

Research Program on the
MANAGEMENT OF SCIENCE AND TECHNOLOGY

[Time Allocation Among Three Technical
Information Channels By R & D Engineers]

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ABSTRACT

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

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

A handwritten signature in cursive script, appearing to read "Austin", is located in the lower right quadrant of the page.

INTRODUCTION

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

To assist in obtaining a performance evaluation for each information channel, instances were sought in which the same problem is attempted by two or more research groups.¹ In this way, a comparison can be made between the information sources leading to specific solutions. The fairly common practice of the Department of Defense and the N.A.S.A. to award parallel study contracts during the early phases of R & D provides an opportunity for control over the effect of variations in the problem substance. The data presented are from four parallel contracts involving eight R & D groups.

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

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

1. Literature will be used more heavily at the initiation of a project and will be replaced by personnel outside the laboratory (principally vendors) as the predominant information source as the project progresses.
2. Sources within the lab will be resorted to intermittently over the course of a project.
3. Teams conducting an extensive information search at the beginning of a project perform better.
4. Subsystems with a high degree of uncertainty (uncertainty is operationally defined) receive greater attention in terms of time spent on information gathering than do those which are low in uncertainty.

METHOD

Once a parallel project has been located, its work statement is obtained and analyzed and factored into a reasonable number of subproblem areas (generally subsystems). The breakdown is then checked with the technical person who prepared the work statement, and data collection forms based upon it are designed. After all data have been collected from the contractors, the technical monitor is revisited and asked to provide a confidential evaluation of each lab's performance. Data are

gathered by four means: (1) time allocation forms, indicating the amount of time each engineer spends on the job in several activity categories; (2) before and after interviews with the individual engineers; (3) periodic tape recorded progress reports by the project manager; and (4) solution development records.

Time allocation forms supported by data from Solution Development Records are the principal source of the data here under consideration. An example of the time allocation forms used is presented in Appendix A. Respondents are asked simply to record the breakdown of each day's activity among 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 in consulting with experts outside the laboratory; and time spent in analytic design. The Solution Development Record provides a means of following the progress of an R & D project through its subsystem design changes, and has been described in detail elsewhere (Allen, 1965).

Description of the Projects

The four projects under consideration involved the following general problems:

1. The design of the reflector portion of a rather large and highly complex antenna system for tracking and communication with space vehicles at very great distances.
2. The design of a vehicle and associated instrumentation to roam

the lunar surface and gather descriptive scientific data.

3. The study of possible mission profiles for manned flights to another planet.
4. The development of a detailed mathematical cost model yielding complete R and D and operational program cost estimates of space launch vehicle systems.

Unit of Analysis

Man-hours devoted to an information channel is the unit of analysis employed. (cf. Menzel, 1960). Since engineering man-hours expended is quite closely correlated with cost on 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.

Data Analysis

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

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

from team to team within projects; and percentage representation allows intraproject comparison.

Percentages for any given time period of a project are the ratio of the total time spent by all individuals on the variable in question to the total time reported by all individuals. Since this method ignores the variance due to individuals taken separately, all percentages derived for the entire project were recomputed on an individual basis. The individual percentages were then averaged, and results compared with the aggregate figures. Although this method gives undue weight to individuals who worked only a small part of their time on the project, it does provide a check of the total percentage analysis. Because of the inordinate weight given to part-time participants, individual percentage treatment is used only as a check and mentioned only when results differ from those of the total percentage method.

Two-sample "t" tests are used to test for differences in the percentage means. Because of the small sample sizes employed (four or eight) and because of the exploratory nature of the study 0.10 is used as the cut-off significance level on a two-tailed test.

RESULTS

Relations Between Performance and Time Allocation

Higher and lower rated project teams are determined on the basis of the government technical monitors' performance ratings. The percent of time spent in total information gathering, and in literature search, out-

side consultation, staff consultation, and analytic design are averaged for the higher and lower rated teams. The results in Table I show that on the average, higher and lower rated teams spend approximately the same percent of time in each of the five areas.

TABLE I
Time Allocation by Function
(Four Parallel R & D Projects)

	Higher Rated	Lower Rated
all information gathering	13.86%	13.43%
literature search	5.02	5.32
outside consultation	5.09	5.32
staff consultation	3.77	2.00
analytic design	77.90	71.40
other	8.24	15.71

Necessity of Analysis Over Time

Figure 1 shows that the time spent in gathering information varies considerably over a project's life [$F(5,136) = 3.32; p(0.01)$] and the components that make up the total time spent gathering information vary in a somewhat different manner, although the interaction term is not statistically significant. Information gathering is greatest in the initial time period. Literature search and outside consulting make up the largest component in this state, corroborating the general belief that initially on a new project engineers conduct an extensive literature search and seek out

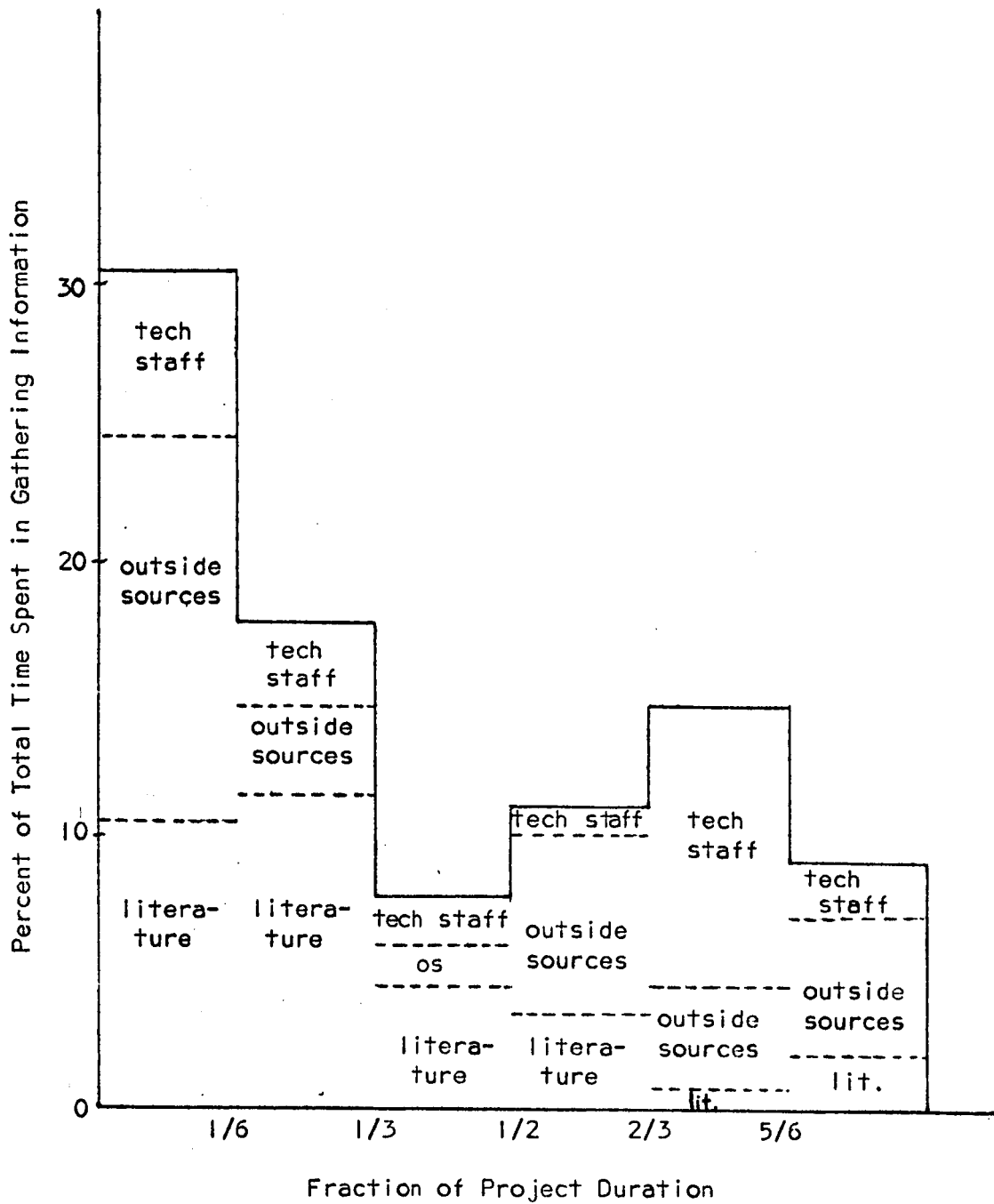


Figure 1. Percent of total time which is spent in gathering information as a function of project life span (averaged for four matched pairs of R & D projects)

possible suppliers for ideas as well as components.

While literature search is the primary information gathering tool in the initial stages, it quickly decreases as the projects progress and is replaced in importance by person-to-person communications. Outside consulting is relatively high initially, but generally speaking is an important factor in all phases of the projects. Staff consultation is the dominant activity in only one phase of the projects, near the end.

Performance Relations Over Time

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

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When computed on an individual basis, the result is in the same direction but is not significant. This is the only case where a result obtained by the total percentage method was not supported by the individual percentage method.

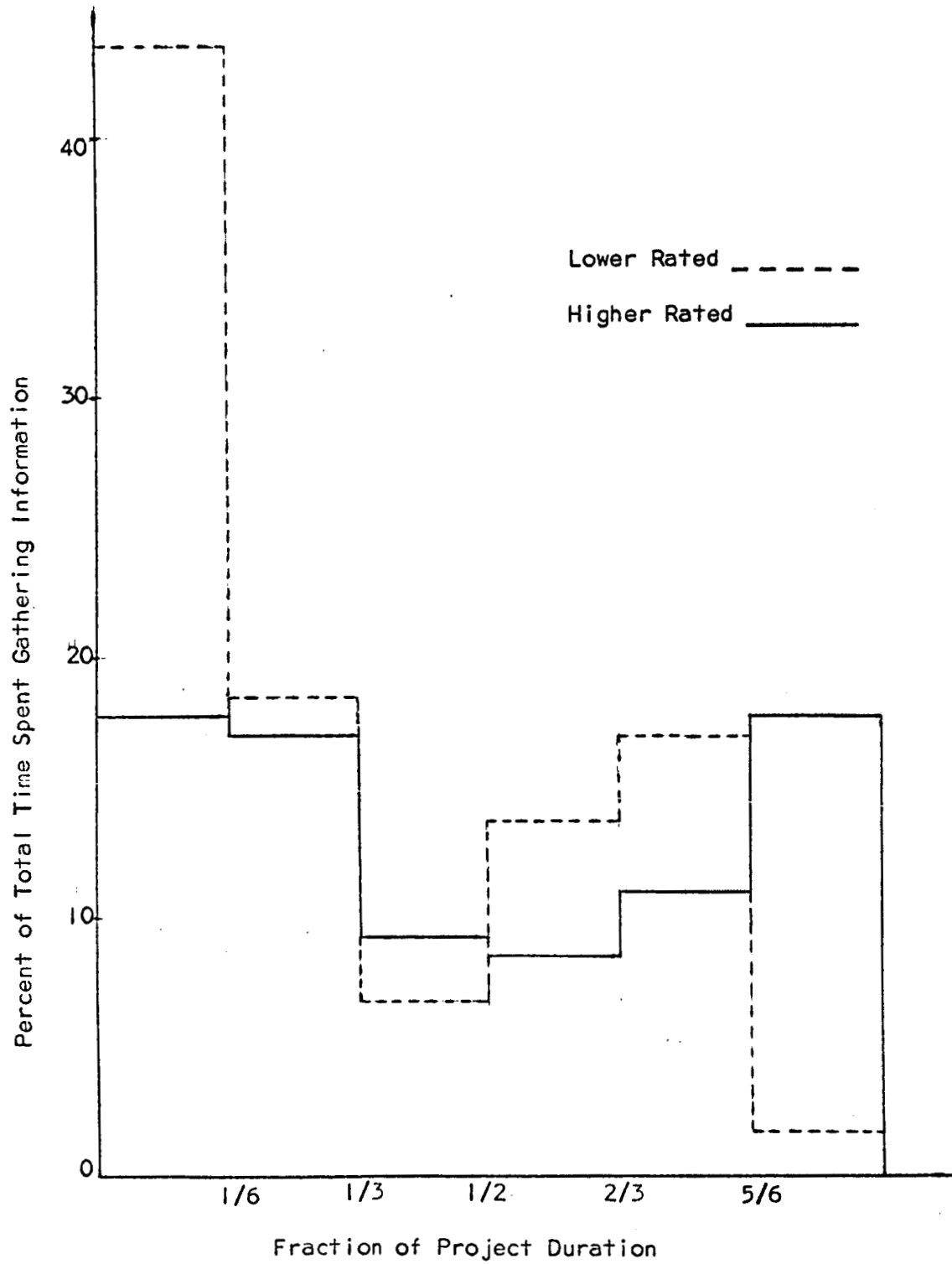


Figure 2. Comparison of percent time spent by higher and lower rated project teams in information gathering

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

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

Technical Staff. Although the time spent with this channel is the smallest reported (2.0% for losing teams and 3.8% for higher rated teams), it is a very important source of technical information. Staff specialists

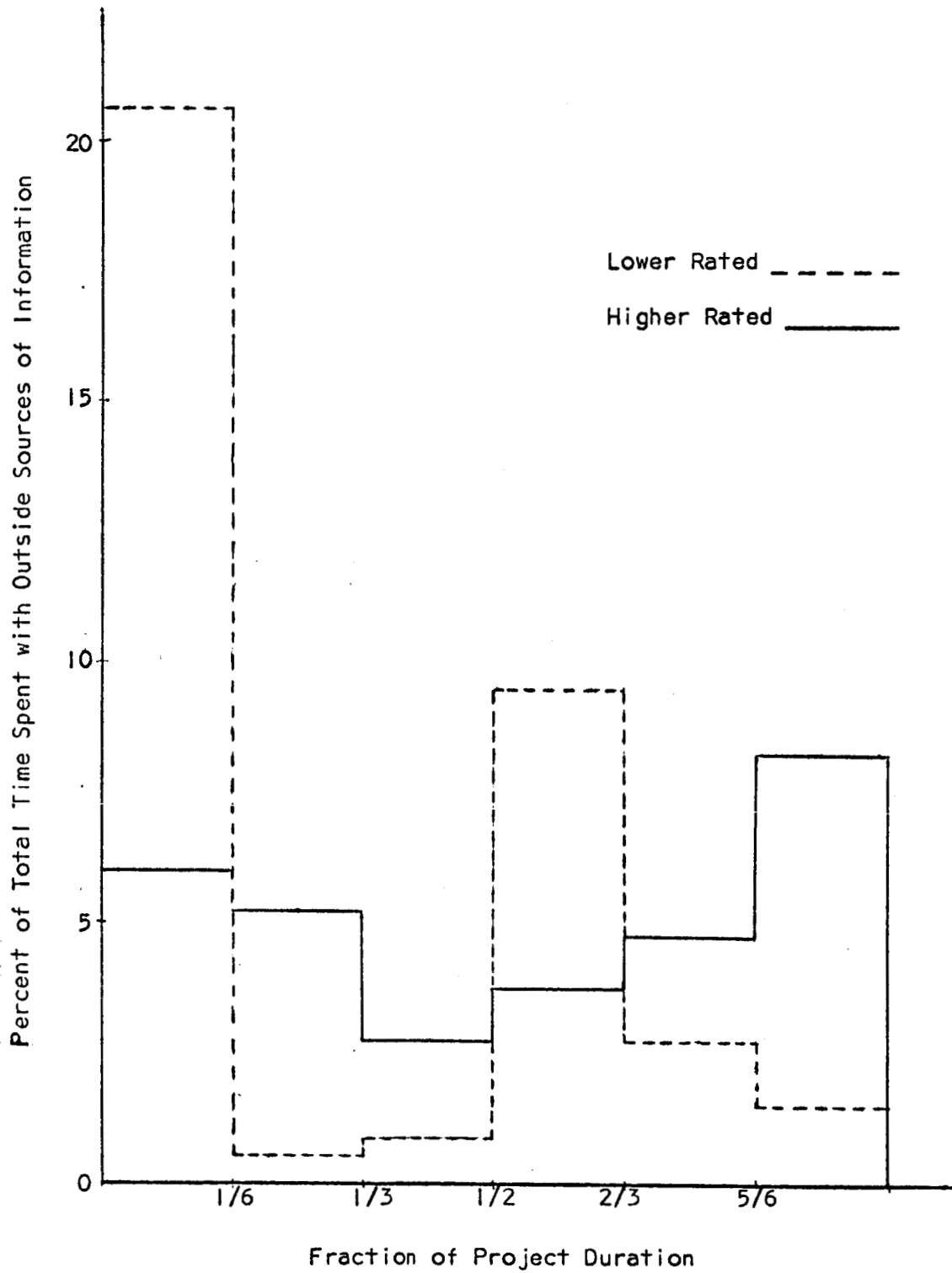


Figure 3. Comparison of percent time spent by higher and lower rated project teams in consulting with sources of information outside the laboratory

are often called upon to solve critical problems beyond the capability of team members. Again the time pattern follows that established for outside sources -- consistency over time by the higher rated teams and fluctuation by the lower rated teams. Higher rated teams spend significantly more time only in the last stage of projects (Figure 4).

Literature Search. Although the differences between higher and lower rated teams are not significant, the general pattern is similar to that for the other information channels. Higher rated teams remain fairly steady and lower rated teams fluctuate. The lower rated teams, however, are not quite as erratic as in other information activities, showing instead a rather steady decline as the project progresses (Figure 5).

Uncertain Subsystems

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

To test this, it is first necessary to define and measure uncertainty. At least two estimates of uncertainty are available from the data. From the Solution Development Record, the average weekly value for Δp can be

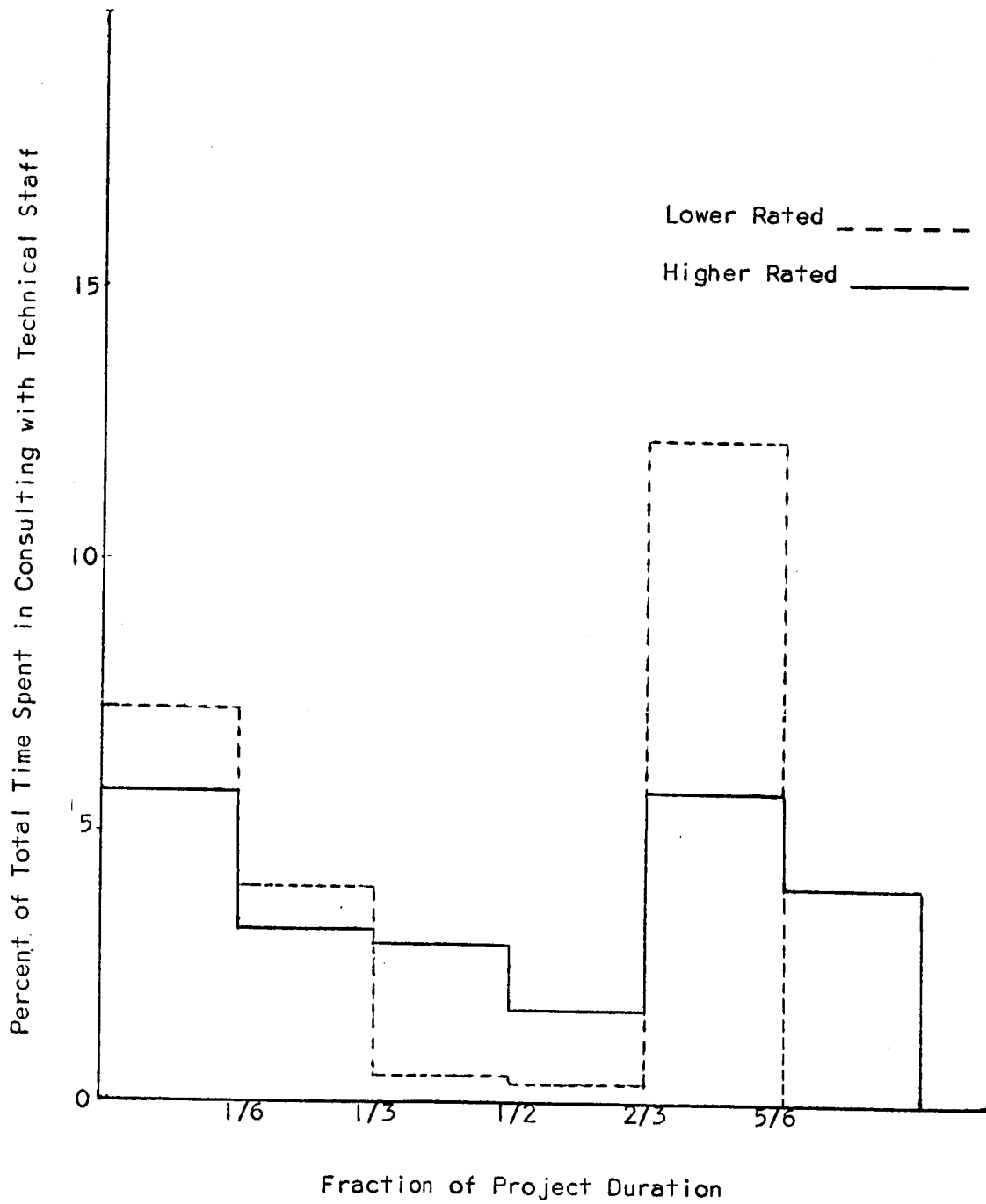


Figure 4. Comparison of percent time spent by higher and lower rated project teams in consultation with the lab's technical staff

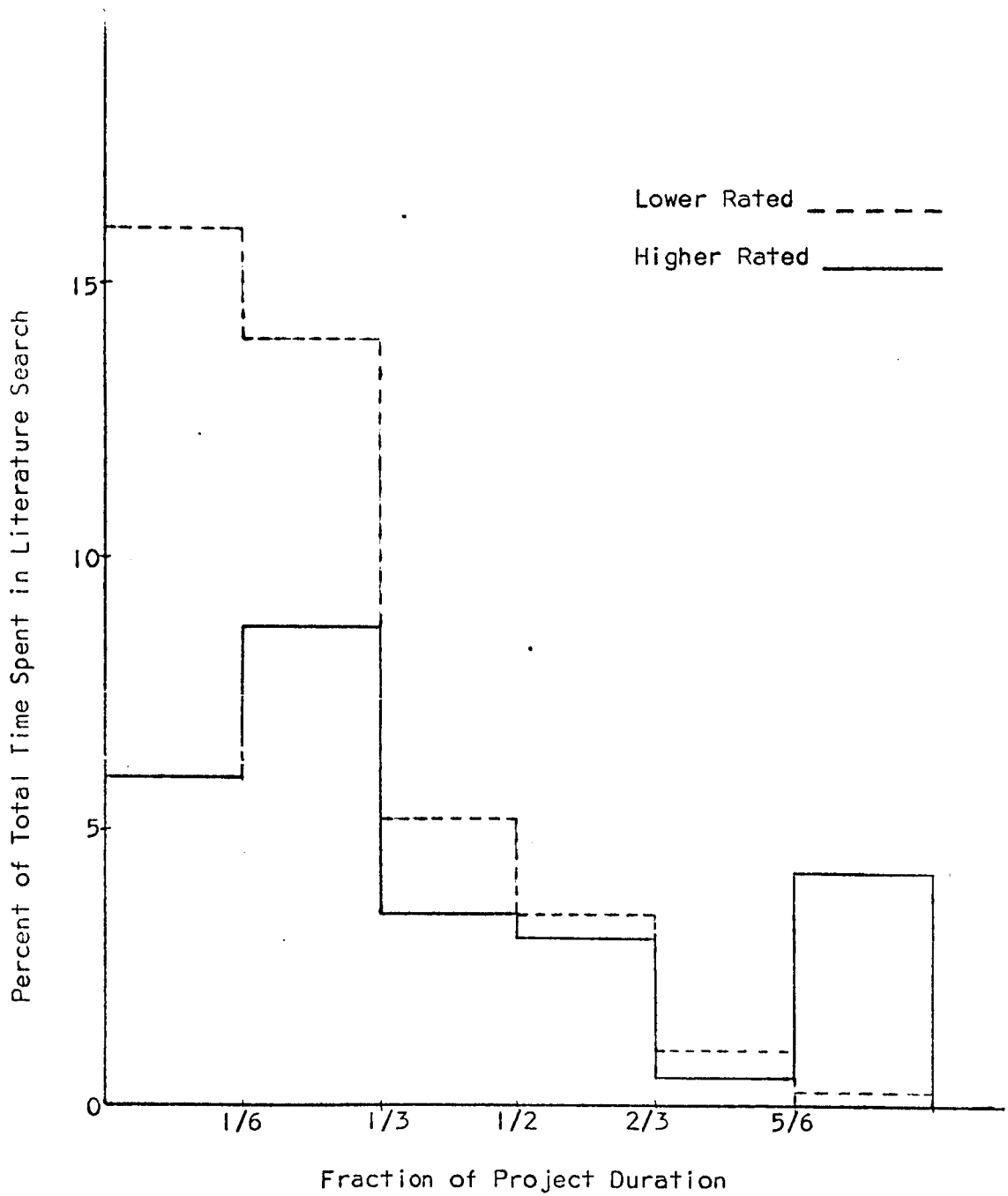


Figure 5. Comparison of percent time spent by higher and lower rated project teams in literature search.

determined for ⁴each subsystem. A large value of Δp should indicate high uncertainty but in some cases several alternatives are carried at a low level throughout most of the project with none achieving clear dominance; in such cases Δp can be very small and yet the uncertainty is obviously high. A more reliable and sensitive measure appears to be the number of weeks the winning alternative maintains a probability less than 0.7 on the Solution Development Record. If the winning alternative is reported at a probability of 0.7 or higher throughout most of the project, the subsystem is one with a relatively high degree of certainty. Conversely, if the probability of acceptance exceeds 0.7 for only a small portion of the project, this would indicate uncertainty relative to the design of the subsystem.

Uncertain subsystems are thus defined in the following two ways:

- (1) Those whose final solution maintained a 0.7 or higher probability for a number of weeks which was less than the average for the project.
- (2) Those with a weekly Δp greater than the average for the project.

The two operations research projects are omitted from this analysis because in these instances subsystems are not clearly defined, and relative uncertainty is therefore impossible to determine. In each

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Engineers provide a weekly estimate, on the Solution Development Records, of the subjective probability that each alternative considered as a possible solution will in fact be finally chosen as the solution. The measure Δp is the total change in probability level for all alternatives in a given subproblem (Allen, 1965).

of the other two projects, it is possible to identify twenty-one individual subsystem designs. There is some overlap among individuals in their responsibility for subsystems; in these cases assignment is made equally to each. This is a conservative procedure which results in a general weakening of correlations for the subsystems affected.

With these limitations noted, the percent of information gathering devoted to each subsystem is compared with the project average. Figure 6 shows the results of Fisher exact probability tests (Siegel, 1956) of the hypothesis for each of the definitions of an uncertain subsystem.

These results indicate that the engineers working on problems of higher uncertainty do allocate more time to information gathering than on problems of lower uncertainty. This fact should be recognized, and special provision made to supply those engineers who are working on subsystems which are relatively complex or are pushing the state-of-the-art with the necessary technical information for their work.

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

		uncertain subsystems	certain subsystems	
Percent of Total Time Spent in Information Gathering	High	10	5	probability of occurrence under the null hypothe- sis = 0.097
	Low	1	4	

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

Certainty based upon weekly probability change.

		uncertain subsystems	certain subsystems	
Percent of Total Time Spent in Information Gathering	High	11	5	probability of occurrence under the null hypothe- sis = 0.082
	Low	1	4	

Figure 6. Proportion of time devoted to information gathering as a function of subsystem certainty (21 R&D subsystems).

CONCLUSIONS

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

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

The percent of total time spent in all phases of information gathering varies significantly over the duration of projects. When the activities are measured over time, a clear relation with performance emerges. Higher rated teams are more consistent over the duration of the projects in all phases of information gathering, while lower rated teams initially spend more time gathering information than they do in the later stages and fluctuate more throughout. Literature search by lower rated teams is regular in its declining use from the beginning to the end of projects. These results hold for two methods of computing percent time spent in any activity.

The time of R & D engineers is a most valuable commodity. Much of this time is spent in seeking and gathering needed technical information.

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

APPENDIX

Time Allocation Forms are specially designed time sheets which permit the engineer to indicate the manner in which he divides his time among four modes of information gathering and processing activity.

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Time Allocation Form

Name _____

Date _____

Day Activity	Sun.	Mon. <u>DATE</u>	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							

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