not collected, or were of too poor quality to be used.

3. Literature references: 12 projects; on the remaining 9; this form of data was not requested.

Chapter 8

WRITTEN vs. ORAL INFORMATION CHANNELS: THEIR RELATIVE IMPORTANCE TO TECHNOLOGY

Once again we compare written with oral mechanisms for the transfer of information. The results presented in this chapter may help to clarify a currently rather confused state of knowledge in this regard. The reader will recall that while much of the present discussion centers around the importance of informal channels in the realm of science, that in fact, when one views the evidence available, written channels remain the more important. An explanation of this apparent contradiction may derive from the observation that most user studies to date have failed to clearly distinguish between the scientists and technologists in their samples. There are, as we shall see, very great differences in the behavior of the two populations. Their behavior in fact often appears quite counter-directional. To use a statistical analogy: what we may often be observing as a zero correlation when viewing the total population (of scientists and engineers) may well result from two opposing populations. But this is getting a bit ahead of the story. So let us first examine how the engineer obtains the information necessary for his work, that we may better compare his behavior with that which we have observed for the scientist.

The Engineer as a Consumer

How do engineers obtain technical information? What sources are available to them? Do they ever use the literature once they have left school? While this last question may at first appear inane, substantial evidence has arisen in recent years to provide a basis for considering it seriously.

What methods for keeping abreast of technical developments, other than reading the literature, exist for the engineer, and what is their importance relative to the technical literature? Such are the questions to which we shall address ourselves in the present chapter.

The Twin Development Projects

As with the modulation transfer project, data were gathered during the course of twenty-two development projects, composing nine parallel sets of development projects and four single projects (in which one member of a parallel set refused or failed to cooperate). These data were obtained by the use of Time Allocation Forms, Solution Development Records and post-project interviews. The nature of the data which were gathered varies somewhat among the ten sets of projects. Time Allocation forms were obtained from the first four sets of projects listed below. The 22 projects studied involved the following twelve 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 teams)

2. The design of a vehicle and associated instrumentation to roam the lunar surface and gather descriptive scientific data (2 teams)

3. An investigation of possible mission profiles and propulsion techniques for manned flights to another planet (2 teams)

4. The development of a detailed mathematical cost model yielding complete R&D and operational program cost estimates of space launch vehicle systems (2 teams)

5. The preliminary design of an earth-orbiting space station (1 team)

6. The design of a deep space probe, and appropriate instrumentation (3 teams)

7. The preliminary design of an interplanetary space vehicle (2 teams)

8. The preliminary design of a special-purpose manned spacecraft for cislunar missions (2 teams)

9. The preliminary design of an earth-orbiting space laboratory (2 teams)

10. The development of a mathematical model for an interplanetary transportation system (1 team)

11. The development of a container for cryogenic fluids (1 team)

12. The development of a low thrust rocket engine for maneuvering manned spacecraft (2 teams)

Time Allocation Data. Time Allocation forms were obtained from engineers on twelve of the twenty-two projects studied. With respect to the time allocation data, the reader should bear in mind that all of the projects were preliminary design studies and only three of the problems involved even prototype hardware production. As a result, the number of men assigned was small (median number about 6), and the proportion of time spent in communication and analysis may be high compared to that which an engineer involved in a true hardware development might spend. In other words, on a project which was nearer to actual production, an engineer might be expected to spend more time in setting up and conducting systems tests and in negotiating the actual manufacture, and less time in information gathering and analysis. As a result, our figures may be a bit high, but as we will see when we compare results from other studies, they probably do not amplify the situation very much, and since we want to find out whether engineers read at all, we may as well examine a somewhat extreme situation first.

Another word of caution: it was not possible to gather time data from all engineers on each project. Often people were assigned for a short period of time after the project was underway, and we were not always able to obtain forms from these people. In addition, for the two groups working on one of the problems, time data were gathered from only about half of the people assigned (the other half submitted Solution Development Records). This half was not arrived at randomly, but was what remained after we had selected the lead engineers to complete Solution Development Records, so they were generally not the people principally responsible for subsystems, but were rather the bottom-most engineers in the project hierarchy. Again, this may result in a slight inflation of the figures for proportion of time spent in information gathering and processing, but this time the bias should be toward a more realistic appraisal of how the typical "bench" engineer spends his time.

The results in Table 8-1 show that the engineers on the twelve projects spent almost 95 percent of their time gathering and processing technical information.[1] Actual information gathering accounts for about 17 percent of the engineers' time, and it is rather evenly divided between the literature and oral communication.[2]

Comparing the behavior of these engineers with the scientists of the modulation transfer project, it appears that they spend about half as much

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[1] The analytic design category, which was originally intended to represent time spent in direct problem solving was interpreted by most of the respondents to include group meetings and all non-information gathering of a technical, non-managerial nature.

[2] This measure does not include oral communication within the project group.

Table 8-1

Allocation of Time Among Four Activities as a Percent of Total Time Reported (Twelve Development Projects)

Channel	percent of total time allocated		
	total for 12 development	four higher-rated projects	four lower-rated projects
analytic design	77.30%	77.90	71.40
literature use	7.88	5.02	5.32
oral communication	8.46	8.86	7.32
total communication	16.43	13.86	13.43
other activity	6.27	8.24	15.71
total time reported (man-hours)	20,185	6,566	7,975

time in communication, with almost as much time devoted to the oral component, but less than half as much to the written. The scientists, you will recall, spent two-thirds of their information gathering time with written sources, and the remaining one-third with oral sources.

The literature then, from at least the aspect of total time expended over a project, appears to be a less important channel for the engineer than it is for the scientist. On the other hand, engineers do spend some eight percent of their time reading, and a component as large as eight percent of an engineer's time is hardly trivial.

For the four parallel sets of projects for which relative evaluations were obtained, there appears little relation between the pattern of time allocation and performance. Both sets spend almost exactly the same proportion of time with the literature, and although the higher rated teams spend slightly more time in oral communication, the increment is not significant statistically. Three considerations remain, however, before we complete our analysis of relative importance. First, the relative emphasis on channels may vary over the course of the project; second, channels may differ in the efficiency with which they deliver "messages" per unit of time; third, we must consider the value of the information received from each channel. We should not conclude a priori that engineers use more frequently those channels which provide more valuable information.

Beginning with the first of these considerations, Figure 8-1 compares the use of written and oral channels over the life of the development project. In addition to illustrating the expected surge in information gathering from both written and oral sources at the outset of the project, this figure confirms the secondary position in which written sources remain through most of the project's life. Again, this is in quite sharp contrast to what was found for scientists. The use of written material appears to decay quite consistently once the project is underway. The greatest demand for this material is in the first third of the project, during which about half of the total literature search takes place. Oral channels, on the other hand, show a much more pronounced periodic element, with two cycles over the course of the project. The first cycle peaks at the outset; the second cycle occurs near project completion. The second cycle quite likely derives from problems resulting from the interfaces among subsystems, and as we shall see is directed somewhat more toward sources within (as opposed to outside) the laboratory.

Post-Project Interview Data. As with the modulation transfer scientists, the engineers working on nine of the parallel sets (17 projects) were interviewed at length concerning changes in probability levels assigned to the several technical alternatives under consideration during the solution of each subproblem. The tape-recorded post-project interviews have been completely coded for all functions shown in Figure 2-3, for four of the 17 projects. Tapes from all 17 projects have been coded to determine the sources used for what is probably the most important of the several problem-solving functions, that of generating solution alternatives. In other words, we will present data on information sources used during four projects for each of six functions and on information sources used in idea generation during all 17 projects.

When considering all problem solving functions (Table 8-2), the formal literature provides something like four percent of all messages received. Even excluding those messages which originate within the problem solver himself (previous experience, and analysis and experimentation), the literature accounts for only 8.5 percent of the externally generated messages, comparing rather poorly with the 63 percent supplied by oral sources. Here again, a comparison with the findings from the modulation transfer project is quite striking. In that case, the literature provided 82 percent of the messages, while oral channels supplied but 13 percent.

For the important function of generating alternative solution candidates, oral sources are again dominant (Table 8-3), providing 35 percent of the messages compared with less than ten percent for the literature. The customer appears as an important source in development projects, having

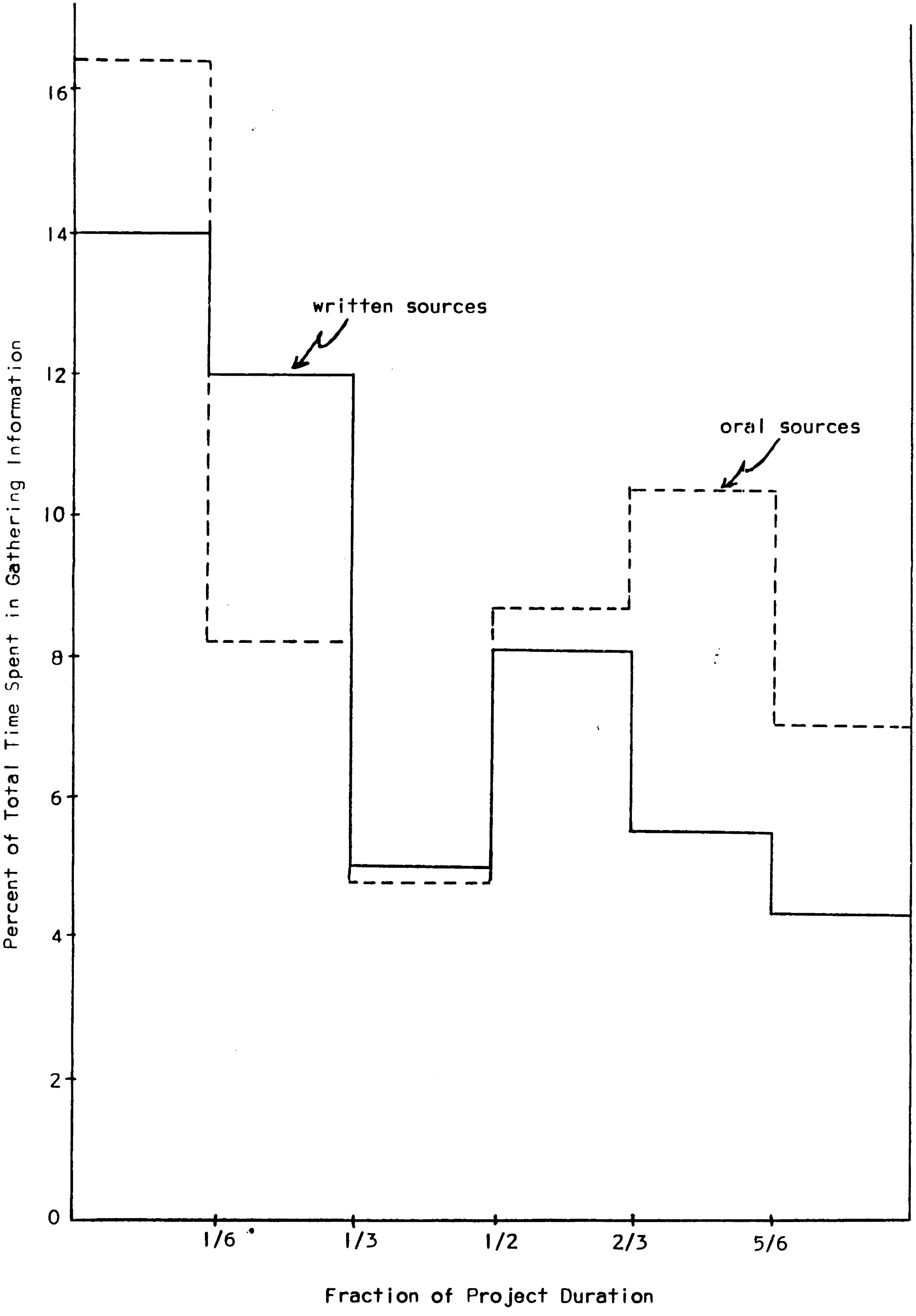

Figure 8-1. Allocation of Communication Time Between Written and Interpersonal Information Sources as a Function of Project Life Span (averaged for four twin pairs of development projects)

Table 8-2

Relation of Problem Solving Function to
Information Channel
(Four Development Projects)

	Information Channel				
Function	written sources	oral sources	customer	previous experience	analysis and experimentation
generate alternative approach to subproblem or expand existing approach	2.5% (3)	25.4% (30)	33.9% (40)	12.7% (15)	25.4% (30)
reject alternative approach	0	26.5 (18)	1.5 (1)	10.3 (7)	61.8 (42)
generate criteria against which competing approaches are to be measured	2.8 (2)	31.0 (22)	8.5 (6)	4.2 (3)	53.6 (38)
set limits of acceptability for each criterion or modify existing limits	3.5 (3)	39.1 (34)	6.9 (6)	4.6 (4)	46.0 (40)
decide whether to modify criteria or generate new alternatives	0	9.1 (1)	9.1 (1)	9.1 (1)	72.8 (8)
test alternative approach against criterial dimensions	8.5 (9)	20.8 (22)	2.8 (3)	1.9 (2)	66.0 (70)
total	3.7% (17)	27.6% (127)	12.4% (57)	7.0% (32)	49.5% (228)

*Numbers in parentheses indicate actual message count.

Table 8-3

Sources of Messages Resulting in Alternatives Considered During Seventeen Development Projects

channel	number of messages received	percent of total
literature	53	7.5%
oral sources	249	35.3
customer	132	18.7
previous experience	56	7.9
analysis and experimentation	216	30.6

suggested nearly 20 percent of the alternatives. The customer (a government laboratory) while generally transferring information by oral means, is shown in Table 8-3 as a distinctly separate channel for reasons which will become apparent later. The engineers themselves were responsible for generating the remaining 40 percent of the alternatives.

Comparison with Other Studies

Comparing the results from the parallel development projects with the Auerbach (Berul, et. al., 1956) data and with a study by McLaughlin, et. al., (1965) (Table 8-4) we find that, with the exception of the Auerbach Study, there is general agreement in direction if not in the actual percentages or their ratios. The differences in the ratios of the two numbers shown, is due, of course, to the heterogeneity of units and the methods of measurement used in the studies.

Table 8-4

Written vs. Oral Channels: Their Use by Engineers

	written	oral
Twelve development projects (percent of total time)	7.88	8.46
Eight sets of parallel development projects (17 projects) (percent of "solution alternative-generating" messages received)	7.5	35.3
Berul et. al. (1965)[1] (percent of all information "chunks" received)	55	30
McLaughlin et. al. (1965)[2] (percent of "most recent instances" of information use)	44	56

[1] 2,999 members of the U.S. government laboratories who belong to the conjunctive set of those whose "kind of activity" was classified as "exploratory, advanced, engineering or operational systems development" and for whom the task in which the information was used was classified as being "exploratory, advanced, engineering or operational systems development."

[2] 430 "industrial technologists" in a "large multidivisional American industrial firm."

The three studies demonstrate rather clearly the importance of oral means of transferring information in technology. Engineers keep abreast of the "state of the art" as much by maintaining informal contact with other engineers both within and outside of their own laboratories as by reading. And as we shall see later, even their reading is of an informal nature, mainly involving unpublished engineering reports produced by their own lab and by other industrial and government laboratories.

In terms of quantity, the literature is used somewhat less by engineers and provides markedly fewer messages; it would therefore appear to assume lesser importance than oral channels as an information source; the question of quality, however, remains. If the literature, though little used, supplies the best ideas, it would remain quite important for us to provide the engineer with greater ease of access to and use of it. Thus, before we leave this comparison of formal and informal media, we should look at their relative performance in terms of quality as well as quantity.

Performance in Engineering Problem Solving

Since performance evaluations were obtained at both the project and subproblem levels, the degree to which the several information channels are used can be taken as independent variables and related to this criterion. In addition, considering the generation of solution alternatives, there is another, somewhat earlier level of evaluation performed by the engineer himself. While several alternative solution possibilities may be suggested to him by the various channels, the engineer generally accepts only one of these as the solution to each of his subproblems. The ratio of messages accepted to the total number generated (acceptance ratio) may then be used as a measure of performance for each information channel In sum, there are three levels of analysis and three criteria employed in the ensuing paragraphs. First, at the project level, the proportion of total engineering man-hours allocated to each information channel will be compared to overall project performance. Next, at the subproblem level, the engineer's measure of performance (his acceptance ratio) will be assigned to each information channel used. Finally, again at the subproblem level, absolute and relative performance measures provided by the government technical monitor will be assigned each solution by the technical monitor, the relative evaluation stems from a comparison of these scores for each matched set of subproblem solutions in which the scores differed.

Time Allocated. Beginning with the project level, Table 8-5 shows that, on the average, the higher and lower rated project teams spend about the same amount of time in each of the activities compared. The differences, while not significant, show that the higher rated teams did spend slightly more time in oral communication.

Table 8-5

Comparison of Time Allocation Among Four Activities by Higher and Lower Rated Project Teams (four pairs of twin development projects)

activity	total for 12 development projects	four higher rated projects	four lower rated projects	level of statistical significance*
analytic design	77.30%	77.9%	71.4%	.4163
literature use	7.88	5.0	5.3	.4923
oral communication	8.46	8.9	7.3	.4670
total communication	16.43	13.9	13.4	.4918
other activity	6.27	8.2	15.7	.3718
total time reported (man-hours)	20,185	6,566	7,975	

* Of test for differences in proportions between the four higher and four lower rated projects.

Acceptance by the Engineer. At the subproblem level of analysis, the actual time allocated is in most cases not known, but we do know most of the information sources from which the solution alternatives were derived. Looking first at the rate of acceptance of these alternatives (Table 8-6),

Table 8-6

Messages Received and Messages Accepted by Engineers as a Function of Information Channel (Eight Parallel Sets of 17 Development Projects)

channel	messages received	messages accepted	acceptance ratio
literature	53	21	0.40
oral sources	249	109	0.44
customer	132	41	0.31
personal experience	56	17	0.30
analysis and experimentation	216	72	0.33
unknown	60	6	-

The differences between acceptance ratios for the following channels are statistically significant at the 0.05 level (2-tailed):

Between oral sources and customer

Between oral sources and analysis and experimentation

we see total frequency counts for messages received and accepted from each of five channels. Sixty alternatives could not be attributed to a channel, either through the unavailability of the knowledgeable engineer for interview, or through inability to obtain this information during the interview.[3] These data show quite a diversity in both relative use and performance of

[3]The low acceptance rate for these messages is probably due more to the interviewer's greater emphasis upon getting at the sources of accepted alternatives than upon any tendency to "forget" the poorer ideas.

the five channels. A chi-square test performed on accepted and rejected (total minus accepted) messages[4] shows a significant (X^2 = 9.37; p = 0.05) difference in the allocation of acceptances and rejections among channels. Oral sources supply a considerably greater number of acceptable approaches than would be expected by chance, while ideas from the literature are accepted at just about the expected rate. The difference between their acceptance ratios, however, is not statistically significant. We shall see a reason for this, and gain a clearer understanding of their relative performance when we examine oral channels in greater detail in Chapter 10.

Customer Evaluation. For 27 of the 82 subproblem pairs, relative evaluations of solutions were obtained from responsible technical monitors in the customer agencies. In the remaining 55 pairs, scores were either tied or no evaluation was available. This relative evaluation permits a comparison of the information channels used to arrive at a solution judged superior to the solution presented by other teams. Stated differently, messages can be divided on the basis of whether they result in higher or lower rated solutions, and their sources compared.

Table 8-7 shows the proportions of higher and lower rated solutions to which each channel contributed. Again, it is obvious that oral sources are used to a greater extent than are written ones, but there is no distinction in terms of the ratings received. While there appears a slight tendency toward higher evaluation of channels originating within the engineer himself

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[4] Alternatives of unknown origin are excluded, but their inclusion would obviously only inflate the value of X^2.

Table 8-7

Messages Resulting in Higher and Lower Rated
Sources of Solutions
(25 subproblem pairs)

channel	percentage of solutions suggested by messages received through each channel: 25 higher rated solutions	25 lower rated solutions	p
literature	4%	16%	0.16
oral sources	84	80	0.71
customer	8	8	1.00
personal experience	48	56	0.57
analysis and experimentation	60	48	0.39

(previous experience and analysis and experimentation) the differential among channels in performance is not statistically significant. Oral channels, on the average, seem not to perform much differently than written ones.

Channel Ratings. Since on five sets of parallel development projects (10 projects) a numerical score ranging from 1 to 5 was assigned each solution by the technical evaluator, this score could be assigned to the channels whence each solution originated, and mean ratings derived for the channels. To control for differences among evaluators, each evaluator's scores were normalized on his median ranking. Mean ranks were then computed for each channel across all evaluators.[5]

[5] Since no evaluator provided scores for all channels, a measure of agreement or concordance among evaluators was not derived.

The ranking of information channels, thus derived, is shown in Table 8-8. Again, the literature turns in a slightly poorer performance than do oral channels. But again, the performance differential is not significant statistically.

Table 8-8

Mean Scores Attributed to Information Channels from Evaluators' Ratings of Solutions Produced (10 development projects)

Channel	Mean Score*
literature	2.80
oral sources	2.02
customer	2.20
personal experience	2.34
analysis and experimentation	1.98

* Means of normalized scores, on a basis of 1 = highest; 5 = lowest score possible.
N = 99 solution messages.

Summary

The preceding analysis has shown that engineers make far greater use of oral channels than they do of written channels. This fact has been demonstrated by both measuring the amount of time spent by engineers in each of these activities over the course of several projects, and by counting the number of information messages which they received through each channel.

Despite the gross differential in relative use, we have thus far been unable to detect any difference in the performance of the two media. Oral channels consistently show a slight advantage over written channels, but in no instance measured, was the difference great enough to lead us to believe that it was other than a chance occurrence. There is a reason for this, but it is a bit premature to go into it, other than to say that there exist different types of oral, as well as of written, channels. Some types of oral channels outperform the written ones, but others do not. We shall see in Chapter 10 just how this occurs, and what it means to both the information scientist and the R&D manager.

Chapter 9

WRITTEN INFORMATION CHANNELS: THEIR FUNCTIONS AND PERFORMANCE IN TECHNOLOGY

Although literature was shown in the preceding chapter to occupy considerably less of the average engineer's time than does oral communication, it nevertheless does, on an absolute basis, represent a considerable portion of engineering time and may very well perform certain required functions more effectively than do oral channels. For this reason, we will in the present chapter examine in some detail the nature of the literature used by engineers, the manner in which it is used, and the functions for which information obtained from the literature is employed. In addition, we would like to find out why the literature occupies a secondary status and what steps, if any, can be taken to improve its performance. In order to explore these issues, we must examine in more detail the form of literature which is now used and the means by which the user acquires written material. The latter point is, of course because a difference in the difficulty of channel acquisition (differential user cost) could explain a major component of the variance in use. A second major component in this variance will be explained by examining the value of the information obtained through each channel. The consideration of value will occupy much of our effort in this and the succeeding chapter.

For twelve development projects[1] in which time allocation data were obtained (p.8-3), the engineers were asked to indicate specific literature

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[1] On one project, this provision was introduced at some point after work had begun and time data had been collected on an earlier version of the time allocation forms. Literature references were obtained only on approximately the latter half of that project.

references and to record in code the means by which the literature was acquired and the function that it served. In Table 9-1 is compared the relative use of formal (formally published in the public domain) literature and

Table 9-1

Relative Use of Formal and Informal Literature by Engineers

	percentage of instances	percentage of total man-hours	average number of man-hours per instance
formal literature (books, journals, periodicals, etc.)	45%	26%	1.5
informal literature (unpublished reports)	55	74	3.2

informal (unpublished or restricted publication) literature. The average engineer in our sample divides his use of the two media on about an equal basis with a slight edge in favor of the informal publications. Since engineering reports are usually much longer than journal articles and since, as we shall see, books are used only briefly for specific purposes, the engineer spends about twice as much time per instance of use when he reads reports, compared to formal literature. The net result, naturally, is a threefold greater expenditure of time with informal reports.

Formal Written Channels

In Table 9-2, we find that just as with the scientists (Table 4-1), textbooks again dominate the formal written channels. They are responsible

Table 9-2

Relative Use of Formal Literature Sources by Engineers on Twelve Development Projects

	percentage of instances	percentage of man-hours	average number of man-hours per instance	principal functions
textbooks	28.0%	0.5%	1.5	1
handbooks	9.9	12.3	1.7	1
professional engineering journals	10.8	9.9	1.1	7,1
scientific & mathematics journals	2.5	4.3	2.4	
privately sponsored engineering journals	19.7	17.2	1.2	8,7
trade journals	20.2	14.5	1.0	7
other journals*	4.4	7.7	2.4	4
conference proceedings	3.0	2.3	1.1	2,1
abstracts	1.5	1.3	1 2	-
total on which percentages are based	203 instances		276 man-hours	

Function Code:

1. Aid in direct solution of a problem (e.g., handbook-type information).
2. Determination of results of related work performed by others.
3. Determination of procedures (e.g , testing procedures, fabrication procedures).
4. Learning new specialty - broadening areas of attention (to include brushing up on old specialty).
5. Browsing of technical literature, resulting in significant discovery.
6. Verifying reliability of an answer.
7. Keeping abreast of developments in one's own particular field.
8. Keeping abreast of developments on related or competing systems.
9. Aid in definition of operational environment.

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*The category "other journals" comprises four references in which journal title was not indicated and five references to Scientific American.

for nearly one-third of the instances of formal literature use and a comparable percentage of the time allocated. Trade journals and privately sponsored journals (those published by some agency other than a professional society, usually for the profits to be obtained through advertising) follow second and third each being responsible for about 20 percent of the instances of use. There are few references to any scientific journals, and even the professionally-sponsored engineering journals turn in a rather poor performance. These (chiefly the Proceedings of the IEEE; AIAA Journal; and Mechanical Engineering) account for only eleven percent of the instances and ten percent of the time. Within the formal channels, and contrary to the contrast that was found between formal and informal channels, instances of use and number of hours spent in using a channel appear to be substitutable measures. The number of hours per instance remains fairly constant around 1.5 hours, and the rank order correlation between the two measures is nearly perfect ($r_s = 0.95$, $p<0.001$).

Several other studies show a similar distribution of channel usage (Table 9-3). Seldom, in any of these studies, do the formal literature channels compare with the informal channel of unpublished reports, and among the formal channels, themselves, textbooks, profit-oriented engineering journals, and trade magazines head the list with the professional society publications in a decidedly secondary position. Further, the wide variety of populations which were sampled in the several studies of Table 9-2 shows that this poor performance of the professional literature is not a phenomenon which is limited to any specialized segment of the engineering

Table 9-3

Literature Sources Used by Engineers
(Ranking of Degree of Exposure or Use)

	professional society journals	other engng. and trade journals	books[1]	hand-books	ab-stracts	unpub-lished reports
twelve development projects	4	3	2	5	6	1
Berul, et. al.[2] (1965)	4[a]		3	2	-	1
Scott & Wilkins[3] (1959)	5	2	3	1	6	-
Fishenden[4] (1959)	-	2	3[b]		-	1
Shaw (1956)[5]	3	1	4	6	5	2
Herner (1954)[6]	4	5	3	2	-	1

[a] no distinction made between classes of journal.

[b] no distinction made between texts and handbooks.

[1] includes monographs and textbooks.

[2] 2,999 members of U.S. government laboratories who belong to the conjunctive set of those whose "kind of activity" was classified as "exploratory development," "advanced development," "engineering development," or "operational systems development," and whose most recently completed task was classified as being of the same nature. Based on number of "chunks" of information from each source. (critical incident interviews)

[3] technologists in grades from foreman upwards in British electrical or electrical or electronics industry. Based on percent "remembering useful information obtained" from each of 19 listed channel types. (interview)

[4] "applied" research workers at Atomic Energy Establishment, Harwell, England. Based on percent of useful items of information obtained over two-month period (diary record).

[5] 51 engineers at Forest Products Laboratory, U S. Forest Service. Based on number of reading acts performed over period (diary record).

[6] 336 workers in "applied" science at Johns Hopkins University. Based on number who say they "use" each channel (interview).

profession. The society publications in all fields of engineering are failing to meet the present needs of their intended audience.

Why should this be so? Well, one reason is simply that many of the professional journals are incomprehensible to the average engineer. This is not necessarily the fault of the journals, it merely states a fact of life, which is due in part to an increasing obsolescence rate among engineers in rapidly advancing technologies. In part too, it is due to the formation of "invisible colleges" (Price, 1965) in such highly active fields as computer technology and certain areas of electronics. These invisible colleges function in much the same way as those in science, with publication intended primarily to preserve for posterity that which is already well-known by the peer group, and with no attempt to present the material in a form which would ease its comprehension by an "outsider." As a result, the _Proceedings of the Institute of Electrical and Electronics Engineers_ is utterly incomprehensible to most electrical or electronics engineers and the _Transactions_ of this society are only slightly less so. The practicing engineer, then, must look elsewhere for his information, and he goes either to informal sources or to any of a number of journals which have arisen to fill the gap between the society journals and the average engineer's capabilities. The latter have grown up, for the most part, outside the surveillance of the engineering societies and are published by private organizations whose purpose is to gain a profit through sale of advertising space. What is wrong with this situation? Perhaps nothing. Some of the profit-making journals are quite good. The problem lies in the fact that there is no guarantee of quality or even honesty in their presentations. Papers submitted to such journals are not subjected to refereeing by colleagues. The editorial staff undoubtedly reviews and rejects a certain percentage of the articles submitted, but the editorial staff cannot be fully competent in all the areas of such rapidly burgeoning technologies as electronics, and some fallacious work must get through. Furthermore, since many such journals are fully supported by advertising (subscriptions are free to anyone who can qualify as being a member of the audience which advertisers hope to reach) and all of them derive a major portion of their income from this source, there must exist a rather strong aversion to rejecting articles submitted by influential employees of key advertisers. Such a situation could easily lead to the publication of articles which are slanted toward the products or capabilities of the advertisers. Of course there is nothing wrong with a firm promoting its products and abilities, but to do this through the technical paper would be highly unethical and must ultimately destroy this device as a vehicle for the communication of knowledge in the technological community.

What can be done? Perhaps before we attempt to answer this question, we should state what we think shouldn't be done. Certainly we shouldn't invest a lot of time and money in developing systems to improve the engineer's ease of access to information which he can't and won't use, anyway. Instead of wasting our energies in such a fruitless undertaking, we should be attempting first to, in some way, close the gap between producers and consumers. Certainly, this is connected with the general problem of technical obsolescence, which for the most part, is beyond the scope of our present considerations. The problem of the engineering literature must, however, be viewed in the context of this more general problem. And any steps to remedy the situation must be properly coordinated with the programs which will be developed to combat or counteract obsolescence. This is an opportunity for the professional engineering societies to make an important contribution. Certainly, industry, the universities and to some degree the Federal government will have to become involved in this problem, but it seems to this viewer that the engineering societies operating through the Engineers' Joint Council is the logical coordinating body and is in a position to inject leadership and guidance into an area where it is sorely needed and where the potential gains are extreme. The proper societies have a real obligation to their membership in this area and they are now far from fulfilling it. What is required is a two-pronged attack. First, the obsolescence problem must be faced. The average engineer's capabilities to read the literature must be enhanced. But in addition to an attack on the consumer's problems, the producers must take steps to move their product nearer to the consumer's capabilities, avoiding in the process as much loss of content as possible.

The writers of engineering papers and the editors of most engineering journals do little to make their products understandable by the average degree-holding engineer. Any argument that this is an impossible task is readily refuted by the accomplishments of the writers and editors of such journals as Scientific American and International Science and Technology. These two journals have long demonstrated the feasibility of taking the most esoteric subject matter and presenting it in a form which is readily understood by most intelligent, educated humans. So the task is not an impossible one. It is difficult, to be sure, but it nevertheless can be done, and perhaps with less difficulty than is entailed in the creation of the acquisition systems presently being contemplated. But before attempting to merely ape the editors of successful journals, we should look a bit deeper into the problem and ask ourselves just what it is we are trying to accomplish.

The Institute of Electrical and Electronics Engineers has recently prepared a program (Rubinoff, 1965) of recommendations for the improvement of information dissemination and retrieval in electrical engineering. These recommendations, while certainly imaginative in many respects, fail to confront the basic question of the role of the professional paper in electrical engineering. That this role is well-defined and accurately understood is simply assumed at the outset. Such, however, is decidedly not the case; and until we have settled upon an accurate description of what this role presently comprises and what we desire to have it become, we will have missed the essential prerequisite for discussions of the dissemination process. Any steps to initiate a program of, say, editorial deposit will be premature without a thorough understanding of exactly what we wish to accomplish through such an innovation and some estimates of the innovation's capability for accomplishing the role requirements.

The present data provide us with a beginning step toward arriving at this role definition. In Table 9-4, we see that engineers use the professional journals either for aid in the direct solution of a problem or when they feel a need to acquaint themselves with a new specialty or to broaden their competence. A rather surprising and interesting result appears in this table. When an engineer wishes to keep abreast of developments in

Table 9-4

Literature Channels Used by Engineers in Performing Nine Functions

1. aid in direct solution of a problem	unpublished report, text, handbook or professional journal
2. determination of the results of related work performed by others	unpublished report
3. determination of procedures	unpublished report
4. learning new specialty -- broadening areas of attention	unpublished reports, professional journals or <u>Scientific American</u>
5. browsing which results in significant discovery	unpublished report or trade journal
6. verifying reliability of an answer	unpublished report
7. keeping abreast of developments in one's own particular field	trade journals
8. keeping abreast of developments on related or competing systems	privately-sponsored engineering journals
9. aid in definition of the operational environment	unpublished reports

his own field he refers to the trade journals; to keep abreast of developments on related or competing systems, he uses the privately-sponsored engineering journals; to expand into new fields, he uses the professional journal or <u>Scientific American</u>. One might expect the results to be quite different; perhaps professional journals for the engineer's field, privately sponsored journals for learning a new specialty, and trade journals for other systems. Certainly, that would appear to be the order of decreasing technical sophistication, and one would expect the engineer to seek reading material of decreasing technical sophistication as he moved farther from his own specialized area. However, a chi-square test, comparing journals used, shows the relation to run not only counter to expectation but to be so highly significant statistically ($X^2 = 33.11$; $df = 6$; $p = 0.001$) as to leave little doubt that the contradiction is not by chance.

Perhaps the fact that professional journals are also used to some degree in the direct solution of engineering problems and the fact that Scientific American is used to broaden the engineer's interests will provide a clue to what is going on. First of all, the professional journal is not used to keep abreast of developments in one's own field. The engineer learns of the general nature of such developments through trade journals, and the specifics are either guessed at and filled in from general wisdom and knowledge of the field, or learned through channels other than the literature. Chances are, that for security reasons (industrial or military) many of the details of developments never reach the literature anyway. Since state-of-the-art or review articles represent a major part of the content of privately-sponsored engineering journals, these are used to provide information on systems which are related to or compete with the engineer's own. Since he should be quite familiar with the state-of-the-art concerning his own system or specialty such journals are of less use to him there. But when he wants to learn about another system, they provide quite valuable information which is considerably more detailed than that available in the trade journals. On the other hand, when he wishes to learn more about a new technical area, he does not use the private journal. This is a bit surprising since these journals do contain some tutorial articles, but judging from the data, they are little used. Apparently the tutorial papers which have been appearing in increasing quantity lately in the professional journals better serve this purpose. In addition the excellent editorial accomplishment of the Scientific American is also useful in this regard. This latter fact stresses the need for simplified presentations of complex material to aid the engineer in developing new skills. Perhaps the combination of the presentations of the Scientific American to provide general concepts, followed by explorations in the more mathematical papers of the typical professional journal, is what is needed to best expand one's skill base in new directions. This is something which the professional societies and others concerned with technical obsolescence should certainly investigate in much greater detail.

Informal Written Channels

Tables 9-1 and 9-3 show the unpublished report to be the principal written vehicle for transferring information in technology. Seldom does the information generated during the course of a major technological development reach the point of publication in any of the formal media. A large volume of informal reports is generated however, and this practice has expanded to a point where the expense of documentation has become a major component in the cost of large systems developments.

This documentation takes on a wide variety of forms; at one extreme are scholarly publications recording advances in the state-of-the-art and the solution of very sophisticated analytic and mathematical problems, both worthy of publication in the formal journal literature were it not for the restrictions of national or industrial security. At another extreme are documents of a very pedestrian sort containing for example, detailed test procedures for system components or scheduling documents for the installation of missile bases or rocket launch facilities. For the most part, since the majority of the development projects in our present sample were preliminary design or feasibility studies, the reports cited are most likely quite sophisticated in their content. Unfortunately we know little more than this about the contents; we do, however, know something about their origins, the manner in which they were acquired and the uses to which they were put (Table 9-5). Rather surprisingly, documents which were generated within the organization are used to a slightly lesser extent than external reports. The division is nearly even, but one might expect in-house reports to be used much more than those generated by other organizations. As a result, there appears to be quite a flow of informal literature type among organizations in the aerospace industry. Moreover, impressions gathered during the course of post-project interviews indicate the customer agencies to be instrumental in maintaining this flow. The customer supplies a contractor with reports of his own and other government laboratories' work and with certain reports of other contractors. As a matter of fact, the customer appears to be responsible for providing nearly all of the reports in the "other company" category. In regard to

Table 9-5

The Use of Informal Literature Sources by Engineers on Twelve Development Projects

Origin of report	percent of instances	percent of total man-hours	average man-hours per/instance	principal functions
internal	33.8	36.5	3.5	2,1
other company	22.9	25.1	3.5	2
government	16.5	14.3	2.8	1,2
university	1.2	0.9	2.3	2,9
unknown origin	25.7	23.2	2.9	2
totals on which percentages are based	249 instances	796 man-hours		

Function Code

1. Aid in direct solution of a problem (e.g., handbook-type information).
2. Determination of results of related work performed by others.
3. Determination of procedures (e.g., testing procedures, fabrication procedures).
4. Learning new specialty - broadening areas of attention (to include brushing up on an old specialty).
5. Browsing of technical literature, resulting in significant discovery.
6. Verifying reliability of an answer.
7. Keeping abreast of developments in one's own particular field.
8. Keeping abreast of developments on related or competing systems.
9. Aid in definition of operational environment.

function, all but the documents of other companies find their principal use in direct problem solving; the "other company" reports are used chiefly, and not surprisingly, to determine the results of related work done by others.

Having seen the importance of the unpublished report in technology, and having some idea of how an individual engineer acquires and to what use he puts it, we may ask just how this particular device came into being.

You will recall that the scientific paper developed along with the norm of communality among scientists, requiring them to share their research results with their colleagues. The technological report developed in response to a quite opposite set of forces.

Three forces (competitive pressures; the requirements of national security; and the limited relevance of much of the information generated as a by-product of technological activity) have operated to require that the distribution of much of technology's information output be given very limited distribution. This limited distribution is accomplished through the control which can be exercised over the dissemination of unpublished technical reports.

The distribution of these reports can, to a very large degree, be controlled by the organization producing them. This is the secret behind their development. Since organizations for various reasons attach a condition of ownership to much of the technological information which their employees generate, and since, in one form or another, many organizations hope to sell this technological information at some time, they find it necessary to impose controls upon its dissemination. Such controls naturally preclude publication in the open literature. Now since it is to the organization's benefit to have the information recorded for reference, and disseminated within a limited domain (among employees, potential customers, etc.) the vehicle of the organizationally-sponsored informal report has arisen. These reports are issued in limited quantity for use within the organization and to selected individuals outside of the organization. In this way, at least to the first person receiving it, the audience can be effectively controlled. Of course there is no way of controlling for the people to whom this first person passes the document or its contents, but the limited number of copies available, and proper selection of the initial recipients pretty effectively circumscribe the audience reached by the information.

Nevertheless, even within a limited audience this form of documentation performs a valuable service in propagating the technological state-of-the-art. It is rather interesting to examine the manner in which this device operates. First of all, with the advent of low-cost, high-speed reproduction machinery, the dissemination of an important document <u>within</u> an organization can be very rapid. There would seem to be little control over the distribution within an organization. Once a document enters from the outside, it can be quickly reproduced and made available to anyone desiring it. The only point at which true control can be exercised is at the organizational border. First of all, the issuing agency can prevent dissemination beyond its own border. Once having allowed it to reach another organization, however, the issuing body must rely upon individuals outside of its own domain of control to protect its interests. This makes it rather difficult to control the flow within the recipient organization. When it comes to the question of having the document passed to another organization, however, an interesting situation has arisen. There seems to have developed in technology a rather strong norm against the transfer of another organization's reports beyond the limits of your own organization. Very frequently, the situation is encountered in which an engineer possessing another agency's report will tell someone from another organization of its existence, but with the admonition, "You'll have to write to _________ at ________for a copy." There is a very definite tendency to recognize another organization's proprietary interests. Violations of this norm are, of course, much easier to detect than is the further dissemination of information within an organization. When word gets back to the originator that a third organization has knowledge of a report's contents, the source of leak can be very obvious. This ability to detect violations is, of course necessary for the development of the norm, and explains the fact that the norm developed around the transmission of information between organizations rather than between individuals.

The importance of the unpublished report and some of these peculiarities in its dissemination pattern should clearly make it a subject of great interest to communication research. We have much to learn about this important vehicle and research should be directed toward determining its precise role and the roles of various mediating agencies in its propagation.

The rather heavy inter-organizational flow of informal reports, cannot help but assume a large measure of the responsibility for maintaining engineers' awareness of the state-of-the-art. In every case, indications are that they are used both in direct solution of problems and to find out what others are doing. This then may be one of the keys to the mysterious propagation of the state-of-the-art in technology, and is worthy of a much deeper and more detailed investigation.

Comparison of Formal and Informal Written Channels

The preceding demonstrates quite convincingly the importance of the informal literature which has developed in technology. Engineers, on the average, spend almost three times as much time with informal sources such as industrial and government reports as they do with formal literature sources. This finding varies, of course, with the nature of the project; over the twelve projects in our sample the ratio of time spent in using formal as opposed to informal literature ranges from 0 to 2.26. Comparing highly evaluated projects with those receiving a low evaluation reveals no significant difference in ratio between the two. In each case, high and low teams divide their time in about the same way between formal and informal literature. The nature of the technology appears to be the overriding determinant in the engineer's decision as to how he will divide his time between these two literature forms. As a result, a true assessment of the relation between use of literature and quality of the work must await the accomplishment of a field experiment in which one half of the teams in a set of parallel projects is encouraged to increase its use of one or the other of these media.

Method of Acquisition

Before an engineer can make use of a written channel of information, he must somehow acquire access to it. The method by which acquisition is accomplished is quite easy to determine. For each literature reference we simply asked the engineer to note his means of acquiring it. Five possibilities were suggested and a code provided to the engineer to enable him to easily indicate the method he used.

Clearly the majority of the engineer's formal reading material is maintained in the vicinity of his own desk (Table 9-6). More than half of the

Table 9-6

Method of Formal Literature Acquisition Employed by Engineers on Twelve Development Projects

Methods of acquisition	Instances in which a publication was acquired	
	number	percent
personal library search	36	26.9
search by library assistant	3	2.2
discovered through use of technical abstract	2	1.5
on desk or in personal file	73	54.5
borrowed from colleague	19	14.2
other	1	0.7
total	134	100.

acquisitions of this material were made in his own personal work area. Including books and journals borrowed from colleagues, we find that 92 percent of acquisitions were accomplished informally. The library is the second most important single source, but seldom is its complete potential utilized. While 29 percent of the acquisitions involve the library, in only six percent of these cases was a library assistant used. The vast majority of acquisitions resulted from personal library search, so we find the engineer's technique for acquiring formal literature to be quite informal. If the material is not available in his own work area, he either seeks it from a colleague or conducts a personal library search. Only on very rare occasions does he resort to such formal aids as a library assistant or technical abstract.

Comparing the mechanisms employed in acquiring books with those used for periodical literature, we find (Table 9-7) that books tend to be

Table 9-7

Methods by Which Texts and Journals were Acquired by Engineers Working on Parallel Development Projects (Twelve Development Projects)

Methods of acquisition	Number of publications acquired: texts and handbooks		journals and abstracts	
personal library search	8		21	
search by library assistant	3		0	
technical abstract	2		0	
total formal		13		21
on desk or in personal file	8		65	
borrowed from colleague	2		18	
other	0		1	
total informal		10		84

For total formal vs. informal, $X^2 = 11.2$, $p < 0.01$.

obtained through the library while journals do not. This would hardly be surprising did it not contrast so sharply with the behavior of the scientists on the modulation transfer project. They relied on the library to provide them with journals (Table 4-3) while most of the books used were their own. At least part of the explanation for this must stem from the fact that a major portion of the journals used by the engineers were of the free-subscription type, thus removing the expense of acquiring a personal copy. This is not the case with scientific journals, and the cost of personal subscriptions is quite high. On the other hand, the scientist over his longer training period acquires a larger personal library than does the engineer and in many companies, he finds it somewhat easier to have the company purchase new books for him, so he becomes a bit more independent of the library.

Since unpublished reports occupy such a dominant position in the engineer's reading collection, it is interesting to know just how the engineer goes about acquiring them (Table 9-8). Once again the informal

Table 9-8

Method of Informal Literature Acquisition Employed by Engineers on Twelve Development Projects

Methods of acquisition	Instances in which a publication was acquired	
	number	percent
personal library search	11	7.5
search by library	1	0.7
discovered through use of technical abstract	2	1.4
on desk or in personal file	49	33.3
borrowed from colleague	79	53.7
other	5	3.4
total	147	100.

acquisition mechanisms are more important than the library and its bibliographic aids. Of course, this time the finding is not as surprising. What is surprising is the importance which colleagues assume in supplying the engineer with reports. In considering the formal literature sources, it was seen that colleagues rank second and far behind the engineer's personal collection as an intermediary in the acquisition process.

Now colleagues assume the dominant role. The difference probably is attributable to the need for such reports to change hands many times over the course of a project. This is especially true of reports originating outside of the laboratory. They are necessarily limited in number on the one hand and widely required on the other, resulting in a situation in which they are passed back and forth among colleagues several times over the course of a project.

Although no explicit attempts were made during the study to assess the merits of the libraries available to the engineers, the topic did come up several times during the interviews. In general it can be said that as a potential information source they were not a very salient consideration in the minds of any of the subjects interviewed. The typical response seemed to be: "Oh sure, we have a good library, but ..." This was generally followed by an excuse for not using it such as: " ... it's a pretty good walk over these," or a contradiction: " ... they usually can't find what I want anyway." One is reminded of the attitude of the college hero in John Hersey's novel toward classroom attendance, and is led to conclude that engineers find the library simply, "too far to walk." There are clearly two reasons for such an attitude developing. Engineers have either an improbable innate animus toward libraries or a background of library experience which has not been very rewarding. The latter possibility most likely stems from inadequacies on both sides of the checkout counter. First of all, engineers seem for the most part to be ignorant concerning the use of bibliographic tools and to discount the potential of technical librarians for locating needed information. On the other side, there may well be a reason for this. Such tools as abstracts are certainly not as well developed in technology as they are in chemistry, medicine or psychology, and engineers may well have experienced unsatisfactory results in the few cases in which they have used technical librarians. The point, of course, is that we must examine both possible sources of the difficulty before we can formulate remedial action to bring the engineers and the library together on a satisfactory basis.

Chapter 10

ORAL INFORMATION CHANNELS: THEIR FUNCTIONS AND PERFORMANCE IN TECHNOLOGY

Recalling the discussion in Chapter 8, we found that the general medium which we classed as "oral channels" was used to a considerably greater extent than were written channels of communication, but when we examined relative performance of the two, we were unable to find much more than a very weak tendency for the oral channels to show higher performance. None of the differences in performance were large enough for us to discount the possibility that they arose through chance.

In the present chapter we will examine the various types of oral channel in much greater detail and compare their performance both relative to one another and in comparison with the written channels.

The presentation will follow a format which should by now be quite familiar to the reader. Beginning with a measure of the time spent with oral channels originating in two locations, we will proceed through a count of messages received through several types of oral channels to a general discussion of the manner in which two important classes of oral channel function in transferring information.

Time Spent with Oral Channels

The time allocation forms allowed the engineer to report time spent in communication with experts both inside and outside of his own laboratory. In Table 10-1, we see that development engineers divide their time rather evenly between internal and external sources. For the four sets of parallel projects for which relative evaluations were available, there

Table 10-1

Time Spent with Oral Information Channels
(Twelve Development Projects)

Location of channel	percent of total time allocated: total for 12 development projects	four higher-rated projects	four lower-rated projects
external to the laboratory	4.45	5.09	5.32
within the laboratory	4.01	3.77	2.00
total	8.46	8.86	7.32
total time reported (man-hours)	20,085	6,566	7,975

appears to be a slight tendency toward greater use of the lab's own technical staff by higher rated project teams. The difference between the two while suggestive, is, however, not statistically significant.

When viewed over the course of the project (Figure 10-1), we see that the second cycle of information gathering involves sources both inside and outside of the laboratory. External sources in this case are generally vendors and are contacted for coordination purposes prior to the final stages of the project. The reason underlying the second surge in consultation with the lab's technical staff is less clear, but probably involves certain types of problems which arise at this point. Interface problems are a possible example. When changes in the probability levels reported on Solution Development Records (an index of the extent to which designs are being modified) are plotted over time, a similar pattern of two cycles of activity is observed. The second cycle in design changes appears to correlate quite well with the information gathering cycle. The cause of this mid-project activity appears to lie in the fact that following an initial

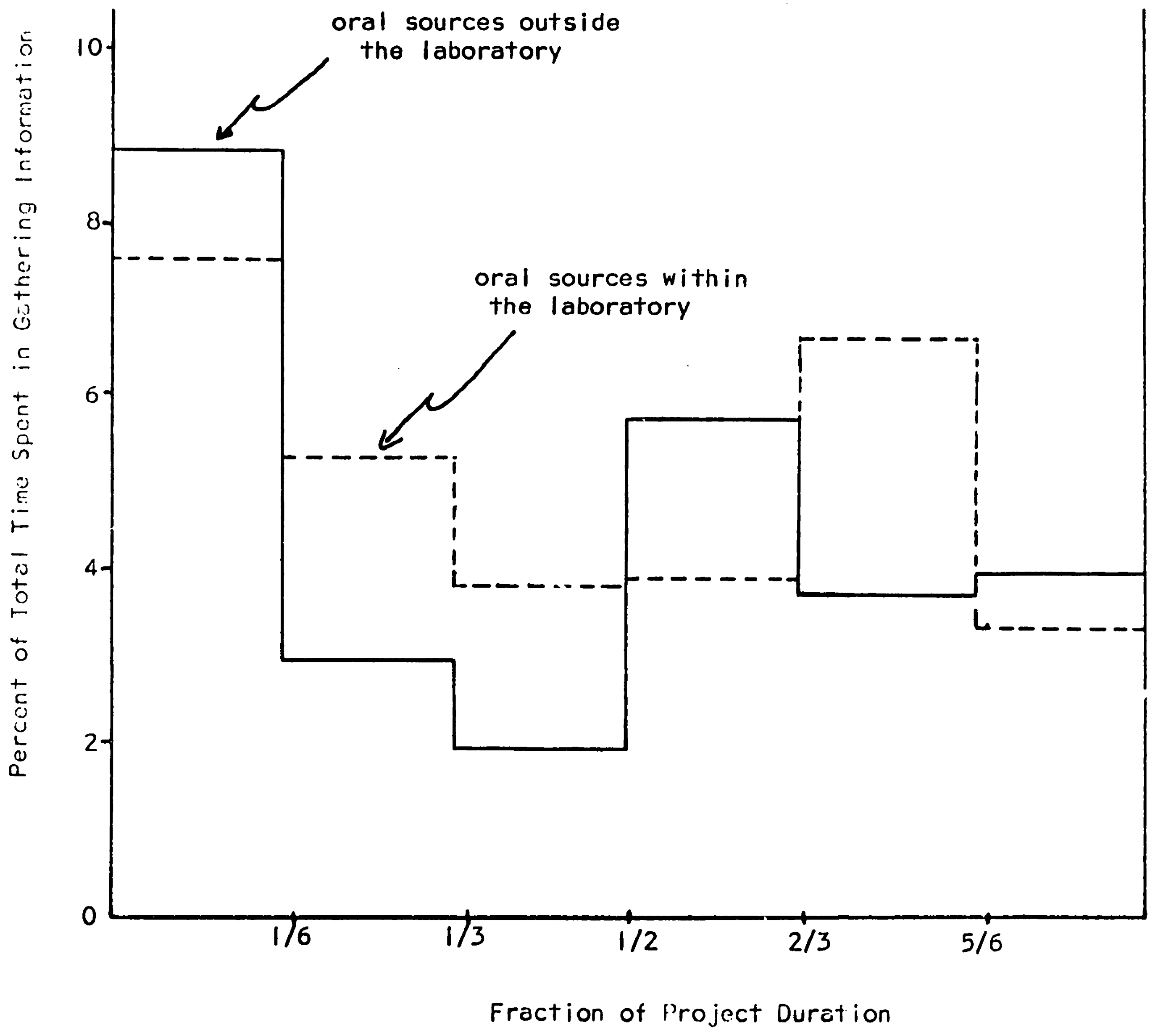

Figure 10-1. Allocation of Communication Time Between Oral Sources Within and Outside of the Laboratory Organization as a Function of Project Life Span (averaged for four twin pairs of development projects)

period of coordination, subsystem designs progress in a manner which is largely independent of one another. As the project enters its final half, the need for coordination among subsystem designs once again becomes apparent. Quite naturally when the designers of each subsystem learn that progress and changes in the design of adjacent subsystems have modified their interface requirements, they modify their own design and in the process seek out information upon which to base the new design. This requires not only coordination with vendors and associate contractors (external sources), but assistance from technical experts within the lab as well.

Messages Received through Oral Channels

In Table 10-2, the general classification of oral channels is broken down into components lying either within or outside of the laboratory. Sources outside of the lab, especially vendors, are used quite extensively for all of the functions investigated. This is especially true for generating alternatives; setting limits of acceptability for alternatives; and testing alternatives against the criterial dimensions. That vendors are a fertile source of ideas is certainly no surprise; they are, of course, promoting their own products as components and suggesting that they have the solution to the engineer's problem. That vendors aid in setting the limits of acceptability and in testing alternatives against specifications is a bit surprising until one considers that the vendor frequently provides the service of "reality testing" for the engineer. Since the vendor is more familiar with the lower order portions of a system design he can often tell the engineer what can or cannot be done with these components. There were a number of instances during the projects in which vendors actually

Table 10-2

Relation of Problem Solving Function to the Use of Oral Channels (Four Development Projects)

Function	number of messages received from:			
		channels outside the lab		channels within the lab
	customer	vendors	other external sources	technical staff
generate alternative approach to subproblem or expand existing approach	57.2% (40)	24.3% (17)	2.9% (2)	15.7% (11)
reject alternative approach	5.3 (1)	47.3 (9)	5.3 (1)	42.1 (8)
generate criteria against which competing approaches are to be measured	21.4 (6)	25.0 (7)	10.7 (3)	42.9 (12)
set limits of acceptability for each criterion or modify existing limits	14.7 (6)	39.4 (16)	14.7 (6)	32.0 (13)
decide whether to modify criteria or generate new alternatives	50 (1)	0	50 (1)	0
test alternative approach against criterial dimensions	12.5 (3)	41.6 (10)	16.7 (4)	29.2 (7)
total	31.0 (57)	32.1 (59)	9.2 (17)	27.7 (51)

*Numbers in parentheses indicate actual message count.

recommended against the use of their own product, on the grounds that it would not satisfactorily meet the requirements of the system. The vendor then provides very important feasibility information, and we see several alternatives rejected as a result of performance data acquired from a vendor that allowed the engineer to set or modify the limits of acceptability for either the subsystem for which the vendor was to provide a component, or one with which the vendor's component had to interface.

While the technical staff of the laboratory is used somewhat less than external sources for all of the functions, it does aid in rejecting alternatives and in determining those dimensions which are critical to the design. The importance of experience comes into its own in the latter function. The more experienced specialists on the technical staff are able to tell the engineer just which considerations are important to his design. The staff, for example, is often used to clarify for the engineer the relative importance of design criteria such as, should he really be concerning himself with weight in this subsystem, or is something else such as thermal dissipation or power consumption, or reliability the really important criterion.

Considering only the function of generating alternatives, data are again available from eight sets of parallel situations comprising seventeen projects. The two levels at which performance can be evaluated are: (1) the acceptance rate by the engineer and (2) the evaluation given to each solution by a technical monitor in the customer agency.

At the first level, we find that oral sources display a rather large variance in performance (Table 10-3), ranging from the customer who suggests

Table 10-3

Messages Received and Messages Accepted by Engineers as a Function of Oral Information Channel Used (Eight Parallel Sets of 17 Development Projects)

channel	messages received	messages accepted	acceptance ratio
customer	132	41	0.31
vendors	101	33	0.33
other external sources	67	32	0.48
technical staff	44	24	0.55
company research	37	20	0.54

The differences between acceptance ratios for the following channels are statistically significant at the 0.01 level (2-tailed):
- Between customer and company research
- Between customer and technical staff

and for the following channels at the 0.05 level (2-tailed):
- Between vendors and other external sources
- Between vendors and company research
- Between vendors and technical staff
- Between customer and other external sources
- Between customer and company research
- Between customer and technical staff

more than three ideas for every one that is accepted to the lab's technical staff who need suggest fewer than two ideas to have one accepted. In addition, a new information source is introduced at this point which we will call "company research" (see Table 2-1). As we progressed in our data gathering, it became obvious that many solution alternatives had been suggested by previous or simultaneous experiences which the lab (rather than the individual engineer) had had. The channel itself is not a "pure" one by our category system. It often involves the use of written company reports, but since at least a large portion of the information flow through this channel assumes an oral mode,[1] we include it here under oral channels. So, at this level, the lab's technical staff and external sources other than vendors perform better than do vendors or the customer as sources of technical alternatives. But note the frequency with which these channels are used. It is almost perfectly reversed from this measure of relative quality! We shall return to this point later in the discussion.

At the second level of evaluation, we again are able to divide parallel solutions on the basis of their ratings (higher or lower) by the government technical monitors (Table 10-4). Now the distinction between the per-

Table 10-4

Sources of Messages Resulting in Higher and Lower Rated Solutions (25 Subproblem Pairs)

	percentage of solutions suggested by messages received through each channel		
Information channel	25 higher rated solutions	25 lower rated solutions	probability
customer	60%	48%	0.20
vendors	32	32	0.50
other external sources	4	24	0.02
technical staff	24	16	0.24
company research	24	8	0.06

formance of internal and external channels becomes quite obvious. While internal channels suggest fewer ideas than channels outside of the

[1] If the engineer had himself been involved in the other project, the source of the idea was coded as "personal experience" rather than "company research."

laboratory, those which they do suggest have a much greater probability of receiving a higher rating by the technical evaluators.

The hypothesis to be tested here is based upon the findings of Allen (1964) for R&D proposal competitions. The use of information sources outside of the laboratory was found in that case to be inversely related to the technical quality of proposals, while use of sources within the lab was weakly but positively related to quality. The hypothesis predicts that poorer performing groups will rely more heavily upon sources outside of the lab, and better performing groups more upon sources within the lab.

In order to test the hypothesis, the actual number of solutions derived from each set of channels is aggregated in Table 10-5. Since a solution can result from several messages, each received over a different channel, those solutions to which only internal channels contributed are compared with solutions resulting only from external channels. To complete the set, a third category has been included. This category comprises solutions deriving from neither internal nor external channels, and solutions derived from both in combination. A chi-squared test rejects the null hypothesis of no difference in the performance of internal and external channels at the 0.03 level of statistical significance.

A somewhat more general test of the information gathering behavior of the engineers working on each subproblem can be performed by comparing the sources used in generating all of the solution alternatives which were considered for the subproblem. In other words, general information seeking behavior varies as a function of the individual and his particular circumstances. Table 10-6 shows that a comparison at this level strengthens the

Table 10-5

Sources of Messages Resulting in
Higher and Lower Rated Solutions
(25 Subproblem Pairs)

Information channel	number of higher rated solutions suggested	number of lower rated solutions suggested
Channels Outside the Laboratory external sources or vendors but not technical staff or company research $(ESUV) \cap (TSUCR)$	5	9
Channels Inside the Laboratory technical staff or company research but not external sources or vendors $(RSUCR) \cap (ESUV)$	7	1
Other Channels both or neither $(TSUCR) \cap (ESUV)$ or $(TSUCR)' \cap (ESUV)'$	13	15

$X^2 = 5.79$, $p < 0.03$

conclusions reached on the basis of comparing the sources of the solutions alone.

Higher and lower performers again show little difference in their use of the literature, vendors and analysis and experimentation and in their reliance upon personal experience in generating solution alternatives. Poorer performers once again rely more heavily upon external oral sources and better performers upon sources within their own laboratory, i.e., upon their technical staff and other company research programs.

Table 10-6

Sources of Messages Resulting in All Technical Alternatives
Considered by Engineers Submitting Solutions
Receiving Higher and Lower Ratings
(25 Subproblem Pairs)

Information Channel	percentage of alternatives suggested by messages received through each channel		
	79 alternatives associated with higher rated solutions	78 alternatives associated with lower rated solutions	probability
customer	47%	50%	0.35
vendors	23	28	0.23
external sources	5.1	15	0.02
technical staff	13	5.1	0.03
company research	17	3.8	0.005

For the six projects, on which numerical evaluations were obtained, ratings can be assigned to the sub-categories of oral channel in the same manner that was done in Table 8-8 for a more general categorization of channels. This assignment of ratings is shown in Table 10-5. On the basis of the numerical ratings, internal channels appear clearly superior to those outside of the lab. A Mann-Whitney U-test performed on the data underlying Table 10-7 shows the probability to be less than 0.02, that the scores assigned internal and external channels could differ as much as they do, as the result of a chance occurrence.

The results to this point have shown the three measures made concerning the use of oral channels. Two of these measures deal with performance, the third gauged the extent to which each channel was referred by the engineers in the study. Let us briefly recapitulate and bring the three

Table 10-7

Mean Scores Attributed to Oral Information Channels from Evaluators' Ratings of Solutions Produced

Channel	Mean Score*	
vendors	2.24	
customer	2.20	
other external sources	2.28	
mean for external channels		2.22
technical staff	1.67	
company research	1.76	
mean for internal channels		1.73

*Means of normalized scores on a basis of 1 = highest; 5 = lowest score possible.
N = 67 solution messages.

measures into the same focus. In Table 10-8 are shown the rank orderings of oral channels on the basis of the three measures. Looking at the first

Table 10-8

Rank Ordering of Oral Information Channels on the Basis of Three Measures

Message acceptance rate by the engineer	Customer evaluation of solutions	Frequency of use
technical staff	technical staff	customer
company research	company research	vendors
external sources	customer	external sources
vendors	vendors	technical staff
customer	external sources	company research

two, we see a reasonable amount of agreement. Aside from the placement of two channels, the engineer and customer evaluations are remarkably similar. Even the two exceptions are quite plausible differences. The customer tends to rate his own ideas considerably higher than does the engineer. And engineers apparently overrate ideas originated by external sources. When an engineer resorts to a consultant, he quite likely tends to overestimate the consultant's competence in the areas and, as a result does not exercise sufficient skepticism (Cf. the high acceptance ratio, Table 10-3) in assessing the idea. In contrast to the degree of correlation between the first two columns, we find the rank ordering of the third to be almost the exact reverse. In other words, the frequency with which a channel is used, shows an almost perfect inverse relation with its performance in producing ideas. While the discovery is certainly quite astounding, one does not have to search very far for an explanation. Simply look at the channels in the third column and subjectively rank them in terms of accessibility. You will probably reproduce the ranking shown in the table. Certainly the customer is the most accessible channel; he foists his ideas upon the engineer whether or not they are desired. Vendors, also are a highly accessible channel. The simplest way to design almost anything is to let potential vendors know that you are contemplating the idea of becoming one of their customers. They will come battering down your door and do a considerable amount of speculative design work and engineering in the hope of an eventual sale.

Now why should external sources be more accessible than one's own technical staff? First of all it must be explained that approaching either of these sources entails a certain psychological cost on the part of the engineer. He must concede that the other person knows something more than he does concerning a technical aspect of his own problem. This is a bit difficult for any engineer. But perhaps it is a bit less difficult to expose our ignorance to someone with whom we know we will not have to live in the future. In addition the outsider may be more willing to give his time; he may be a friend, a paid consultant, or a university professor who sees the engineer as a vehicle for having his ideas implemented, or a researcher in a government laboratory who feels a commitment to the overall mission of which the engineer's design is a part. The technical specialist within the engineer's own laboratory, on the other hand is quite likely to see the engineer as some "incompetent from the 'X' project" who, "wants to pick my brain," and who is unable to provide a quid pro quo. The technical specialist is not rewarded for consulting with the project engineer; he is rewarded for performing his own assignment, and consulting merely detracts from that accomplishment. This plus the low degree of utilization of company research both of which are rated highly by the two performance measures agrees quite clearly with the finding that while few solution alternatives were obtained from these two channels, it was primarily the higher performing groups, that used them.

In sum, it appears that the process of channel selection and use follows a pattern like that shown in Figure 10-2. The selection of a channel is based to a very large degree upon its accessibility. Now this, of course, carries from instance to instance with the circumstances surrounding each situation in which the engineer finds himself. But over time, some channels are on the average more accessible than others and this is witnessed in the varying frequency with which they are used. So far we have

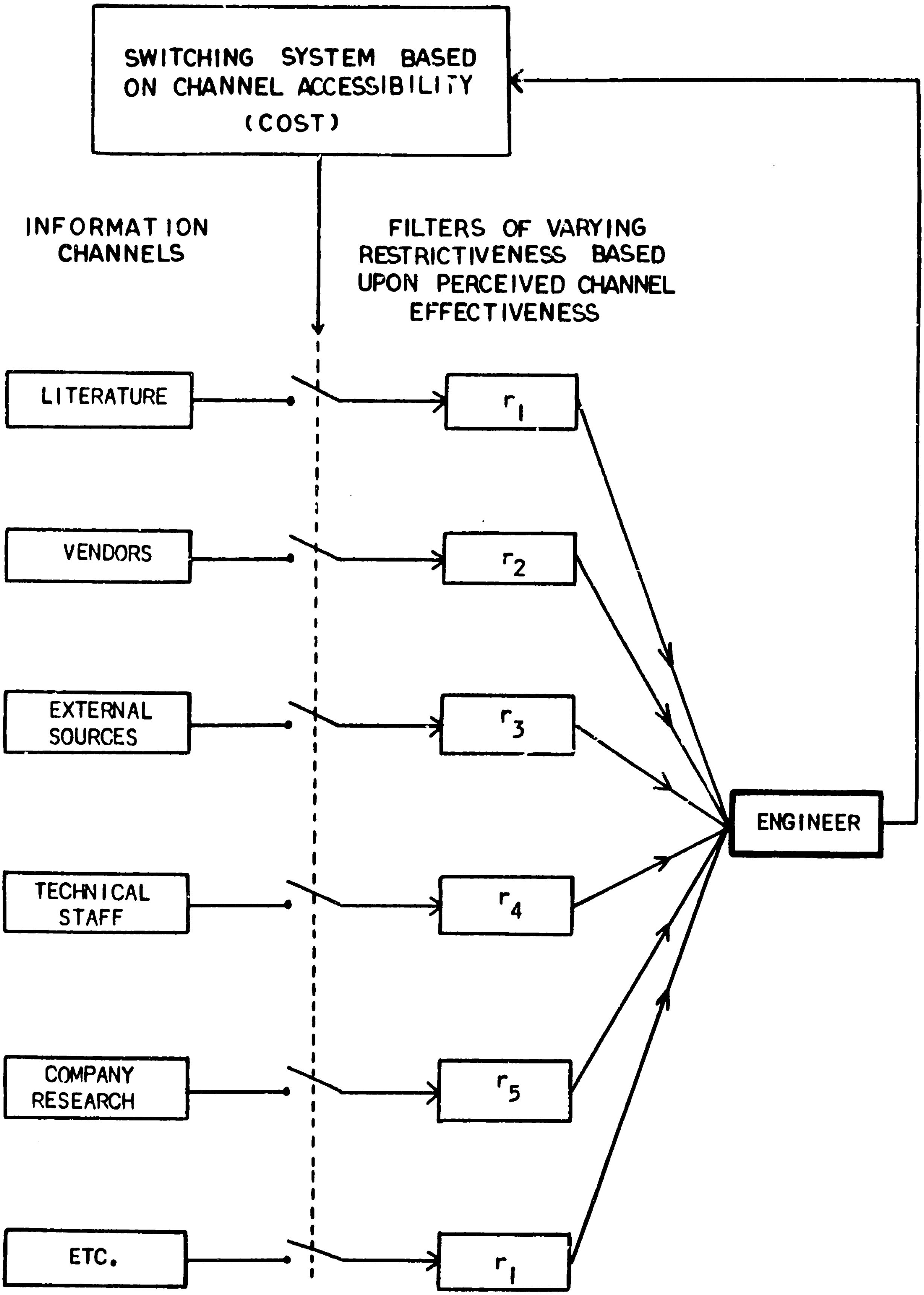

FIGURE 10-2. CHANNEL SELECTION AND FILTERING

not mentioned channel effectiveness. That parameter is reflected when receiving information from each channel. The functioning of the filters is demonstrated by the variable acceptance ratios found for each channel. The acceptance ratios are based upon the engineer's perception of the performance of or the quality of the ideas generally delivered by each channel.

Channels External to the Laboratory

It is rather obvious from Tables 10-4 and 10-8 that external channels are over-utilized relative to their value in providing the engineer with the information he requires to produce a high quality design. Previous discussion has explained these circumstances as in part resulting from the ease of access to such channels. But the question of value remains. Given that they are readily available, what is the reason for their apparent failure to produce information, which is comparable in value to tha available from sources within the laboratory organization. To answer this question, we must return to the discussion of Chapter 5, in which we considered the use of oral channels by scientists.

The phenomenon of a communication impedance at the organizational boundary appears to exist for both engineers and scientists to the extent that they are considered members of an organization. While we have noted many contrasts in the information seeking behavior of the two populations, at this point, the situation under consideration appears common to both. It is more a function of the nature of the organizational entity itself, that of the characteristics of the membership.

The phenomenon first became apparent in a study of R&D proposal competitions (Allen, 1964). The proposal competitions studied varied widely in the nature of their problem and ranged throughout the research spectrum from quite fundamental basic research studies to hardware-oriented development and test projects. Across this wide range of problem types, teams which relied more heavily upon outside information sources were found to produce poorer quality solutions. Fourteen of the fifteen correlations between the extent to which outside sources were used and rated technical quality of the proposals, were found to be negative. The mean rank order correlation for 15 competitions was $-0.30 (p < 0.001)$. In searching for an explanation, it was found that lack of technical competence within the lab was largely responsible for at least the decision to use outside sources. Inverse relations were found between the use of such sources and, both the size of the lab's technical staff and its ratio to the total employment of the lab. Laboratories which do not have the necessary technical manpower resources attempted unsuccessfully to substitute for this lack by reliance upon outside technical personnel.

Similarly the study by Shilling and Bernard (1964), which has been cited earlier (Chapter 5) shows consistent inverse correlations between the extent to which "paid consultants" were employed by industrial bio-scientists and eight measures of laboratory "productivity and efficiency." All of these correlations were statistically significant at the 0.05 level, or better. Furthermore, the authors found that the use of paid consultants was the only factor "which clearly and unequivocally differentiates (university from government and industrial) laboratories."

In the studies of parallel R&D projects, we first witnessed the variation in use of external and internal channels in observing the modulation transfer project. It will be recalled that while scientists in both labs spent about the same amount of time in oral communication with other scientists, one team was strongly oriented toward external sources, the other toward sources within its own laboratory. With a sample of only two projects, nothing could be said at that time concerning the relation of these dichotomous orientations to the relative performance of the two teams. With the parallel development projects, however, the limitations of sample size are surmounted, and a very definite relation appears at two levels of performance evaluation. So the evidence which has accumulated is indeed quite convincing, but it does not as yet provide an explanation for the situation which is found to exist. The nearest we have come to an explanation is the finding of an inverse relation between the size (both absolute and relative to total company employment) of a lab's technical staff and the extent to which outside sources are used during proposal competitions. This suggests two factors which must be operating. First, those teams, or more precisely those laboratories whose research teams rely on outside help possess other characteristics which are more likely to be the actual cause of the poor performance. The most plausible of these is simply the lack of the required technical competence within the lab. Certainly, the use of an information source can seldom be held to directly <u>reduce</u> quality. Rather, the initial lack of knowledge on the part of the R&D team members would be directly responsible. Some information sources are more capable than others of counteracting this initial condition. This introduces the second factor: sources outside are either less well-informed, which is rather unlikely, or there exists an impedance at the organizational boundary which interferes with information flow through the introduction of what Bar-Hillel and Carnap (1953) call "semantic noise." That is, the impedance to which we presently have reference causes error in the interpretation of messages, and is analogous to noise sources in physical systems which cause error in reception of messages (Cherry, 1957).

How is it that the discontinuity between organizational systems operates to introduce noise into communication? Before addressing this question directly, let us first examine an instance which at first appearance runs counter to the evidence thus far. Remember that in the case of Hagstrom's (1965) scientists,[1] the organization imposed nc such barrier. He found a strong correlation (Q = 0.85), between extra-departmental communication and productivity in terms of papers published. The correlation between productivity and intra-departmental communication is considerably lower (Q = 0.42). Now how does this relate to the present findings and how can the apparent contradiction be resolved? First of all, Hagstrom's measure of extra-departmental communication was, it should be noted, restricted to communication within the individual's academic discipline. Furthermore, the organization in Hagstrom's case is somewhat different; it was a university department; all of the other results stem from studies of industrial organizations.

It follows that, the differences in the effectiveness of extra-organizational Communication found between the two situations can be attributed in large part to two factors:

1. The relative commitment of the individual to the organinations or social systems at hand, and

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[1] See p. 5-7.

2. the degree to which the boundaries of these organizations are formally structured.

In this context, Hagstrom's scientists confronted a low impedance in communicating across the bounds of their academic departments (but within their disciplines), because the academic department elicits a lower degree of commitment from scientists than does their professional discipline, or "invisible college." At the bound of the latter, we should expect to find a higher impedance than at the bound of the academic department, but possibly not so high as at the periphery of a more formalized organization such as an industrial or government laboratory. Here, we bring in our second consideration. The difficulty lies in the nature of the bureaucratic form of organization.

The impermeability of bureaucracy to the influx of information and technology has been deplored in recent years by many social scientists. Bennis, for example (1966), in cataloguing the many criticisms which have been levelled at bureaucracy includes the charge that it, "cannot assimilate the influx of new technology or scientists ...," Katz and Kahn (1966) provide us with some explanation for this, revolving about two major points:

1. In order to control its intake of information and thereby avert the possibility of being so overwhelmed that the resulting condition is one of pure noise, the organization established a "system boundary" which defines the appropriate region for organizational activities, and " ... constitutes a barrier for many types of interaction between people on the inside and people on the outside."

2. Every organization like every individual develops a coding system with which to order its world. Each R&D laboratory, for example, has its own way of attacking problems which members assimilate over time. Some labs are noted for the conservatism of their designs; others are gamblers and are noted for farout thinking and occasional outstanding breakthroughs. These characteristics as well

> as certain of the long-run organizational goals become engrained in the members of the organization, and thereby provide a conceptual or coding scheme by means of which they both categorize their world, and communicate about it to others.

The coding schemes to which we refer are far less exclusive than, for example, most languages. There is a great deal of overlap among the coding schemes of different organizations, operating within the same culture. On the other hand, the non-overlapping areas, however small, can potentially operate to produce semantic noise. Organizational coding schemes, in this way, both enhance the efficiency of communication among those who hold them in common, and can detract from the efficiency of communication between holders of different coding schemes. As Colin Cherry (1957) tells us:

> The semantic-information content of a statement (which includes all that is logically implicit in that statement) is available only insofar as the rules of the language system are known ...

In other words, communication between coding systems, without knowledge on the part of one or both communicators of the other's coding system, introduces the possibility that part of the semantic-information content of the message will be lost.

Returning to Katz and Kahn's two points we see that they are clearly complementary. The first is accomplished in part through the second. System boundaries are, to some degree, defined and maintained by a difference in coding schemes. The boundary, of course, is not intended to be completely impenetrable. The organization must have some exchange with its environment. In order to allow this and yet control the degree it establishes a limited number of officially recognized channels through which communication must be directed. We have, for example, libraries and purchasing departments and field offices, through which information must be funnelled. In the situation with which we are presently concerned, the official limitation of channels probably occupies a secondary position, as an impediment to communication. Engineers (often to the dismay of librarians and field office managers) are generally quite uninhibited in short-circuiting such devices. It is rather the development of coding schemes which best explains the evidence which we have seen.

Let us now briefly review our results. First of all, several studies of industrial and government scientists and engineers have shown an inverse relation between extra-organizational communication, contrasting with direct relation between intra-organizational communication and performance. Second, in Hagstrom's study where the organization (an academic department) appears to occupy a subsidiary position to a more inclusive social system ("invisible college" or academic discipline), and where the communication process measured was external to the first entity but <u>internal to the second</u>, a strong positive relation was found between the extent of communication and performance. Third, in the instances in which external communication bears an unfruitful relation to performance, there is evidence that it is not this communication, per se, which degrades performance but other factors, such as lack of the required knowledge by the engineer or scientist seeking information. The internal channels are better able to compensate for this deficiency, than are external ones.

Applying the rationale of the shared coding scheme produces a rather simple and straightforward explanation. In industrial and governmental situations, the laboratory organization dominates the scene. These organizations demand a degree of loyalty and affiliation far outweighing that required by academic departments. In addition, the members of industrial and governmental organizations acquire through common experience, and organizational imposition, shared coding schemes which can be quite different from the schemes held by other members of their particular discipline. This is not true of the academic scientists. They generally feel more aligned with scientists who share their peculiar research interests than with a particular university or department, and would therefore tend to share a common system of coding with such individuals outside of their department. In other words, the "invisible college" now becomes the mediator of the coding scheme.

The mismatch problem is compounded when, as is often the case, incompatibilities between the two coding schemes go unrecognized, or when identical coding systems are assumed which do not in fact exist.

There are, of course, possible measures which can be applied to reduce the organizational boundary impedance. One which may well take place under uncontrolled circumstances is a two-step process in which certain key individuals act as bridges linking the organization members to the outside world. Information, then, enters the organization most efficiently when it is channeled through these individuals, who are capable of operating within and transmitting between two coding schemes.

The possible existence of such individuals, who in effect straddle the coding systems and are able to both function efficiently in the two, and perform a transformation between them holds promise for their potential utilization in information transfer. In other words, it appears that information must be gotten to its user by an indirect route. Attempting to bridge the organizational bound directly is not the most efficient path. Rather, the "technological gatekeepers" in the lab must first be reached and it is only through these men that the boundary impedance can be effectively surmounted.

Channels within the Laboratory

Considering now the processing of technical information after it has entered the organization, we see in Tables 10-6 and 10-8, that despite the fact that internal channels (technical staff and company research) show the highest performance on all measures, they are the least used of the channels studied. This apparent under-utilization of internal channels indicates that there are rather important benefits to be derived from improving the communication flow within the lab itself. For example, technical staff who are knowledgeable in particular areas could be made more readily available for consulting by project members, and rewarded for the contribution which they make through this form of activity. The distribution of company documents resulting from R&D programs and company-sponsored research can very definitely be improved. In Chapter 9, we saw that unpublished reports were the most highly used of all literature forms. Yet time and again, we discovered during the interviews, cases in which information originating in another company project was for some reason or other obtained too late to be useful. Very often engineers related experiences of amazement at the discovery of related work going on in their own laboratory. Most project managers, when questioned about this, agreee that the communication among projects in their laboratory leaves much to be desired.

The present results merely point up the problems and add a suggestion of the benefits to be derived from the better utilization of these important channels. The question remains, of what steps might be taken to improve the internal flow.

One of the first steps, certainly, is to attempt to develop a more complete understanding of what is involved in the actual process of transferring information within an organization and what factors can be found that impede or enhance the flow.

A classic study in industrial sociology, by Peter M. Blau (1963) addresses itself to just this topic. Blau studied the consulting relationship among agents in a federal law enforcement agency, and has this to say about the psychological costs which are involved with using this particular information channel:

> A consultation can be considered an exchange of values; both participants gain something, and both have to pay a price. The questioning agent is enabled to perform better than he could otherwise have done, without exposing his difficulties to the supervisor. By asking for advice, he implicitly pays his respect to the superior proficiency of his colleague. This acknowledgment of inferiority is the cost of receiving assistance.

In describing the extreme case in which a man comes to rely heavily upon intra-organizational consulting as a source of information, Blau goes on:

> Asking a colleague for guidance was less threatening that asking the supervisor, but the repeated admission by an agent of his inability to solve his own problems also undermined his self-confidence and his standing in the group. The cost of advice became prohibitive if the consultant, after the questioner had subordinated himself by asking for help, was in the least discouraging -- by postponing a discussion or by revealing his impatience during one.

To an engineer, this cost is at least equal to, and perhaps many times more than what it amounted to for Blau's agents (Cf., Shepard, 1954). The prestige of an engineer among his colleagues is founded almost entirely upon a mysterious characteristic called "technical competence." To admit a lack of technical competence, especially in an area central to the engineer's technological specialty, is to pay a terrible price in terms of lost prestige. This is why it is so much easier to seek consultation outside of one's own organization. The prestige loss cannot be nearly as great when the relationship is brief and there is little chance that any knowledge of the transaction will ever reach one's organizational colleagues. As a matter of fact, the engineer need not even pay this price to the consultant. Since the outsider has no knowledge of the man's organizational reputation, nor of the specific technical content of his responsibilities, the engineer can easily excuse his lack of knowledge by passing himself off as an "expert in something else" who needs some help in "broadening into this new area." By such a strategem, the engineer can disguise his lack of competence on a topic of which he is supposed to be knowledgeable, and run little risk that anyone in his home organization will ever learn of his game. The ruse would, of course, not work as well when consulting with someone within the lab since the risk of being exposed is far too great.

Considering the other end of the transaction, Blau continues:

> The consultant gains prestige, in return for which he is willing to devote some time to the consultation and permit it to disrupt his own work. The following remark of an agent illustrates this: "I like giving advice. It's flattering, I suppose, if you feel that the others come to you for advice."

But this gain again differs, depending on which side of the organizational bound the consultant is located. For the outsider, it is indeed flattering and it probably adds a great deal to his prestige to have it known that people from other organizations come to him for technical advice. But for the insider there is usually no such gain. Someone approaching from within the organization is not as visible as a visitor entering from without, and besides no one knows why the insider is talking to the consultant anyway. For all his supervisor knows, they may be fishing companions talking over last week's (or next week's) catch. The reward then is much less and the cost is greater. The man who consults with outsiders has an organizational blessing on his activity; else the organization would probably have discouraged the visitor in the first place. The internal consultant, on the other hand, pays the full price of spending time to the neglect of his organizationally assigned responsibilities.

Blau again:

> All agents liked being consulted, but the value of any one of very many consultations became deflated for experts, and the price they paid in frequent interruptions became inflated. One of them referred to the numerous requests for his advice by saying, "I never object, although sometimes it's annoying." Being approached for help was too valuable an experience to be refused, but popular consultants were not inclined to encourage further questions.

Homans (1961) states the above principle in more precise terms as one of his propositions of human exchange:

> The more often a man has in the recent past received a rewarding activity from another, the less valuable any further unit of that activity becomes to him.

Again in more homely terms, an engineer who very frequently seeks consultation will soon wear out his welcome.

Armed with this knowledge of the social psychological principles underlying the observed reluctance to consult with members of the technical staff, what recommendations can we make to improve the situation? Blau and Shepard (1954) suggest one interesting possibility. Both of these analysts point out the way in which technical discussion sessions function to maximize gain while minimizing cost to the participants. Blau, for example, points out:

> The recognition of both participants in a consultation that one provided an intellectual service to the other raised the status of the consultant and subordinated or obligated the questioner to him. These were the inducements for the consultant to give advice, and simultaneously, the cost incurred by the questioner for receiving it. Discussions of interesting problems, on the other hand, were not recognized as providing a service to the speaker, and he did not start them because he experienced a need for advice. Manifestly, both he and the listeners, who sometimes commented, participated in these discussions because they were stimulating. The fact that they facilitated his solving of problems was disguised from the speaker as well as from his listeners; this was a latent function of such discussions.
>
> In the absence of awareness that a service was furnished, no need existed for the speaker to reciprocate for the help he did, in fact, obtain. He did not subordinate or obligate himself to listeners. Such inducements were unnecessary for finding an audience, since interest in the problem and its solution supplied sufficient motivation for listening. This constituted the major advantage of consultations in disguise over direct consultations. We find ..., that the extraneous factors that motivate an interaction pattern that is not intended to, but does, fulfil a given function make it more efficient than a different pattern intended to fulfil this same function. Only a service intentionally rendered creates obligations, which make it costly.

Shepard, in describing the activities of a project group in a university affiliated laboratory, has this to add:

> The exchange of technical information was a social act, with a significance in terms of interpersonal relations in addition to its significance as part of a body of knowledge. The greatest respect was reserved for those who had proved themselves competent in solving the most sophisticated problems. The provision of technical aid to those who had problems to solve was at once a sign of solidarity and a contribution to the system of reciprocated acts which kept the currency in circulation ... A series of exchanges in which everyone contributed technical information of equal value would result in the same relative statuses at the end of the series as at the beginning, but each member would be wealthier in terms of technical knowledge than before, and his status relative to members of other groups would be increased.

Technical discussions, in which all participants are able to make a contribution appear, then, to circumvent the dysfunctional aspects of social exchange underlying the consulting process. Seminars including engineers from several projects and from functional areas as well as can be organized around topics that will allow all participants as equals. In this way, the status differential inherent in the consulting relationship can be avoided. While certainly the members of functional staff units (who would normally be the consultants) should bring information of the more abstract variety concerning physical theory and general state-of-the-art, the project members bring an equally important contribution in terms of specific new problems and applications. Since the inherent value ascribed by the technological community to these two types of information is somewhat out of proportion, management must assume responsibility for redressing the imbalance. The importance of information concerning applied problems must be stressed, and the potential contribution of project team members to the work of functional staffs should be emphasized.

Periodic seminars organized around specific problem areas or specific technologies in which management feels that the laboratory has particular competence hold promise then for improving the flow of information between technical specialists and project members. Such a device will, of course, not entirely eliminate the need for bi-lateral consultation. Unforeseen problems will arise and project members will have to seek assistance from staff specialists. The seminar program will undoubtedly have some spin-off in assisting this practice. This will result in two ways. First, the seminars will increase the visibility of staff specialists. Very often, it is suspected, a project engineer will go to a source outside of his organization for information, simply because he is unaware of the expertise available within the organization second, the exchange process taking place within the seminar discussions diminishes the one-sided nature of later bilateral exchange. This results from the fact that the project engineer has demonstrated his ability to make a positive contribution to the knowledge of the specialist. When he later approaches the specialist for help, he is first of all not unknown and more important he is recognized for his particular brand of competence and seen as a potential contributor not a pure information sink.

Empirical support can be mustered for the seminar plan by referring once again to the study by Shilling and Bernard (1963), of 64 biological laboratories. One of the queries in the Shilling and Bernard questionnaire dealt with the extent to which informal technical discussion groups had formed in the lab. Specifically, they asked each respondent, "Are you a member of any group that informally discusses research"? They summarize the general finding in the following manner;

> On the basis of a 50 percent participation criterion (50 percent or more of the respondents answering in the affirmative) it would seem that participation in group discussion is a custom in the scientific community; for example, in the median laboratory 60 percent of the scientists did participate in such groups. However, the great variability and the composite nature of the distribution suggests that the composition of the total set of laboratories may be blurring the picture ...
>
> Participation in discussion groups is clearly not part of the "culture" of the government laboratories; nor is it of the industrial laboratories. In none of these two types of laboratories did as many as half of the scientists report discussion group participation. In the other three types (private university, public university, and private research institute), well over half did.
>
> The median private university and the median private research laboratory tended to show a larger proportion of their staff participating in such groups than the median public university laboratory. But among all three, it could clearly be said that group discussion was an established "custom."
>
> Because of the more bureaucratic organization of the industrial and government laboratories, it may be that taking

time off for group discussion has not yet become recognized as a valuable scientific activity. In the universities, such discussion is part of a long academic tradition.

Correlating the degree to which discussion groups exist in each lab, with their measures of laboratory productivity, they find a direct relation with all eight measures, and report, as statistically significant, seven of the eight correlations.

Industry has often attempted to emulate and simulate the university atmosphere in dealing with its scientists and engineers; and we see for example the campus-type facilities, in which many corporations have invested, and as Norman Kaplan (1965) points out, they have for the most part operated on a false set of assumptions. Perhaps, we now have a situation in which industry could well profit by emulating an academic tradition.

In addition to the seminar program, management must take other steps to increase the general awareness of what is going on and what information is available within the laboratory organization. One very simple step which should have a high payoff in terms of increased awareness is the distribution of summary documents, reports, and brochures of the sort normally prepared for marketing purposes. Once the laboratory feels that it has attained a certain degree of competence in an area, summary documentation could be prepared, presenting the state-of-the-art, the nature of the lab's capabilities and the names of key people who are available for consulting. This is, of course, frequently done for presentation to customer agencies, but how often is such documentation prepared specifically for in-house use?

Another possibility lies in the formation of technical review panels. Frequently a research and development project will, at intervals be subjected to a management review, in which a panel comprising members of the laboratory's management are presented with evidence of the project's status in terms of costs, schedule, manpower and so on. An analagous technical review system, in which the management panel is replaced by one composed of several of the lab's leading technical specialists in appropriate areas,[2] and the focus of the review is upon progress on the project's key technical problems. In this way, the staff specialists are brought directly into contact with the project.

Of course in order to work properly, the project members must feel that they will not suffer for having revealed their problems. This is an essential point, and the success of the system rests entirely with it. Should they feel that the revelation of problems will be held against them as evidence of incompetence, they will naturally conceal problems and frustrate the system. Project members must feel that they can trust the panel. To aid in attaining this goal at least two steps may be taken:

1. Members of management (especially those with line control over project members) must be excluded from the panel and from panel review sessions.

2. Project engineers must have a strong hand in the selection of panel membership.

The exclusion of management is an absolute necessity if project members are to feel that their future with the organization will not be affected by their candid revelation of technical problems. The second point supplements this. Election by project members would prevent the

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[2] The idea of technical review panels was first suggested to the author by Peter G. Gerstberger, and resulted from discussions with project engineers who had cooperated with the research project.

suspicion that the panel was a surrogate for management. On the other hand, management must have some voice in this selection process, if for no other reason than to insure against the election of friends who have no real claim to authority in the technical areas of concern, and of course, to exercise some control over the allocation of manpower in the laboratory.

Beyond this, there is a great deal of evidence (Roberts, 1966; Wainer, 1965; Teplitz, 1965; Forseth, 1966) that one of the most efficient mechanisms for the transfer of technology lies in the transfer of people. Systematic programs for the transfer of personnel among programs and functional areas should be instituted. Such programs would be tied in with long-range manpower planning (an innovation in itself for most labs!), and could to a large extent be handled by computers. Computers would operate on file data which in addition to the normal descriptive data, degrees, age, field, etc., would contain descriptions of each engineer's technical experience on a number of dimensions.

Three additional measures can be taken to encourage the use of bilateral consultation. First the organization's reward system should be restructured to reflect the importance of this activity. In other words, technical staff specialists should be rewarded for assisting the members of projects with their problems, as well as for work directly related to their own problems. Second, and this will be taken care of in part by the seminar program, engineers should be made aware that seeking consultation will in no way reflect on their own competence, but will be recognized as an attempt to increase competence by educating themselves. Both of these measures attack the costs associated with the social exchange transaction. In addition key individuals, who are not only knowledgeable in particular areas but who are capable of translating technical information to match the project engineer's needs should be identified and their identity should be publicised through the lab. This is a crucial point, and will be treated in much more detail in the next chapter.

Chapter 11

A TWO-STEP PROCESS?

Origins of the Two-step Hypothesis

Twenty years ago, Lazarsfeld, Berelson and Gaudet (1948), to explain a phenomenon which they had observed in a study of popular decision-making during the course of the 1940 election campaign, first proposed what has become known as the two-step information flow hypothesis. It appeared that ideas flow from radio and print to opinion leaders and from them to the remainder of the population. Katz and Lazarsfeld (1955) in a subsequent study built a major hypothesis around this "two-step" process and were able to marshall considerable support for it. Instead of a simple direct connection between mass media and the general public they discovered the process to be more complex and to involve a number of intervening variables. Furthermore, the intervening variables (e.g., relative exposure; channel preference; the effect of message content; attitudes and psychological predispositions of the audience) all involve the involve the individual's social attachments to other people and the character of the opinions and activities which he shares with them. Thus, the response of an individual to a communicated message could not be accounted for without reference to his social environment and to the character of his interpersonal relations. This two-step flow was found to be mediated by "opinion leaders" who in every stratum of society perform a relay function: controlling the flow, for example, of political information from mass media to electorate, and thus influencing the vote. The opinion leaders, it was found, were considerably more exposed than the rest of the population to the formal media of

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Specifically, it was found that "leaders in a given sphere (fashions, public affairs, etc.) were more likely to be exposed to the media appropriate to that sphere" (Katz, 1960). In addition to mass media exposure, influentials tend to have a greater number of interpersonal contacts outside of their own groups. Thus in a study of drug adoption by physicians, Menzel and Katz (1956) discovered that the more influential doctors were characterized not only by greater attention to medical journals but also by more frequent attendance at out-of-town meetings and the diversity of places with which they maintained contact. Similarly in studies of the adoption of such innovations as hybrid seed corn (Rogers, 1962), concluded that opinion leaders in this instance can be characterized in terms of the relative frequency of their trips out of town, and in a general predisposition toward "cosmopolitaness."

In summarizing fifteen years of research in communication, Katz (1960) has the following to say:

> Opinion leaders and the people whom they influence are very much alike and typically belong to the same primary groups of family, friends, and co-workers. While the opinion leader may be more interested in the particular sphere in which he is influential it is highly unlikely that the persons influenced will be very far behind the leader in their level of interest. Influentials and influencees may exchange roles in different spheres of influence. Most spheres focus the group's attention on some related part of the world outside the group, and it is the opinion leader's function to bring the group into touch with this relevant part of its environment through whatever media are appropriate. In every case, influentials have been found to be more exposed to these points of contact with

the outside world. Nevertheless, it is also true that, despite their greater exposure to the media, most opinion leaders are primarily affected not by the communication media but by still other people.

The main emphasis of the two-step flow hypothesis appears to be on only one aspect of interpersonal relations -- interpersonal relations as channels of communication. But from the several studies reviewed, it is clear that these very same interpersonal relations influence the making of decisions in at least two additional ways. In addition to serving as networks of communication, interpersonal relations are also sources of pressure to conform to the group's way of thinking and acting, as well as sources of social support. The workings of group pressure are clearly evident in the homogeneity of opinion and action observed among voters and among doctors in situations of unclarity or uncertainty. The social support that comes from being integrated in the medical community may give a doctor the confidence required to carry out a resolution to adopt a new drug. Thus, interpersonal relations are (1) channels of information, (2) sources of social pressure, and (3) sources of social support, and each relates interpersonal relations to decision-making in a somewhat different way.

Relation to the Flow of Technology

The most obvious connection between our present interests and the studies cited above would appear to be through the studies of the adoption of agricultural and other innovations. The qualitative nature of the information being exchanged is certainly more akin to the type of information which is our concern than is, for example, the information contained in communications which influence a person's vote or his choice of food or fashions. The results of such studies have been well summarized in the volume by Rogers (1962), and there is certainly a clear analogy between the transfer of information in the form of innovations from technology into societal utilization, and our present concern, the transfer of information from science to technology or from one organization to another within science or technology. Nevertheless there is much which can be learned from the mass communications studies which will be of value in better understanding the process of technological information flow. The research to be reported in the present chapter has, therefore, drawn heavily upon the work of both the mass communication theorists and of social scientists concerned with the transfer of innovation.

Both Katz and Lazarsfeld (1955) and Rogers (1962) stress the importance of the individual's face-to-face relations in transferring information of these two diverse types. Katz and Lazarsfeld, for example, confess that their studies have led them to "rediscover" the primary group. In other words, the primary, or face-to-face contacts of the individual are found to be the principal avenue through which he obtains information. There is quite clearly a parallel in the research and development laboratory. We have seen rather strong evidence in earlier chapters that engineers are not very closely connected to the formal communication media, and that they rely much more heavily upon oral channels. There is also some evidence (although the research reported to this point did not attempt to assess the flow of information within the engineering project) that other members of the engineer's immediate work group are often instrumental in delivering information to him, or of making him aware of the existence of a particular source. Repeatedly, when the researchers attempted to determine the source of a particular idea, it turned out that no single source was responsible but rather that several sources mutually contributed to the discovery or formulation. Two examples are given in Chapter 2. In one case, an engineer's colleague hears a paper delivered at an SAE conference, associates the device described with a problem which the engineer has, and tells him about it. The engineer, himself, follows up the lead, searches the literature, contacts the man who delivered the paper, and gets in touch with a vendor who can supply some of the hardware. The other case is quite similar. A vendor visits a particular engineer and tells him about a new piece of equipment which his company has developed. The engineer knows of a colleague to whose problem this equipment might be relevant. He suggests that vendor contact his friend; the vendor does, and sure enough the application is appropriate.

These are true instances, stated exactly as they were related to the interviewer. And they are not isolated occurrences. Very frequently a mediator either directly relates information which he has himself obtained from another source, or indirectly assists in the transaction. The evidence from the parallel studies is sufficient to at least indicate the possibility of a two-step flow in technological communication. Furthermore, recalling the previous chapter, we postulated the existence of certain individuals who are capable of operating in two quite different coding schemes and of transforming messages between the two systems. They would quite obviously be the mediators in a two-step process. This is not to say that relays must necessarily take this form, but merely that such individuals to the extent that they exist perform a valuable function in connecting the organization to external information sources.

The Hypotheses

Based upon the findings of earlier studies in mass communication, and upon the indications in the data reported in earlier chapters, two major hypotheses have been generated:

1. Technological Gatekeepers. There can exist in an R&D laboratory certain key individuals who are capable of effectively bridging the organizational boundary impedance and who provide the most effective entry point for ideas into the lab. These gatekeepers will be characterized in three ways:

   a. They will be the people to whom others in the lab most frequently turn for technical advice and consultation.

   b. They, themselves, will be more exposed (than others in the lab), to such formal media as the scientific and technological literature.

   c. In addition to exposure to formal media, the gatekeepers will maintain a greater degree of informal contact with members of the scientific-technological community outside of their own laboratory.

2. The Influence of the Primary Group. The role of the primary group in mediating information flow will be manifested in two ways:

   a. Communication patterns will tend to follow the structure of both the formal work group structures and the informal social relationships in the laboratory.

   b. Technological attitudes, attitudes toward such things as feasibility of particular approaches which are not yet physically testable, will be strongly influenced by the attitudes held by other members of the primary groups to which the engineer belongs.[1]

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[1] This hypothesis is, of course, directly attributable to the thinking of Kurt Lewin and his followers, who proposed that when an opinion or attitude cannot be tested directly against "physical reality" that the individual will resort to a test against "social reality." In other words, he will look to his peers for confirmation of disconfirmation and react accordingly. This is now a concept which is treated in some detail in most Social Psychology textbooks; see, for example, Newcomb, Turner and Converse (1965), p. 234. The present hypothesis merely extends this line of reasoning into an area where attitudes are usually, <u>but not always</u> accessible to physical testing.

The Laboratory Study[2]

As an initial step in testing the hypotheses, a sociometric study of interpersonal relations and information flow was conducted in a small laboratory, where work is being performed on new materials and devices in the fields of direct energy conversion and solid state electronics, for both military and industrial applications.

The data were collected from the 28 of the 34 professional members[3] of the laboratory by means of written questionnaires[4] followed up by brief personal interviews.

Sociometric Relations. Table 11-1 shows a listing of some of the different sociometric responses that were obtained. The questions were aimed at determining the manner in which information flow in the lab relates to other sociometric choices. For instance (part a of hypothesis 2), are the persons that a respondent sees socially also the same persons with whom he has technical discussions. It is quite obvious from the table, that two distinct classes of sociometric relations were considered. The first of these deals with the various social relations within the lab. The second provides an indication of the routing of technical information through the

[2] This section is based in part upon a Master of Science thesis written by Stephen I. Cohen at the M.I.T. Sloan School of Management and in part upon an analysis by the present author of additional data gathered by Mr. Cohen. The author gratefully acknowledges Mr. Cohen's permission to use these materials.

[3] Of the six people who did not respond two had only worked for the lab for a very brief period of time, and the other four were people who had hardly been mentioned by their colleagues in any of the sociometric choice questions.

[4] See Appendix.

Table 11-1

Sociometric Relations Studied

socialization	name the 3 or 4 persons from the lab with whom you meet most frequently on social occasions.
work group	name the people whom you consider to be members of your present work group.
technical discussion	name the 3 or 4 people with whom you most frequently discuss technical matters.
special information	(obtained during the interviews subsequent to the questionnaire) -- the source, if any, from which the respondent reported having received special information that influenced him during the course of his last completed research project.
research idea	to whom in the lab would you first express an idea for a new research project.

organization. To the sociometric queries were added a third class of question. This deals with individual information gathering behavior, and includes questions on technical reading habits, and degree of technical discussion and contact with members of organizations other than their own (Table 11-2). These questions are directed toward the testing of parts a, b, and c of hypothesis 1. To test part b of the second hypothesis, respondents were asked to indicate their attitudes on each of three rather uncertain technological questions confronting the laboratory.[5] The degree of agreement within various possible groupings (work group, social cliques, etc.) could then be examined. For purposes of the study, two persons were said to agree on attitude if their scores on each question were within plus

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[5]These were obtained from the research director of the lab.

Table 11-2

Factors Related to Information Gathering Behavior

1.	the number of technical periodicals read regularly.
2.	the extent to which the following information sources are utilized:
	a. personal friends outside the organization
	b. technical specialists within the lab

or minus one category on a seven point attitude scale.

The Sociograms. A preliminary examination of the sociometric relations revealed a marked distinction between those members of the lab holding Ph.D. degrees and those without. This distinction so permeates the data, that in much of the ensuing analysis, it will be treated as a variable for which some control is required. The socialization matrices are especially pointed in illustrating the dichotomy (Figure 11-1). Except for subjects 11 and 12, who are social isolates, the Ph.D.'s group together quite strongly. Non-Ph.D.'s, on the other hand, show relatively few social contacts among themselves. The large circle labelled "non-Ph.D." in Figure 11-1b represents the Ph.D. to non-Ph.D. choices, and shows practically no social intercourse. The circle labelled "Ph.D." in Figure 11-1a gives an indication of which non-Ph.d.'s choose into the Ph.D. group. Only five non-Ph.D.'s do so, and in only one case, subject 24 is the choice reciprocated. Reciprocal choices are indicated in the diagram by double-headed arrows.

Relations among Sociometric Choices. Considering the way in which the social structure of the lab affects the exchange of information, Table 11-3

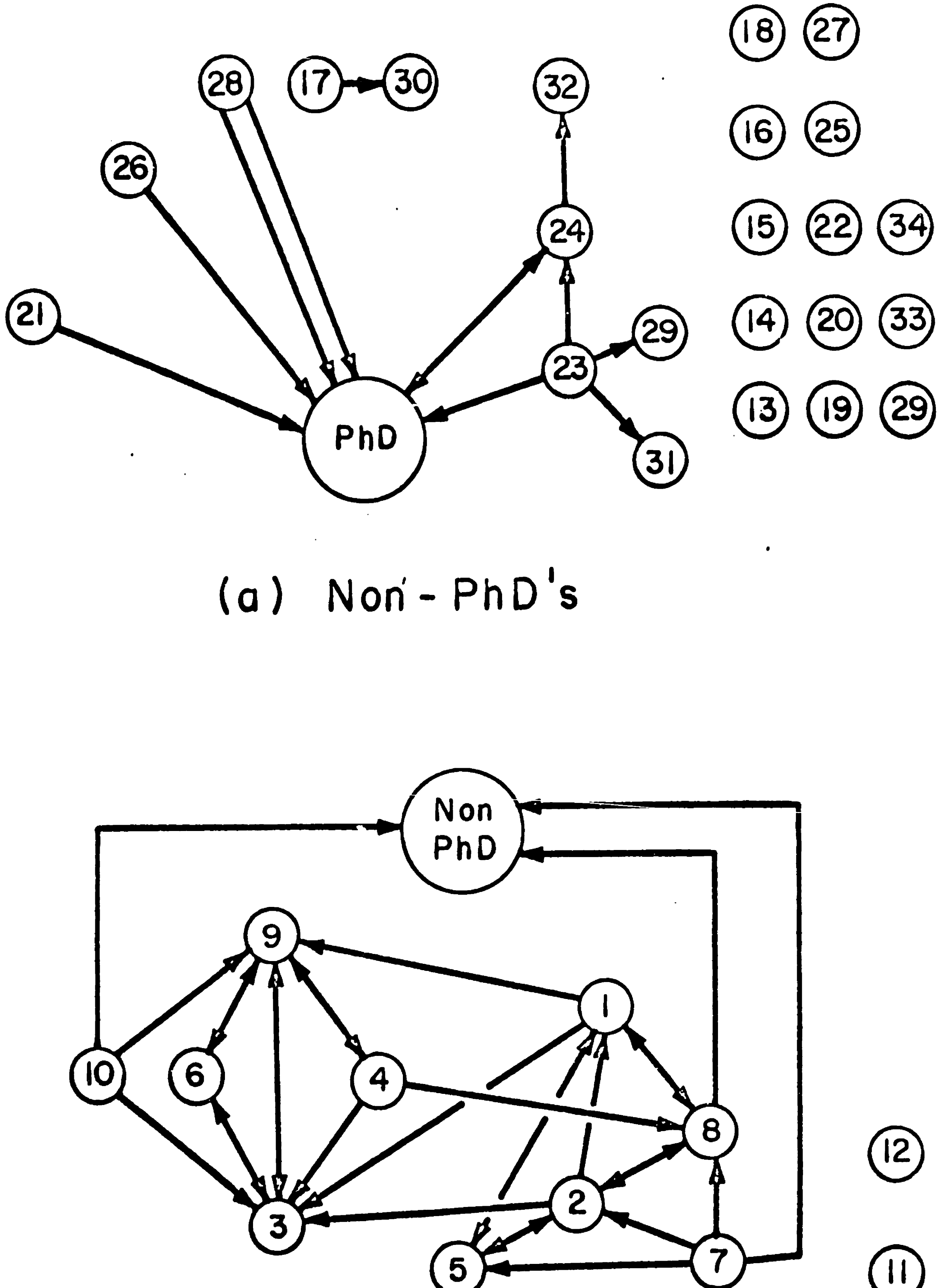


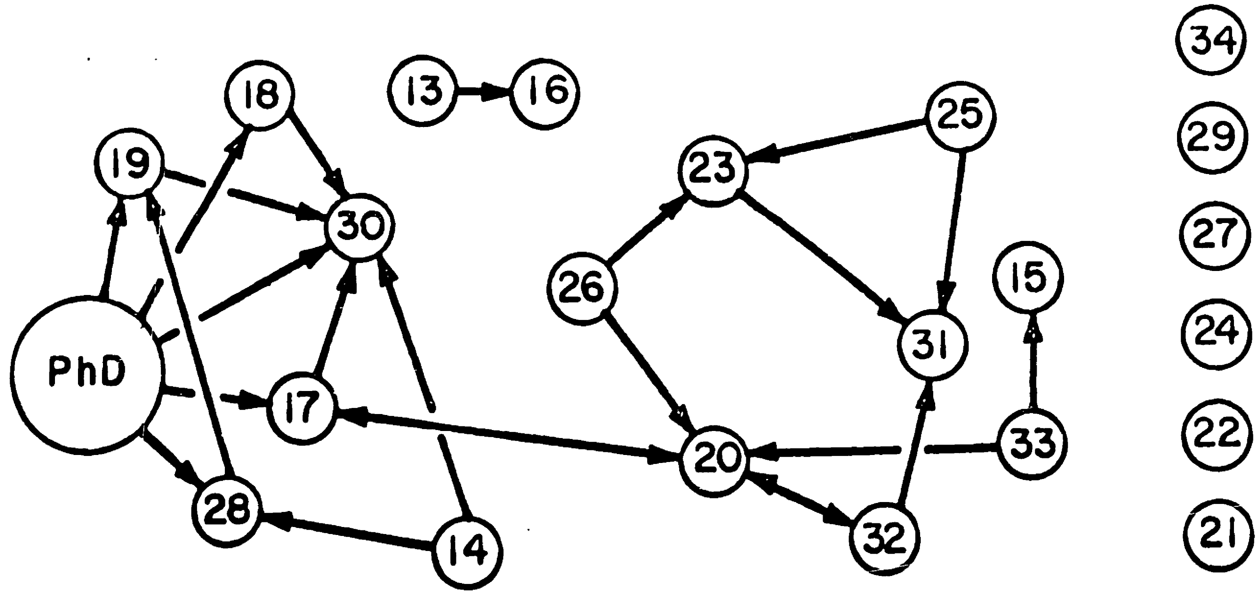
Figure II-1 Socialization - Choices

Table 11-3

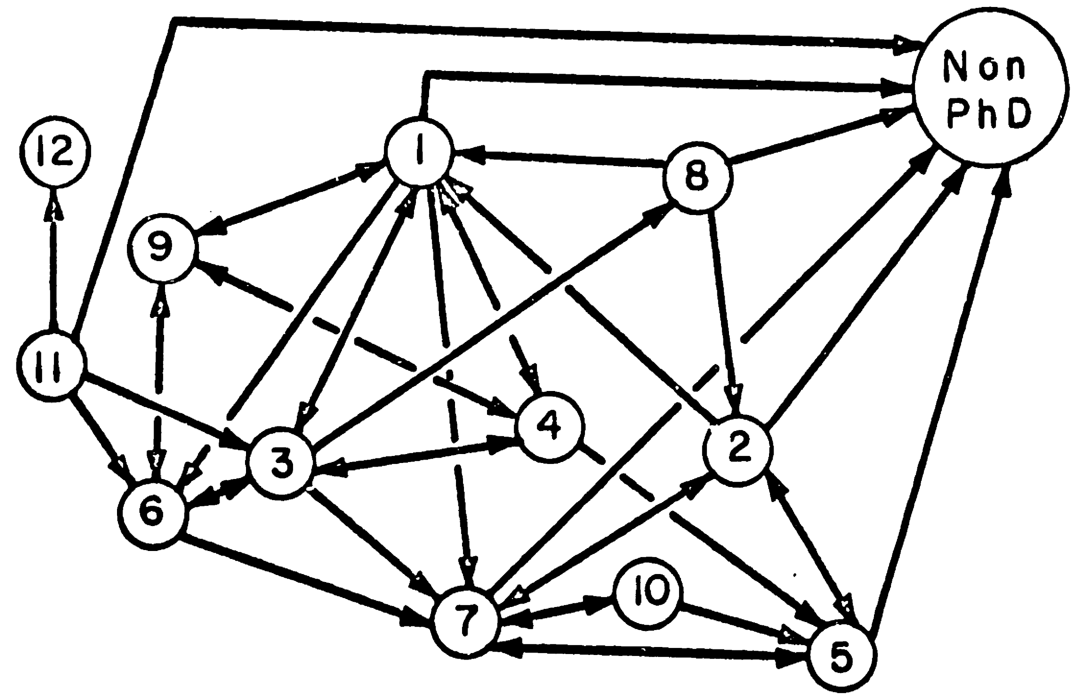
Comparison of Socialization and Communication-Oriented Sociometric Choices

	chosen socially	not chosen socially	X^2	level of statistical significance
percentage of technical discussion choices	28%	2%	125	0.001
percentage of choices as a person to whom respondent turned for special technical information on his last completed project	35	4	62	0.001
percentage of choices as a person to whom the respondent would take a new research idea	86	4	42	0.001

presents results for the comparison of three communication-oriented sociometric choices with the socialization choice. It is seen quite clearly that there is strong agreement between the selection of individuals for socialization and technical communication. This is due in part, but certainly not entirely to the rather tight clique found among the Ph.D.'s in the lab, who restrict both socialization and technical discussion to themselves. The technical discussion matrix shows three rather well defined cliques (Figure 11-2). In addition to the Ph.D.'s there are two cliques among the non-Ph.D.'s. The relation between technical discussion and socialization is statistically significant among the non-Ph.D.'s in these two cliques as well as among the Ph.D.'s alone, although the latter relation is somewhat stronger. Social contact, then, correlates very highly with the three mechanisms, considered in Table 11-3, for the



(a) Non - PhD's



(b) PhD's

Figure II-2 Technical Discussion-Choices transfer of technical information. Furthermore, the relations hold equally well in this lab for both Ph.D.'s and non-Ph.D.'s. While it is impossible from data such as these to determine the direction of the causal link (i.e., does socialization bring about transfer of technical information, or do people socialize more with those with whom they like to discuss technical matters), we are led quite clearly to conclude that the informal structure of the lab occupies a very important position in the transfer of information.

A question now remains concerning the impact of the formal organizational structure upon communication. Since the organization of the lab studied is quite fluid and revolves around a number of long and short-term projects all reporting to one of two research directors, our consideration of formal structure will be restricted to the ad hoc project groups. The respondents were asked to name "the people whom you consider to be members of your present work group." Table 11-4 shows that much, but not all of

Table 11-4

Comparison of Work Group and Socialization Choice

	chosen socially	not chosen socially	X^2	level of statistical significance
percentage who are members of the individual's work group	42%	7%	26	0.001

the socialization occurs within work groups. A similar situation exists for technical communication (Table 11-5). Most of the technical discussion choices are directed to work group members. Replies to the critical

Table 11-5

Comparison of Communication Choices with Work Group Structure

	members of work group	non-members	X^2	level of statistical significance
percentage of technical discussion choices	54%	6.5%	165	0.001
percentages of choices to whom the respondent turned for special technical information on his last completed project	0	5.3	4.9	0.05
percentage of choices as a person to whom the respondent would take a new research idea	2.9	7.1	2.3	0.20

incident question concerning information which influenced the respondent's last completed project, however, show an interesting difference. This type of information (in the twelve instances discovered) came exclusively from people outside of the recipient's immediate work group. There is also a tendency to take new research ideas to someone outside the work group, but here the difference is not statistically significant.

Both the formal and informal structures are important in mediating information transfer, but in somewhat different ways, employ slightly different mechanisms (discussion vs. query or statement) and possibly handle different types of information. Unfortunately, our data are insufficiently detailed to determine the precise nature of the information which is transferred; this will be the subject of future investigation.

Controlling for the effects of the formal organization, by comparing only those social and technical discussion links which are external to each individual's work group (Table 11-6), produces a stronger relationship,

Table 11-6

Comparison of Socialization and Technical Discussion Choices External to the Work Group

	chosen socially	not chosen socially	X^2	level of statistical significance
percentage of technical discussion choices	40	20	96	0.001

even stronger than was found when work group members were included.

As would be expected, the formation of work groups operates to channel the direction of technical discussion within the lab. But in addition to and supplementing this, the informal patterns of socialization take over in directing this flow.

Information Habits and Sociometric Communication Choices. More to the point of our concern is the relation between actual selection of an individual as a potential source of information and that individual's own personal information gathering behavior. For this topic, we have again selected the three questions which asked each respondent to name individuals with whom he regularly had technical discussions, and those from whom he received special information which influenced the course of his last completed research project. The individuals who were frequently or infrequently named on these sociometric measures were then compared in the extent to which they themselves used three information channels, viz., friends outside the lab, technical staff within the lab, and the literature.

Turning first to those members of the lab who are highly chosen for technical discussion[6] (Table 11-7), we find that the sociometric stars have more exposure to both the literature and to oral sources outside of the laboratory than does the average employee of the lab. This is especially true for that segment of the literature which is sponsored by scientific or professional engineering societies.

In response to the request to indicate the source of any information which influenced the course of their most recently completed research projects, twelve people cited other individuals (seven) within their own laboratory as the source of such information. In Table 11-8 these seven people are compared in terms of their own information gathering behavior in the same manner as were the technical discussion stars, and we again see the pattern of greater contact with experts outside of the organization and more exposure to the literature.

Individuals who are highly chosen as sources or potential sources of technical information differ considerably from their colleagues. They have greater contact with technical people outside of the organization and are more exposed to the technical literature. Moreover, they do not appear to differ very much in the extent to which they rely upon internal consultation.

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[6] Those who received six or more technical discussion choices (eight people). Splitting the sample at the median number of choices (1.5) produces no significant difference between upper and lower halves. The data, however, show a distinct discontinuity between four and six choices so the sample was divided at this point and the sub-samples compared.

Table 11-7

Comparison of Communication Behavior and Technical Discussion Choices

Communication Characteristics	Number of Times Chosen on Technical Discussion Matrix: six or more	four or fewer	level of statistical significance
percentage who are above median in using personal friends outside the laboratory as an information source	63%	25%	0.06
percentage who are above median in using technical specialists within the laboratory as an information source	50	40	0.47
percentage who are above median in total number of technical periodicals read	88	40	0.01
percentage who are above median in number of professional and scientific periodicals read	75	35	0.001

*Based on Mann-Whitney U-Test performed between the two groups.

There appears then to be two distinct classes of individuals within this laboratory. The majority have few information contacts beyond the bound of the organization. A small minority, in contrast, have rather extensive outside contacts and furthermore serve, themselves, as sources of information for their colleagues. There is then clear evidence of a two-step flow of information in the laboratory studied. Six or seven individuals act as technological gatekeepers for the rest of the lab. As further support, it was found that two of these six or seven people were

Table 11-8

Comparison of Communication Behavior and Identification as the Source of Special Technical Information on One of the Lab's Projects

Communication Characteristics	seven individuals cited	others	level of statistical significance
percentage who are above median in using personal friends outside the laboratory as an information source	67%	30%	0.10
percentage who are above median in using technical specialists within the laboratory as an information source	57	40	0.17
percentage who are above median in total number of technical periodicals read	100	45	0.05
percentage who are above median in number of professional and scientific periodicals read	86	35	0.03

*Based on a Mann-Whitney U-Test performed between the two groups.

responsible for introducing all four of what were almost unanimously agreed upon by the respondents as the most important technical ideas that had been introduced into the organization during the preceding year.

The gatekeepers themselves show some variation in the type of information sources they use. Some rely on the literature more than on oral sources, some operate the other way around. Comparing relative exposure to technically-oriented friends outside of the organization and to the scientific and professional literature we find some correlation (Kendall $\tau = 0.27$), but the relation does not approach statistical significance (p = 0.21). So there is some variation anyway in the behavior of the gatekeepers. Quite fortunately, it would appear, for the lab, they don't all tend the same gate.

Attitudes and Sociometric Choice. Table 11-9 reveals a rather interesting situation. Comparing agreement in attitude toward three technological

Table 11-9

Comparison of Sociometric Choices and Technical Attitude Agreement

	technical attitude agree	technical attitude disagree	X^2	level of statistical significance
percentage of socialization choices	7.1%	3.8%	0.64	0.35
percentage of technical discussion choices	16	8	9.12	0.01
percentage who are members of work groups	16	7.3	5.74	0.02

areas with both socialization and technical discussion choices, we find only technical discussion to be related to attitudinal agreement. No relation is found between socialization and attitude. We are led, therefore, to conclude that social interaction must take place on a technical base before it bears any relation to the attitudes held by the participants. Although one cannot determine directionality from data such as these, and we therefore do not know whether technical discussion leads to attitudinal agreement or whether discussion choices are based upon prior knowledge of agreement, the mere existence of this relation should serve to warn us of possible dysfunctional consequences. For example, there is somewhat strong evidence (Allen, 1966a) that engineers once they have become committed to a particular technical approach tend very strongly to discount information which would disconfirm their attitude. If they, in addition, restrict their technical discussion to colleagues who share their attitudes, the probability of recognizing and accepting valid contradictory information is then correspondingly lowered.

In other words, the bias that has already developed in the individual is reinforced by colleagues to whom he goes for technical discussion, since these discussants tend to be biased in the same direction.

The adverse consequences of such a phenomenon are too obvious to require further comment. Suffice it to say that engineers and scientists should be forewarned to consciously seek out contradictory opinions and attitudes concerning their work and to recognize the value of cultivating contrary colleagues. Research and development managers can, of course, take this situation into account in forming their work groups. Judging from the second row of Table 11-9, this was not done in the lab studied. In that instance work groups for the most part comprised individuals who agreed rather uniformly in their attitudes toward the three technical areas. Even introducing a single individual with conflicting attitudes should produce sufficient jitter to keep the group aware of other points of view. The possibility that the causal direction is such that interaction leads to agreement merely implies that management, should periodically rotate their devil's advocates to prevent their capture by the prevailing group attitude.

But more important than this is the possible role of the primary group in attitude formation. Assuming for the moment that the causal arrow extends from group to attitude,[7] we have once again, to paraphrase Katz and Lazarsfeld (1955), "rediscovered the primary group." Katz and Lazarsfeld report doing just that in mass communication theory, meaning that the influence of the groups to which an individual belonged was for long ignored. The direct impact of mass media on individuals was the topic of concern, and only when this failed to reveal itself did researchers turn to a consideration of group factors. The authors go on to recount a number of similar instances in social psychology beginning with the Hawthorne studies, where counter to expectations group dynamics were found to befuddle the researchers and to effectively nullify the intended effects of management's individual incentive schemes. The World War II studies of army life (Stouffer, et. al., 1949) again follow the same pattern, where, for example, combat motivation was found to be associated with attachment to an informal group. Soldiers assumed the attitude of their reference group toward combat involvement. Again, in sociological studies of the urban community, Warner and his associates (Warner and Lunt, 1941) found the "clique" to be of extreme importance in determining individual's positions in the social hierarchy of the community.

Perhaps we should now add the subject of scientific and technological information flow to Katz and Lazarsfeld's list. These studies began by

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[7] And the studies of mass communication phenomena, as well as the overwhelming body of evidence from social psychological studies of group conformity (e.g., Asch, 1956) clearly make this a reasonable assumption.

relating in several ways the individual user, his choice of information channel, and its effect upon his work. The evidence now requires the involvement of the individual's primary group relationships in any interpretation of user behavior. Clearly there are many engineers and even scientists who make little use of the formal literature. But this piece of evidence viewed alone can be severely misleading. Only upon investigating the relationships of such individuals to the groups, both formal and informal, to which they belong, and the possible use of the formal literature by other members of these groups can we place literature (or any other channel's) value in its proper context.

Conclusions

Returning to the two hypotheses stated at the beginning of the chapter, we find substantial support for both the gatekeeper and for the hypothesis concerning the role of primary groups. Technological gatekeepers very definitely appear to exist in the lab studied. They are the people to whom others turn for technical discussion and consultation and they in turn report a greater amount of contact with the professional and scientific literature or with technically trained friends outside the lab. In addition, upon somewhat closer examination of the situation, we find that there are two people who were responsible for introducing what were almost unanimously agreed upon by the respondents as the four most important ideas into the lab during the previous year. Both of these people are well above the average in both their use of the literature and of interpersonal contacts outside of the organization as sources of technical information.

The complete and distinct relay personality does not, however, appear. Rather, there appear varieties of people who are capable of performing the relay function. Some operate better translating from the literature; others from oral sources. Opinion leaders in the present context are not of a monolithic sort. They vary considerably in the nature of the sources from which they derive information and quite possibly in the functions for which their transmitted information is used. The present data are incapable of testing the latter possibility, but it remains an empirical question, and the subject for further research.

The situation described in the preceding paragraph is not unlike that discovered in mass communications research. In that context, opinion leaders were found to be differentiated by topic; those who were influential in public affairs were not necessarily influential in determining fashion patterns, and so on. Moreover, the nature of the area of influence was found to be related to media exposure.

> ... influentials of every type read a larger number of magazines than those who are not influential ... In other words, then, opinion leaders in each arena -- whether it be marketing, fashions, politics or movie-going -- tend to have greater contact than non-leaders with the features and advertisements in America's magazines.
>
> When we turn from magazines to other media, we find that, as a rule, the same phenomenon holds true; that is, opinion leaders exceed non-leaders in exposure. But at the same time, these other media begin to reveal some idiosyncrasies of the different leader types as well. Consider book reading, for example ...
>
> Again, on both levels ofeducation (high school graduates and non-high school graduates), all the leaders are more likely to read at least one book per month than are the non-leaders. Again, too, this is true on both high and low levels of education. Notice, however, that on both educational levels the marketing leaders exceed the non-leaders by only very little, while each of the other leader types seems to be more clearly differentiated. This, of course, is as we might

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> have expected; intuitively at least, one would not say that the "requirements" for marketing leadership include the reading of a greater number of books, whereas a case could be made for the relationship between reading books and leadership in the other three areas.
>
> Leaders tend to exceed non-leaders in number of hours of radio listening, too, although the differences are quite small and not always consistent. The movie leaders of both educational levels seem to be particularly attentive to radio, together with the lower-educated leaders in the latter two realms, plus the political leaders on both educational levels, do not exceed the non-leaders in time spent listening to the radio. The political leaders, furthermore are the only group which does not exceed the non-leaders in movie-going; all other leaders do.[8]

When medium content was taken into account, it was found at a more detailed level of analysis that movie leaders read more movie magazines, public affairs leaders read more news magazines, fashion leaders more fashion magazines, and so on, suggesting the possibility that we should look in more detail at the content of the messages processed by the various gatekeepers in R&D laboratories. What we are implying is that the selection of channels (e.g., literature vs. external oral sources) by scientific and technological gatekeepers may be based upon the qualitative nature of the information in which the gatekeeper specializes, and that channels vary in their ability to provide different types of information. As an example, the literature has been shown to provide information which is important for keeping abreast of the state of a technological field, while oral sources are probably better in providing more specific detailed information about particular techniques. Gatekeepers who specialize in their knowledge of the state-of-the-art would then tend to expose themselves more to the literature, while those specializing in particular research

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[8] Katz and Lazarsfeld (1955), pp. 310-312.

techniques would interact more with external oral sources. Clearly these are questions which we must now face, if we are to attempt to identify and encourage the use of any of the several types of opinion leader in R&D laboratories.

We have already seen that a finer differentiation of channel information content can make some difference in our present context. When the Ph.D.'s are compared on the basis of number of periodicals regularly read (Tables 11-7 and 11-8), the difference between those who were highly chosen for technical discussion and those who were not was somewhat less than they are when compared on the basis of a particular subset of periodicals (scientific and professional journals).

The next stage in our research must then be concerned with a finer distinction among channels, and information content, and must attempt to determine the characteristics which distinguish gatekeepers of various sorts. The latter goal, of course, has the very practical implication for management of identifying the individuals who are the key nodes in the transfer of various kinds of information within the laboratory.

PART III

CONCLUSION

CHAPTER 12

MANAGERIAL IMPLICATIONS

This final chapter will provide a summary of the research findings of several studies that we now have in terms of their implications for research and development management.

The research findings themselves can best be summarized by dividing the subject into the eight following areas:

1. the contrast between information gathering practices found in science and technology.

2. the variation of information gathering patterns according to phase of project.

3. the use of literature which is relatively remote from the research frontier by scientists.

4. the nature of gap-filling research.

5. the nature and function of the literature in technology.

6. the importance of cost considerations in the user's selection of information channels.

7. the impact of the organization on the flow of technical information.

8. the multiple-step process of the technical information flow.

Differences Between Information Gathering Practices in Science and Technology

In the introductory chapter, it was stated that, since the information systems of science and technology are vastly different in their operation, the volume would be divided into two parts treating science and technology separately. The principal difference revolves around the use of the literature. The literature is quite important to the scientist who spends about 20 percent of his time with it and obtains half of his ideas from it. The technologist, on the other hand, devotes only about eight percent of his time to the literature and obtains a comparable percentage of his ideas from it.

This comparison gives rise to an obvious question. Since we have only looked at the mean values for the several scientific and technological projects, do the differences between these two types of project actually exceed the difference among the projects making up the two sets. In other words, are there other differences among the projects (other than the fact that they can be classified as scientific or technological) which are more important in determining information search behavior? Among the twelve development projects on which time allocation data were obtained, for example, are the differences in literature use greater than the differences between this set and the two scientific projects.

To test for this possibility, an analysis of variance was performed on the two sets of data. The results of the analysis show the scientific and technological projects to be significantly different from one another in the extent to which they made use of the literature ($p < 0.001$). They do not differ significantly in the extent to which they use oral sources of information. Thus there is a quantitative difference in the degree to which the literature is used in the two systems, and as additional analysis (Chapters 4, 5, 9 and 10) shows, a marked qualitative distinction in the manner in which both written and oral channels are employed.

For management, the lesson is quite straightforward. Scientists and engineers are quite different types of employee. Any steps that are taken to improve the flow of information either within or into the laboratory, or any information systems that are to be introduced must take into account the nature of the population to be reached. An information system that is ideal for scientists may be completely useless for engineers and vice-versa. More specifically, assuming that the present behavior patterns are based on fundamental differences in the nature of the two populations or on their particular training, and that they are much less a function of the existing information systems, steps to improve the two systems should be aimed primarily at written communications in science and at those organizational parameters that influence oral communications in technology.

Relation of Project Phase to Information Gathering Patterns

The proportion of total time spent in three modes of information gathering (literature search, consultation with technical staff and consultation with sources external to the organization) varies significantly over the duration of projects in both science and technology. Information gathering is, of course, at its maximum during the earliest portion of the project, tapering off considerably during a second phase, but then rising again during a third phase, or the peak of a second cycle.

Some slight differences exist between the scientific and technological projects (in science, written sources dominate throughout; in technology, oral sources are dominant over most of the project), but in both instances, there is strong evidence for the periodicity in information gathering.

The phase sensitive nature of information gathering over the duration of a project warns us to be careful in interpreting the results of user surveys that do not control for this possibility. If, for some reason, a major portion of the respondents were in an early phase of their respective projects, information gathering would be overreported. Similarly, other phase distributions could result in underreporting. Survey research must control for this possibility, and such statements as "physicists spend X percent of their time reading" should be clarified by a conditioning statement "on the average, over the course of a project," or "during the phase of maximum information gathering on a project."

Since information needs vary with project phase, management must include this consideration in the specification of information system requirements. For example, in the use and assignment of library assistants, some cost savings may be gained by assigning them only to groups that are in peak information need phases of their research, or by assigning more groups per assistant but insuring that the groups are not in phase with one another in their research progress. In this way, the peaks in demand for library assistants can be smoothed out and the feast or famine condition avoided. Similar measures are, of course, recommended with respect to the availability of information retrieval systems and the assignment of both internal and external consultants.

Distance of the Scientific Literature from the Research Front

In Chapter 4 it was noted, much to our surprise, that a considerable amount of the literature used by the scientists of the Modulation Transfer Project was relatively old, and to a large degree already "packed down" into textbooks. While the sample is certainly far too limited to allow any very strong conclusions, the results do suggest that we should be skeptical of the reference-counting studies that set half lives of journal articles as short as three to five years. Much of the literature used in any research project does not appear among the references of the output paper. There may well be a bias in the reference list toward more recent articles, which cloaks the use of much older material, particularly books.

Management's concern at this point is with the maintenance of its literature inventory -- the stocking of libraries and other information systems. If one assumes that a major portion of the user's need is for literature less than five years old, the inventory problem is greatly simplified. Journals of older vintage do not have to be held in ready access positions, but can be stored in basements or on microfilm with rare inconvenience to the user. On the other hand, if the organization must store, say, twenty years' worth of journals, certain retrieval systems which are not economical for low capacity storage may now be much cheaper than ready access library stacks. In addition, given the need for information generated further back in time, the search problem becomes more acute, increasing the need for systems, automated or otherwise, to aid in search.

Gap-Filling Research

The concept of gap-filling research has enormous implications for research and development management. As technological advance becomes increasingly rapid, managements have become more and more concerned with the problem of coupling product development to basic science. In this country, there is a general mounting concern[1] over the expedition of the

[1] Witness the recent reviews of the research policy of the National Institutes of Health (Science, 148, 1965, 1433-1439).

information flow from basic science into technology and eventual application.

In Chapter 6, we witnessed the exceedingly long delays that this process involves when left to proceed by itself. The link between normal frontier science and technology is extremely weak, and occurs randomly with subsequent delays between scientific discovery and technological incorporation. There are exceptions to this general rule, however, and one is the specific case involving what we have labelled "gap-filling" research.

Gap-filling research differs from normal frontier acience in the manner in which the research problems are defined. In normal science, research problems are defined through a complex interaction of the social system of science with the body of accrued knowledge. In the case of gap-filling research, problems are not defined by science itself, but rather by the needs of technology. As a result, technology is prepared, having a recognized need and the proper set, to recognize the association of problem and solution, to quickly adapt the results of gap-filling research to its needs.

Those responsible for research and development management must, accordingly, concern themselves not with a uni-directional (science to technology) phenomenon, but with a two-way channel. They must be as much, if not more, concerned with communicating problems from technology to science as they are with transmitting results from science to technology.

This can, of course, be accomplished in many ways depending upon specific circumstances. The organization with its own basic research laboratory faces an organizational problem. It must communicate its needs to the research laboratory without destroying the "purity" of the research performed. The danger of the latter lies in its tendency to disconnect the organization's basic researchers from their scientific colleagues at large, thereby eliminating their most important source of information and the most plausible argument for supporting a basic research laboratory in the first place.

Some mechanisms have been tried with varying success, including joint seminars and lunches attended by basic scientists and development engineers; temporary cross-assignments between laboratories; and the creation of small buffer groups of respected basic scientists who also possess a special ability in understanding engineering problems. The last of these alternatives is presently being formulated by the Research Institute for Advanced Study (RIAS) of Martin-Marietta Corporation. It should be interesting to see how this develops. An infinite number of special organizational arrangements[2] is, of course, possible, but we have as yet little data concerning the relative performance of any of these.

The Technological Literature

In all of the studies in which any performance criterion is applied, the technological literature shows a consistently mediocre performance. There are many reasons for this. First, as we have seen it is used relatively little by engineers. Second, and more important, the literature itself is qualitatively different. Despite the fact that engineering societies have emulated the scientific societies in the publication and

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[2] One very interesting one, that used by Bell Laboratories at its interface with Western Electric Corporation was discussed in a recent article by Jack Morton (1965).

distribution of tightly refereed journals, the typical engineer devotes a surprisingly small amount of his reading time to these journals. Far more important to the engineer are unpublished reports generated by industrial and government research laboratories for internal use primarily, and privately-sponsored, advertising-supported, profit-making journals. The latter appears to have arisen to fill a gap between the sophistication of the engineering journals and the technical competence (or, better, the mathematical proficiency) of the average engineer.

Management must concern itself with both of these phenomena. First, the role of the unpublished report and the mechanisms by which it is transferred must be studied. A competitive economic system will always impose constraints upon the free dissemination of company reports, but the present impediments to their exchange are perhaps needlessly restrictive. Similarly, with respect to government reports and industrial reports generated under government sponsorship, the Defense Documentation Centers are making an admirable attempt to improve the flow within the government contracting community; but access by individuals and companies outside this community is often impeded by measures intended to prevent the inadvertent export of American technology to foreign competitors. Of course, we cannot be sure at all whether this perceived threat in fact exists, or whether the resulting loss to American industry is perhaps greater than the loss through competition.

With respect to the journals of the professional engineering societies, at least two strategies which approach the problem from opposite directions must be combined. The engineering societies must undertake a serious self-analysis to better determine their role in our society, seriously questioning the need for their activity as an information transfer agent. The mounting evidence demonstrating the wide differences in behavior and needs of engineers and scientists is indeed impressive, and mere emulation of the scientific societies will no longer suffice to justify the existence of professional engineering societies. Thus, an entirely new policy toward publications must be developed, taking into account both the average and the exceptional engineer's information needs and their respective abilities to consume information of varying sophistication.

On the other hand, government, industry, universities and, perhaps again, the professional societies must work to promote the understanding and use of the higher level literature presently published by the professional societies.[3] This leads us directly to the problem of technical obsolescence. Since this problem is far too vast for proper treatment here, we will limit ourselves to the recommendations that greater effort be expended in the search for feasible approaches to countering obsolescence; that industry realistically face up to the problem and take on the expense of allowing time off to attend courses, and perhaps even requiring all engineering employees to periodically take on a course of studies; and finally that industry and the professional societies collaborate to promote the use of the more sophisticated journals either through direct subsidies to the journals or through policies of providing journal subscriptions to all

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[3] Such a policy of course assumes that there will be a positive relation between engineering performance and the use of this journal literature. Empirical results have thus far failed to disclose such a relation, but in the studies to date no attempt has been made to isolate this literature form from the more prevalent use of unpublished reports and private journals so the assumption is still not unreasonable.

professional engineering employees. The free subscription is undoubtedly part of the attraction of the private journals; simply providing engineers with the professional journals, free-of-charge may be a major step in encouraging readership.

The Importance of Information Channel Cost

User studies have until recently[4] ignored the cost variable associated with the use of particular information channels. Researchers' concern has centered on the measurement of relative value, and they have assumed that users' behavior would reflect this single-factor analysis in the selection of channels. The present results show that no relation exists between channel selection and an independent measure of performance and thereby force the consideration of a second factor -- channel cost. This is an important consideration in the analysis of results from future user studies, and makes an already tangled situation even more complex. Both channel performance, or value and cost are functions not only of specific situations but of the personalities of the individuals involved. Channel selection, being based on perceived rather than absolute measures of the two parameters, is greatly affected by both situational and personality considerations. Future research in information use will to some degree have to proceed in the direction of assessing the impact of individual personality differences on behavior.

The emergence of cost considerations is important for management since cost is more easily controlled than value. It is much easier to move the

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[4] Rosenberg (1966) is a notable exception.

library closer to the individual using it than it is to improve the value of its contents. Similarly with other channels it is simpler, and often more desirable, to increase (or decrease) their ease of access than to manipulate the value of the information which they transmit. Management now has a parameter upon which to focus their attention and with which to initiate steps to optimize the performance of information systems.

The Impact of the Organization

Perhaps the single most important finding of the studies reported in the previous chapters is the discovery of the impact of bureaucratic form of organization on the flow of scientific and technological information. The form that business organizations have taken in the western world now appears to constitute a factor seriously impeding the free flow of information.

Looking first at the use of channels within the organization, their under-utilization indicates quite simply that management must initiate steps to lessen the costs associated with their use. This can be done by the direct assignment of consultants to projects and more generally by recognition of the great benefits of internal consulting for the overall functioning of the organization. As noted in Chapter 10, the present reward systems in most laboratory organizations do not recognize this function and not only fail to encourage it, but also in many ways seriously impede it.

The best way, certainly, for management to encourage internal consulting is to reward it, and to see that its practice does not seriously interfere with competing rewards for the consultant's time. In addition, there are several other measures (all discussed in Chapter 10) that should be instituted. These constitute primarily the use of seminars and intra-organizational conferences attended both by development project engineers and by staff specialists, and at which pertinent topics could be discussed and project members apprised of both the technical state-of-the-art and the location of competence within the organization.

With the use of external sources, some caution is advised. It is seen from the data that when a reasonable amount of skepticism is exercised, as in the case of vendors, the dysfunctional effects of the use of external channels is diminished. Apparently, information gained from such expert sources as consultants and members of highly considered laboratories is not submitted in a great enough degree to such skepticism; it is taken at face value and not probed sufficiently to overcome the distortion effects from the mismatch in organizational coding schemes.

Much more must be learned about the consulting relationship before final conclusions are drawn, but there exists the possibility that it may have a serious effect upon the efficiency of communication. Should this be the case, then consulting relations should be allowed to develop gradually over a considerable period of time, consultants should be selected cautiously and maintained under long-term commitment. This allows the development of mutually compatible coding schemes, and should subsequently diminish the incidence of semantic noise in this communication channel.

Guetzkow (1965) in his review of communications in an organizational context guardedly advises redundancy as a means of countering distortion and omission in information channels:

Accuracy is increased in organizational communication by repeating the contents of the message -- through multiple channels in parallel or by mere redundancy.

Accuracy is increased in organizational communication by verifying message contents, often by devices of feedback.

Yet, both devices -- repetition and feedback -- tend to add to the communications load of the organization. Such additional overload induces further transformation of messages, whose contents in turn need to be corrected for omissions and distortions.

This is not an overly hopeful recommendation, but it does clearly underline the need for caution in using external channels.

Information obtained through standard one day visits to highly regarded laboratories should be used with caution. Serious misinterpretations can result from such short communications. A straightforward solution for this problem is not readily apparent, but may involve the establishment and use of on-site offices at important locations. Recognizing all the drawbacks of this scheme, it may still be the only direct mechanism for countering the problem without foregoing these rich sources of technical information. Liaison offices of this sort will only be effective, however, if they are staffed by competent technical personnel who can bridge the coding schemes and translate effectively between them. As a result, management must establish a standard rotational scheme for competent senior personnel on a basis whereby each individual's normal promotional opportunities will not be imperiled by serving a tour in a liaison office, and the rotation period will be short enough so that incumbents will not drop too far out of touch with activities in their disciplines. The problem here is somewhat similar to that discussed earlier when we were concerned with transferring information between science and function in a manner quite similar to that contemplated for the buffer organization at RIAS.

Of all the results, that concerning the problems of using individuals and agencies outside the organization as sources of expertise is probably the most readily extended to general management. Katz and Kahn (1965) in fact provide a sound theoretical basis for such an extension in their Social Psychology of Organizations. The problem of incompatible coding schemes is clearly not restricted to the R&D department.

> Individuals, groups, and organizations share a general characteristic which must be recognized as a major determinant of communication: the coding process. Any system which is the recipient of information, whether it be an individual or an organization, has a characteristic coding process, a limited set of coding categories to which it assimilates the information received. The nature of the system imposes omission, selection, refinement, elaboration, distortion, and transformation upon the incoming communications. Just as the human eye selects and transforms light waves to which it is attuned to give perceptions of color and objects, so too does any system convert stimulation according to its own properties. It has been demonstrated that human beings bring with them into most situations sets of categories for judging the facts before them...
>
> Organizations, too, have their own coding systems which determine the amount and type of information they receive from the external world and the transformation of it according to their own systemic properties. The most general limitation is that the position people occupy in organizational space will determine their perception and interpretation of incoming information and their search for additional information. In other words, the structure and functions of a given subsystem will be reflected in the frame of reference and way of thinking of the role incumbents of that sector of organizational space. The different functions and dynamics of the (several organizational subsystems) imply that each of these subsystems will respond to the same intelligence input in different ways and that each will seek out particular information to meet its needs.
>
> All members of an organization are affected by the fact that they occupy a common organizational space in contrast to those who are not members. By passing the boundary and becoming a functioning member of the organization, the person takes on some of the coding system of the organization since he accepts some of its norms and values, absorbs

> some of its subculture, and develops shared expectations and values with other members. The boundary condition is thus responsible for the dilemma that the person within the system cannot perceive things and communicate about them in the same way that an outsider would.[5] If a person is within a system, he sees its operations differently than if he were on the outside looking in. It is extremely difficult to occupy different positions in social space without a resulting differential perception...

The difficulty caused by incompatible coding schemes may then very well be a general phenomenon in organizations. Consequently, all extra-organizational communications should be viewed with care. The problem may be particularly acute in the case of the management consultant who more than the technical consultant, is treating problems much more central to the organizational identity, and consequently more prone to be affected by the development of unique coding schemes.

The Multiple-Step Process

The problems faced by both information system designers and management are certainly simplified by the existence of a multiple-step flow of technical information.

To the designer of information systems, it quite simply means a drastic decrease in the number of entry points that must be provided. Rather than provide each and every engineer in the organization with a private console, it appears that such complete service may very well never be needed, and that the use of select engineers as entry points into the oral network might provide a more effective and efficient system. The implementation of such an arrangement is obviously less expensive than that of a

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[5]Emphasis added.

system designed to reach the entire engineering population of a laboratory. Additional study should reveal the optimum number of entry points and the depth of service required at each. The best arrangement might possibly comprise combinations of different types of entry points with varying levels of system detail matched to the needs and personality of the user at each point. The study reported in Chapter 11 indicates that information retrieval services need be supplied to less than 20 percent and sometimes to only 5 percent of the laboratory population. Of course, the average working engineer will still require access to whatever information services are available, but the interface hardware can certainly be shared by a large number of such occasional users. It is only the literary technological gatekeeper who will need the most complete service.

To management, the existence of several steps in the flow of technical information into the laboratory means not only savings in the cost of information systems, but the alleviation of the difficulties in communicating with the outside world. Since an organization cannot survive without informational as well as energic inputs, it must maintain relations with experts in the outside world. However, if the information is to lose its meaning and value through the introduction of bias, distortion and noise, it is of no use in sustaining the organization. Measures must then be taken to prevent or counteract the introduction of noise at the organizational boundary. Several possibilities were discussed in the preceding section. To these we now add the possibility of capitalizing upon the existence of a natural multiple-step flow of information into the laboratory. Again, there are key entry points. The evidence suggests that certain individuals are capable of operating in two or more coding schemes and translating between them. These technological gatekeepers allow the effective entry of information into the organization and also abet its dissemination within the organization. Management must locate and utilize the talents of these individuals. Whenever possible, an appropriate gatekeeper should be included in any delegation visiting another technical organization. They should also be rotated through brief tours in liaison offices at important laboratories. Naturally several gatekeepers should be assigned to all major projects. In this capacity, they can serve as both a channel to the outside world and as contacts between the technical staff within the laboratory, who, no doubt, tend to develop independent coding schemes within the organization.

Quite naturally, there will be several types of gatekeeper within any organization. Some, who have come to engineering from basic science will be able to communicate more readily than the average person with their former colleagues and aid in connecting the organizational network to the scientific community. Other gatekeepers will have come from another type of organization or industry or will have developed a special ability perhaps through friends, for communicating with members of organizations of different interests. The problem is merely to match the gatekeeper and the situation.

The extension of this finding to general management is quite direct and has been anticipated by several theorists. Guetzkow (1965) puts forth in his analysis, "three elemental characteristics of communication flows in organizations":

a. the combination of organizational components involved in the communication,

b. whether the process is simultaneous or serial,

c. whether the form of the communication is transitory or storable,

and employs the two-step hypothesis in the integration of the first two.

> Now consider characteristics (a) and (b) together, when one-to-many ("undirected" or "mass media") communication is followed by one-to-one ("directed" or "interpersonal") communication; then we obtain the "two-step flow" process highlighted by Katz (1957). As suggested by the rural sociologists in their study of farm practice adoptions, "for the initial 'awareness' stage of receiving information, the mass media are ... more efficient than interpersonal relations, but the reverse is true for the stage of 'acceptance'" (Katz, Levin, & Hamilton, 1963, p. 247). Although no study of the two-step flow of communication has been made in organizations, it seems reasonable to speculate that these findings would hold within large organizations, as they have been demonstrated to hold within organized communities.

Guetzkow's statement that "no study of the two-step flow ... has been made in organizations" is, of course, no longer completely valid. Thus, we have a far stronger basis for speculation than was available at the time of his writing.

The Technological Gatekeeper

Before closing, we should once again give due credit to a great thinker of another era. The idea of the technological gatekeeper which bodes to be a powerful and potentially useful concept was clearly anticipated by Francis Bacon, who incorporated gatekeepers of divers sort in his design of "Salomon's House." One has merely to turn to the quotation introducing the present volume to realize that we have simply discovered in twentieth century research laboratories the existence of "Depredators," "Pioneers," "Compilers" and "Dowry-men."

APPENDIX

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LITERATURE SOURCE QUESTIONNAIRE

(attached to Time Allocation Form)

LITERATURE SOURCES

Please list the texts, books, periodicals, internal company reports, etc. which you referred to in your literature search, the function which the information served or was intended to serve, and an estimate of the approximate time which you spent with each source. As a publication is used, log it on this form; at the end of the three week period, estimate the total time for each source.

The following code should be used to indicate the function for which the information was used or was to be put to use, and how the information was obtained:

Acquisition Code

A. Personal library search
B. Discovered through use of technical abstract
C. Search by library assistant
D. On desk or personal file
E. Borrowed from colleague

Function Code

1. Aid in direct solution of a problem (e.g., handbook-type information).
2. Determination of results of related work performed by others.
3. Determination of procedures (e.g., testing procedures, fabrication procedures).
4. Learning new specialty--broadening areas of attention (to include brushing up on an old specialty).
5. Brousing of technical literature, resulting in significant discovery.
6. Verifying reliability of an answer.
7. Keeping abreast of developments in one's own particular field.
8. Keeping abreast of developments on related or competing systems.
9. Aid in definition of operational environment.

Title of Journal, or Book (Indicate if internal company document)	Method of Acquisition (by code no.)	Function (by code number)	Total time (in hours)

PROJECT MANAGER QUESTIONNAIRE

Were you the proposal manager for this contract?

Can you identify by order of importance the company's reasons for entering into this study?

_______________ The company had little or no previous experience in this area and wanted to enter the field.

_______________ The company felt that they were strong in this area and it was important to protect their reputation and capability through participation.

_______________ The company had a team of engineers which had performed work in this area which they wanted to utilize rather than dis-banding.

_______________ The company felt that they were in a better position than anyone else to win the follow on effort.

_______________ The company felt that the follow on effort was sufficiently large and important to the company that they should risk the necessary investment.

_______________ The company was already doing company sponsored research in this area and this study allowed them to obtain additional funding for their research.

_______________ The company wanted to increase the amount of business which they presently had with the customer.

_______________ Other (specify).

What was the total cost of your effort on this contract?

a) How much was company funded?

b) How much was customer funded?

When did the company begin any work toward this contract?

Will the company continue work on this project after the completion of the contract?

Will the team remain the same in

a) size How large?

b) leadership

c) What is your estimate of the probability that your company will receive a follow-on contract in this area?

How much time, in man-years or man-months, would you estimate your company spent working in this particular area before the request for proposal?

How many man-years has the company spent in work related to the technical areas under the contract?

How many years has the company spent in work related to the technical areas under the contract?

How many organizational units participated in this effort?

Can you draw your organization chart for the project for us?

We have established the following broad categories as being descriptive of most R&D.

Step I

BASIC RESEARCH — Work of a general nature intended to apply to a broad range of applications to the development of new knowledge about an area.

Step II

APPLIED RESEARCH — Work involving new basic knowledge for the solution of a particular problem. The creation and testing of radically new concepts or components but not involing development for operational use.

Step III

ADVANCED DEVELOPMENT — The combination of existing or feasible concepts with new knowledge to provide a distinctly new application. The application of known facts and theory to solve a particular problem through exploratory study, design, and testing of new components or systems.

Step IV

REFINEMENT AND TESTING — Improvement to existing components, techniques or systems. Recombination, modification and testing of systems using existing knowledge.

In which of the above categories would you place the objectives of this effort? (The arabic numerals indicate the degree of refinement within a category.)

I II III IV

1 2 3 1 2 3 2 1 2 3 1 2 3

Roughly what percentage of the work required to accomplish the objective falls in each of the above categories.

I II III IV

For what purposes do you expect NASA to use your study? Please identify in their order of importance.

_____ For future planning of the national space program.

_____ For the assessment of your company's capability to perform additional studies on this project.

_____ For the assessment of your company's capability to develop the hardware required to meet the requirements of this work statement.

_____ For the preparation of specifications to be used in a competition for a follow on effort.

_____ For the advancement of the state of the art and understanding in the particular scientific area concefned.

_____ For the justification of additional funds in this scientific area.

_____ For the further definition of a system concept.

_____ For the determination of the feasibility of this particular project.

_____ Other (specify)

What per cent of the technical man-hours on the project would you classify nontechnical effort?

	Nontechnical effort
a. less than 10%	________
b. less than 20% but greater than 10%	________
c. less than 30% but greater than 20%	________
d. less than 40% but greater than 30%	________
e. less than 50% but greater than 40%	________
f. less than 60% but greater than 50%	________
g. less than 70% but greater than 60%	________
h. less than 80% but greater than 70%	________
i. greater than 80%	________

What per cent of the technical man-hours on the project was directly related to accomplishing the necessary advances in the state of the art?

a. none ____________

b. less than 10% ____________

c. less than 20% but greater than 10% ____________

d. less than 30% but greater than 20% ____________

e. less than 40% but greater than 30% ____________

f. less than 50% but greater than 40% ____________

g. less than 60% but greater than 50% ____________

h. less than 70% but greater than 60% ____________

i. greater than 70% ____________

Which fields required an advance in the state of the art?

____

____

____

How would you rate the technical complexity of the project?

a. exceptionally complex __________

b. highly complex __________

c. moderately complex __________

d. typical __________

e. less complex than typical __________

f. not complex __________

What do you believe was the most significant (good) aspect of your technical solution to the work statement?

a) What or who was the source of this idea?

What do you believe was the weakest aspect of your solution to the work statement?

a) Who was the source of this idea?

What was your largest management problem on this effort?

Did you in your technical effort, attempt to respond directly to the work statement or did you attempt to emphasize, add to, diminish or delete any areas?

a) What were those areas?

If there were any significant changes in the technical objectives of the project, indicate when they occurred and give a brief description of the cause.

Could you rank in order of importance those factors which you believe could have increased your performance on this project?

_________ More control by the project manager.

_________ A different breakdown of the problems in the work statement.

_________ A different organization of the project.

_________ Personnel of higher capability.

_________ An increase in the number of people working on the job.

_________ More time to work on the project.

_________ Greater previous experience in this area.

_________ Greater contact with and adherence to the desires of the customer.

_________ Less contact with and adherence to the desires of the customer.

_________ Greater use of outside consultants.

_________ Greater use of staff specialists.

_________ Greater time spent in literature search.

_________ Other (specify).

Could you state the three technical sections of this study which the customer will scrutinize most closely?

Could you rank these in their order of importance to the customer?

Would you characterize your effort on this study as:

__________ Much better than you had done on previous projects.

__________ Slightly better.

__________ About the same as on previous projects.

__________ A little below your usual standards.

__________ Considerably below your usual standards.

How would you rate the customer's performance?

Of the last three projects you managed,

a) What was the approximate annual spending rate?

b) How long were you project manager?

c) What percent of your time was spent on each project?

d) How many people did you manage?

	(a)	(b)	(c)	(d)
	Spending Rate (Dollars/Year)	Years	Time Spent (percent)	Number of People Managed
Most recent				
Previous one				
Prior one				

For how many years were you:

a) a functional head?

b) a project manager?

c) a group leader?

d) a supervisor in any capacity?

How were the personnel connected with this project assigned?

	No. of men
1. Professionals:	
a) Full time	________
b) On several projects	________
c) Consultative function	________
2. Technicians:	
a) Full time	________
b) On several projects	________
3. Administrators:	
a) Full time	________
b) On several projects	________
c) Consultative function	________

a) Those people who work full time for the duration of their effort on the project.

b) Those people who work on several projects at once.

c) Those who do not draw a budget from the project but who made some technical contribution.

Educational background of the project personnel.

degree(s)

discipline

years since B.S.

Can you provide us with resumes for the people who worked on this project?

SOCIOMETRIC STUDY QUESTIONNAIRE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SCIENTIFIC/TECHNOLOGICAL COMMUNICATION
SURVEY

Name:

Marital Status: Married____ Single____

Number of years of technical experience in specific field in which you are currently engaged ______yrs.

Since receipt of your last degree, have you taken any technical courses (either in or out of plant)

a. yes____ no____

b. how many? ____

c. number of years since last course _____yrs.

How many years have you been with this organization? _____yrs.

Please give the following:

a. Date of baccalaureate degree_________(year)

circle one: B.S. B.A. in what field_______________

b. Advanced degrees

M.S. date___________ field______________

M.A. date___________ field______________

PhD. or ScD. date___________ field______________

other (please indicate)______________ date__________

field__________________

How many projects are you presently working on? (Please circle one)

0 1 2 3 4 5 or more

How many projects do you prefer to work on? (Please circle one)

0 1 2 3 4 5 or more

To what professional societies do you belong?

IEEE AIME ECS ACS FARADAY APS ASM

other(s)__________________
(specify)

In the past year, how many professional society conventions did you attend?

0 1 2 3 4 or more

During your professional career, how many papers have you presented at professional society meetings?

0 1 2 3 4 5 6 7 8 9 10 11 or more

How many in the past year?

1 2 3 4 5 or more

Approximately, how frequently would you say that you consult your boss for assistance on technical problems pertaining to your work? (circle one)

once a two or three once a once a less than once

Please name the three or four people from the lab that you meet most frequently on social occasions (in the evening, weekends, etc.)

______________________________ ______________________________

______________________________ ______________________________

Please indicate (by a check mark) which of the following periodicals you subscribe to, and which you read regularly.

periodical	subscribe	read regularly
Proc. IEEE	______	______
Physics Today	______	______
Scientific American	______	______
Mechanical Engineering	______	______
Aviation Week	______	______
Chemical & Engineering News	______	______
Civil Engineering	______	______
American Engineer	______	______
Electronic Design	______	______
American Scientist	______	______
Electronics Weekly	______	______
Electrical Engineering	______	______
Electronics	______	______
Nucleonics	______	______
Aerospace Engineering	______	______
Missiles and Rockets	______	______
Space Age News	______	______
Science	______	______
Space/Aeronautics	______	______
Electrical Design News	______	______
Astronautics and Aeronautics	______	______
Missile Design & Development	______	______
Journal of Applied Physics	______	______
Metals Progress	______	______
Metals Review	______	______
Any of the IEEE Transactions (if checked, how many separate transactions? ______________)	______	______

periodical	subscribe	read regularly
Electronic News	______	______
Journal of Operations Research Society	______	______
Computers and Automation	______	______
Datamation	______	______
Industrial Research	______	______
International Science and Technology	______	______
Product Engineering	______	______
Microwave Journal	______	______
Design News	______	______
Acoustical Society Journal	______	______
Electronic Industries	______	______
Electro-Technology	______	______
Current Contents	______	______
Chemical Abstracts	______	______
Journal of Metals	______	______
Journal of the ECS	______	______
Electrochemical Technology	______	______
Chemical Engineering News	______	______
Journal of Physical Chemistry	______	______
Physical Abstracts	______	______
Physical Review	______	______

What other professional, technical or scientific journals do you subscribe to, or read regularly? (please check)

	Subscribe	Read regularly
______________________________	______	______
______________________________	______	______
______________________________	______	______
______________________________	______	______
______________________________	______	______
______________________________	______	______
______________________________	______	______

On the average, how many hours/week do you spend reading the above literature ______________

Of all the people with whom you socialize during non-work hours, approximately what percentage of these would you say are professional employees of this organization?

0 1-10% 10-20% 20-30% 30-40% 40-60% 60-80% 80-100%

Name the three or four people whom you feel are most valuable to the lab in terms of their technical competence.

____________________ ____________________

____________________ ____________________

Name the one or two people in the lab whom you consider your best friends.

____________________ ____________________

If you had a new idea for a research project to whom, in the lab, would you first express this idea?

____

Would you then expect to get the credit for this idea? yes_____ no_____

To what extent do you utilize the following as information sources:
(please circle the one most appropriate number).

the literature

1	2	3	4	5	6	7
very greatly			somewhat			not at all

personal friends outside of the organization

1	2	3	4	5	6	7
very greatly			somewhat			not at all

paid consultants and persons outside the organization who are not personal friends

1	2	3	4	5	6	7
very greatly			somewhat			not at all

a technical specialist within the lab

1	2	3	4	5	6	7
very greatly			somewhat			not at all

vendors

1	2	3	4	5	6	7
very greatly			somewhat			not at all

In general, how would you rate your boss in technical competence (check one)

_____ one of the best in his technical area
_____ above average
_____ average
_____ below average
_____ one of the worst in his technical area

Please name the three of four people from the lab with whom you most frequently discuss technical matters.

____________________ ____________________

____________________ ____________________

Indicate your preference with respect to working habits by checking one of the following:

_____ work alone, very seldom consulting others
_____ work alone, but have occasional work related discussion
_____ work alone, but have frequent work related discussion
_____ work closely with others, but not in a structured group
_____ work in a structured group

At present, what are your actual working habits?

_____ work alone, very seldom consulting others
_____ work alone, but have occasional work related discussion
_____ work alone, but have frequent work related discussion
_____ work closely with others, but not in a structured group
_____ work in a structured group

How many patents have you received (include those pending)

0 1 2 3 4 5 6 if more than 6, how many?__________

In general, how do you feel about this lab as a place to work: (circle one)

one of the best | above average | average | below average | one of the worst

Please indicate briefly (3 or 4 work description) the three best technical ideas you have had since coming here.

1. ____
2. ____
3. ____

Please indicate briefly (3 or 4 work description) the three best technical ideas that the lab has developed in the past year.

1. ____
2. ____
3. ____

Please name the three or four specific technical categories which best describe your present work.

____
____
____

Do you attend the meetings of local chapters of professional societies (e.g. Boston section of IEEE)?

yes_____ no_____

If yes, what societies?

society	every month	every other month	every six months	once a year	less often
	How frequently (check for each attended)				
IEEE	___	___	___	___	___
AIME	___	___	___	___	___
ECS	___	___	___	___	___
FARADAY	___	___	___	___	___
ACS	___	___	___	___	___
APS	___	___	___	___	___
ASM	___	___	___	___	___
other__________	___	___	___	___	___

Do you ever attend the cocktail hours and dinners preceeding these meetings? (please circle one number)

1	2	3	4	5	6	7
always			half the time			never

Name the two or three individuals from this organization with whom you most frequently eat lunch.

Name	How frequently daily	twice/week	once/week	less

Do you consistently (twice a year or more) meet with any other technically trained individual or individuals to eat lunch or dinner?

yes_____ no_____

If yes, indicate the institutional affiliations of these people

Institution	How frequently? twice a year	bimonthly	monthly	more often

List the last names of the individuals who, in your consideration, make up your immediate work group (as of today)?

_______________ _______________

_______________ _______________

_______________ _______________

_______________ _______________

_______________ _______________

Who are the 3 or 4 people within the lab with whom you would most like to work?

_______________ _______________

_______________ _______________

When you encounter a particularly "hairy" technical problem (in your own technical specialty) is there anyone within the lab to whom you would turn for assistance?

yes_____ no_____

If yes, who is this individual?

____

Anyone outside the lab? yes_____ no_____

Please name his organization_______________

Give your own estimate of the likelihood that high energy batteries (100-200 watt hours/pound) will be available for industrial and commercial use by 1970.

certain	very likely	somewhat likely	tossup	somewhat unlikely	very unlikely	impossible

Give your own estimate of the likelihood that large thermoelectric generators (10kw) will be available for use in space by 1970.

certain	very likely	somewhat likely	tossup	somewhat unlikely	very unlikely	impossible

Give your own estimate of the likelihood that high temperature metal composites will be available for use in aircraft by 1970.

certain	very likely	somewhat likely	tossup	somewhat unlikely	very unlikely	impossible

Thank You !

SOCIOMETRIC STUDY INTERVIEW FORM

Name________________________________

1. Think back to the last completed research project that you engaged in. Was there any special information you received that influenced you during the course of research?

_______yes   ______no

If yes, how did you learn of it?

- ____attending papers at conventions
- ____attending symposia at conventions
- ____scanning or reading of journals
- ____informal discussion at conventions
- ____preprints, reprints, or abstracts from author
- ____books or mongraphs
- ____informal discussion with colleagues within the lab -- who?_______
- ____informal discussions with colleagues outside the lab -- org.?
- ____verbal or witten reports from assistants
- ____other

2. On the questionnaire that you filled out for me, you specified the best technical ideas that you have had since coming to work here.

For each of these ideas, tell me how you first got the idea and then what you did with this idea after you got it.

3. The following ideas were selected as being those that were the best technical ideas that the lab has developed in the past year:

   1. a classified project-solid state electronic device
   2. SIC based composites
   3. Bonding and casting of PbTe
   4. Primary reserve battery
   5. Travelling solvent method

For each of these ideas, I would like to know who was responsible for bringing the idea into the lab, and then what this person did with the idea after he brought it into the lab.