WORKING PAPER

SCHOOL OF INDUSTRIAL MANAGEMENT

ORGANIZATION RESEARCH PROGRAM

Problem Solving by Research Groups

# Factors Influencing Technical Quality in the Preparation of Proposals for Government Contract

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July 1963

#20-63

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The research reported in this paper was carried out by T. J. Allen, Jr. under the direction of D. G. Marquis, and is part of a Master's thesis submitted by Allen (1963). The authors acknowledge the help of David Harris in editorial revision.

ABSTRACT

Two proposal competitions for government R & D contract, involving 9 and 12 firms respectively, are examined. Ten variables characterizing the competing laboratories and their research procedures are measured and correlated with the technical ranking of the proposals as determined by the responsiable government laboratory without respect to the bid price. In both sets of proposals the technical quality is uncorrelated with the size of the proposal preparation team but is positively related to the size of the laboratory and especially to the total number of engineers and scientists in the laboratory. Effort (total man-hours) is positively correlated (.31, .33) with technical rank. Time spent consulting specialists in the laboratory is related in both cases (.37, .55), but time spent in analytic design is negatively related to technical quality on the smaller job and positively on the larger (-.29, .38). Time spent in literature search or in consulting people outside the laboratory shows no positive relation.

Research by its very nature is an uncertain activity. Some projects fulfill or exceed expectations for their success; others fail in varying degree. There is at present little systematic knowledge about the factors leading to success or failure. Many considerations can affect the outcome of a research and development project. Some of these are fairly obvious; for example, the technical proficiency (quality) of the researchers, the technical manpower (quantity) employed on the task, the length of time devoted to the job. Even among the more obvious factors, however, little is known about their relative importance.

The investigation of factors in research performance in real life situations on major problems is made difficult by the fact that a particular problem is worked on only once. Amost by definition a research problem is unique; if it has been solved before, it is no longer a research problem. Replication thus is infrequent.

In addition to a few instances of parallel effort in government contracting, replication can be found in the proposal competition for government contracts. There are two additional reasons for selecting this phase for investigation. First, it is the stage in which major decisions are made regarding the overall approach to the problems involved. The preliminary design of a system is accomplished at this time and any changes subsequently made in the design are usually minor by comparison. Secondly, this portion of the R & D effort is normally performed by a number of competing firms working concurrently and often selecting different approaches

to the solution of the same problem. The technical evaluation of the resulting proposals by the government laboratory provides a rating against which a number of factors characterizing the different approaches taken by competing firms may be correlated.

In contracting for research and development, a government agency usually solicits proposals from a number of firms having previous experience or interest in the relevant field of endeavor. The technical staff of the agency draws up a work statement describing the mission the system is to perform and setting forth certain criteria to which the design must conform. This work statement is incorporated in a formal Request for Proposal which is sent to the several firms. The preparation of proposals and preliminary designs may be described as a problem-solving process carried out under conditions of competition and high reward, and with cost penalties for wasted or ineffective effort.

## RESEARCH METHODS

Two contracts were selected for study from the files of the Air Force Electronic Systems Division. The Air Force Cambridge Research Laboratory (CRL) was the agency responsible for technical evaluation of the proposals for these contracts. The contract files contain a copy of the work statement for the task, copies of all proposals submitted, and a report of the technical evaluation performed by CRL. The latter document indicates, with substantiating reasons, which proposals were

acceptable and which were unacceptable, and lists them in order of their technical quality.[1] This evaluation is made by technical specialists who are deliberately kept in ignorance of the bid cost of the several proposals. The final contract awards are made by others who consider both technical quality and cost. The ordinal scale of technical quality thus provided is the dependent variable in our analysis, and several independent variables are measured to determine their relation to technical quality.

The work statements, proposals, and CRL reports relating to each of the contracts were studied carefully to obtain a general understanding of CRL's desires and the situation confronting the firms preparing the proposals. The two problems faced by the competing firms may be stated as follows:

Problem A: To design a portable meteorological set to measure wind velocity, air temperature, relative humidity, and atmospheric pressure. It was to be capable of withstanding a parachute drop from an airplane, or a ten-foot free fall. The set was to be operated by one man and was to be powered by self-contained batteries.

Problem B: To provide an experimental microwave antenna system which would have a design frequency of 35,000 megacycles and meet extremely severe requirements in antenna gain

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[1]The evaluators of Problem B were reluctant to make a complete ordinal ranking of the solutions proposed by the twelve firms in the sample. Seven were evaluated as "acceptable" and ranked in order of technical quality, and of the five remaining "unacceptable" solutions, the ranking of only the last-place firm is known. This results in a four-way tie for ninth place in the ranking.

(68 db), sidelobe suppression (25 db within a 1 degree cone, 55 db elsewhere), noise temperature (20 degrees Kelvin), minimum scan rate (no greater than 0.0005 degree $sec.^{-1}$), and pointing accuracy ($\pm$ 0.01 degree).

Information concerning the process of proposal preparation was secured from all the firms that had submitted proposals. A set of interview questions was designed for each of the problems. The questions were based upon knowledge obtained from the work statements, proposals, and interviews with technical evaluators. They were tailored to the individual contracts, but attempted to elicit comparable information on the ten factors listed in Table XI. In each case, one or more members of the proposal team, usually including the proposal manager, were sought out for interview. An interview usually lasted one hour but in some cases the subjects were so interested in the topic that their interviews continued several hours.

Because of geographic and time constraints, not all of the competing laboratories could be reached for detailed interview. Those which could not be reached were sent a questionnaire dealing with the same factors. Of thirteen laboratories that received questionnaires, ten responded. The size of the sample for Problem A is nine firms. Five of these were covered by direct interview and four completed the questionnaires mailed to them. For Problem B the sample size is twelve, six by interview and six by questionnaire.

Of the many factors that might influence the technical quality of proposals for government contract, ten were selected,

measured, and tested (see list in Table XI). A nonparametric measure of correlation (Kendall tau coefficient) was chosen since true interval scaling is not available for the technical evaluation of the solutions.

## FACTORS INFLUENCING TECHNICAL QUALITY

### 1. Effect of Cost on Other Correlations

The term "cost" refers to the price quoted in the proposal, the cost for which the firm proposes to perform the job. One might imagine that a firm proposing one of the costlier solutions to the problem would perhaps have a relatively more sophisticated solution and therefore receive a higher ranking in the technical evaluation. Conversely, a firm suspecting that the government had a rather limited budget for the project might pare down its technical proposal to cut costs and thereby suffer in the technical evaluation. For these reasons it is conceivable that cost might have a major effect upon other correlations. This possibility was checked by partialling cost out of all correlations and examining the effect. Since the change was in all cases negligible, the effect of cost upon other correlations can be ignored in the ensuing analysis.

Table I shows the relation to technical quality of the costs projected by the competing firms for Problems A and B. (At this writing, contract A has been completed at a final cost of $18,593. Contract B is about 20 per cent completed

TABLE I

RELATION BETWEEN COST AND TECHNICAL QUALITY

| Problem | No. of labs | Median Cost | Range of costs | Corre-lation | p |
|---|---|---|---|---|---|
| A | 9 | 20 | 7-98 | .11 | .38 |
| B | 12 | 795 | 327-1,114 | .29 | .09 |

Cost figures are in thousands of dollars
p = Probability of occurrence of a correlation this high if there were no relation between the variables.

with an anticipated cost overrun of 36 per cent.)

2. Level of Effort Expended on the Problem

Level of effort is measured in terms of the total number of technical man-hours expended in proposal preparation. The results for the two problems (Table II) agree remarkably well in spite of the many differences between the problems and among the problem-solving groups. Technical quality appears to be moderately related to level of effort expended. There may be two opposing factors influencing this relation, and resulting in a U-shaped curve for level of effort. Among the more competent firms level of effort may have a strong positive relation

TABLE II

RELATION OF LEVEL OF EFFORT TO TECHNICAL QUALITY

| Problem | No. of labs | Median effort | Range of effort | Corre-lation | p |
|---|---|---|---|---|---|
| A | 9 | 70 | 14-200 | .31 | .15 |
| B | 10 | 565 | 100-1440 | .33 | .07 |

to technical quality while among less competent firms some may attempt to substitute energy for competence and thus attenuate the relation. Table II-A shows that for proposals

TABLE II-A

RELATION OF LEVEL OF EFFORT TO TECHNICAL QUALITY OF PROPOSALS DIVIDED INTO UPPER AND LOWER HALVES OF THE RANKING

| Problem | Technical Ranking of Proposal | No. of labs | Correlation | p |
|---|---|---|---|---|
| A | upper half | 5 | .60 | .12 |
| | lower half | 4 | -.67 | .17 |
| B | upper half | 5 | .40 | .24 |
| | lower half | 6 | .07 | .50 |
| A&B | upper half | 10 | .57 | .02 |
| | lower half | 10 | -.14 | .33 |

in the upper half of the ranking, there is a strong positive relation between level of effort and technical quality; for those in the lower half there is an inverse relation or none at all.

3. Educational Level of Proposal Team

Lacking any good measure of technical competence of the proposal team members, we decided to rank the mean level of educational attainment. Researchers were assigned scores according to the following scale:

0 Non-technical degree (e.g. business administration)
0 No college degree but engineering job classification
1 No college degree but engineering job classification plus five years experience
2 B.S. engineering or science
3 M.S. engineering or science
4 Ph. D. engineering or science

A score was obtained for each proposal team by averaging the scores of the key members.

TABLE III

RELATION OF EDUCATIONAL LEVEL OF PERSONS PREPARING PROPOSAL TO TECHNICAL QUALITY

| Problem | No. of labs | Median level | Range of levels | Corre-lation | p |
|---|---|---|---|---|---|
| A | 9 | 2.0 | 0-2.5 | .04 | .50 |
| B | 12 | 1.58 | 0-2.5 | .10 | .32 |

The low correlations are due in part to the large number of tied scores resulting in a narrow dispersion.

4. Time Spent in Analytic Design

Each firm was asked, "How many man-hours were spent in analytic design of this system and in comparison of the various alternatives available in the several components of the system?"

TABLE IV

RELATION OF TIME SPENT IN ANALYTIC DESIGN TO TECHNICAL QUALITY

| Problem | No. of labs | Median time | Range of time | Corre-lation | p |
|---|---|---|---|---|---|
| A | 9 | 10.5 | 6-40 | -.29 | .18 |
| B | 12 | 315 | 50-1300 | .38 | .04 |

Table IV shows that time spent in analytic design appears to be a factor in technical quality, for Problem B at least. The inverse relation on Problem A is difficult to explain, but may

be due in part to the nature of the problem. From an analytic viewpoint, this was a much simpler problem than the second. It involved selecting the proper instruments to meet the environmental and accuracy specifications, and bringing them together in a single-package design. In most cases instruments were already available which would perform the job and the only analytic design necessary was that required to adapt an available instrument to the specified mission. The negative correlation might indicate that more homework was required on the part of the less experienced firms to arrive at a (less satisfactory) solution. On the second problem, analytic design was a more important component of the solution process, hence the higher correlation. Mean per cent of total proposal effort spent in analytic design on Problem A was 25.3 per cent, on Problem B, 47.8 per cent.

Yet another factor may have contributed to the negative correlation on Problem A. The laboratory ranked highest had just completed a rather extensive design effort on one of the components for another application. If the time spent in analytic design for this other application is counted in their total, the correlation becomes .03. This still indicates that analytic design effort was relatively unimportant in the solution of this problem but perhaps explains the negative value obtained on the original correlation.

5. <u>Time Spent in Literature Search</u>

No correlation is found between time spent in literature search and technical quality for either problem (Table V).

These results would lead one to conclude that literature search is not a good source of information for solving problems

TABLE V

RELATION OF TIME SPENT IN LITERATURE SEARCH TO TECHNICAL QUALITY

| Problem | No. of labs | Median time | Range of time | Correlation | p |
|---|---|---|---|---|---|
| A | 9 | 8 | 0-40 | .18 | .31 |
| B | 12 | 38 | 0-150 | -.05 | .41 |

of this sort. It should be made clear, however, that the proposal teams were asked to include only that literature search conducted specifically to assist them in solving the problem. Literature search is also conducted on a continuing basis to maintain a current fund of knowledge in a particular discipline. It is conceivable that the latter would show a higher correlation with technical quality, provided it could be measured properly.

6. Team Size

Team size is defined as the number of technical employees on the proposal team. Although it might be postulated that a larger team would include a greater range of competences, team size apparently bears little relation to technical quality on either problem (Table VI).

TABLE VI

RELATION OF TEAM SIZE TO TECHNICAL QUALITY

| Problem | No. of labs | Median size | Range of size | Correlation | p |
|---|---|---|---|---|---|
| A | 9 | 2 | 1-3 | -.06 | .46 |
| B | 12 | 7 | 3-20 | .08 | .36 |

7. Laboratory Size

Total number of employees at the local establishment is used as the measure of laboratory size. In general, the larger establishments tend to allocate more effort to the proposal preparation ($T_{72}$[2]= .40 for Problem A; .58 for Problem B) and to submit a higher bid price ($T_{76}$= .35 for Problem A; .51 for Problem B). The correlations shown in Table VII are not high enough to justify any firm conclusions about the relationship to technical quality.

TABLE VII

RELATION OF LABORATORY SIZE TO TECHNICAL QUALITY

| Problem | No. of labs | Median Size | Range of Size | Correlation | p |
|---|---|---|---|---|---|
| A | 9 | 60 | 22-2000 | .25 | .20 |
| B | 12 | 1600 | 115-15,000 | .29 | .09 |

8. Number of Technical Personnel

Technical personnel refers to the number of engineers and scientists in the laboratory. This includes both graduate

[2]The symbol T stands for the Kendall tau coefficient; $T_{72}$ is the correlation between variable 7 and variable 2 as listed in Table XI.

engineers and scientists and nongraduate engineers who are in an exempt job classification (as defined by the Fair Labor Standards Act). One might expect the size of technical work force to be one of the most important resources for proposal preparation, and indeed it is.

TABLE VIII

RELATION OF NUMBER OF TECHNICAL PERSONNEL TO TECHNICAL QUALITY

| Problem | No. of labs | Median number | Range of number | Corre-lation | p |
|---|---|---|---|---|---|
| A | 9 | 25 | 1-750 | .39 | .09 |
| B | 12 | 550 | 10-2000 | .41 | .03 |

Technical quality is more strongly related to size of technical work force than to laboratory size. The correlation between laboratory size and technical quality is reduced to non-significance when the effect of size of technical work force is partialed out, ($T_{70.8}$= .03 for Problem A; -.10 for Problem B).

9. Time Spent with Laboratory Specialists

An important source of expertise is the use of laboratory specialists who are not on the proposal team but who are available to them for consultation. Table IX shows that this is the strongest contributor to success of the three sources of expertise investigated.

TABLE IX

RELATION OF TIME SPENT WITH LABORATORY SPECIALISTS TO TECHNICAL QUALITY

| Problem | No. of labs | Median Time | Range of time | Corre-lation | p |
|---|---|---|---|---|---|
| A | 9 | 1 | 0-20 | .37 | .13 |
| B | 12 | 45 | 0-200 | .55 | .01 |

10. Time Spent with Outside Consultants

Outside consultants were defined to the respondents as anyone not in the employ of the laboratory who made a technical contribution to the solution on any basis, paid or unpaid, formal or informal. Most of the consultation was obtained on an unpaid informal basis, some of it from potential vendors.

TABLE X

RELATION OF TIME SPENT WITH OUTSIDE CONSULTANTS TO TECHNICAL QUALITY

| Problem | No. of labs | Median Time | Range of time | Corre-lation | p |
|---|---|---|---|---|---|
| A | 9 | 0 | 0-25 | -.11 | .42 |
| B | 12 | 17.5 | 0-100 | -.29 | .09 |

The use of outside consultants did not prove to be of direct benefit in solving either of the two problems. Time spent with outside consultants is inversely related to the percentage of technical personnel in the company (T= -.52 for Problem A; -.59 for Problem B.) Percentage of technical personnel may be considered an index of relative orientation toward research or manufacturing. The results thus would indicate that the more production-oriented establishments rely more heavily upon outside technical consultation in preparing R & D proposals.

TABLE XI

SUMMARY OF INTERCORRELATIONS

| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0. | Technical Quality | | .11 | .31 | .04 | -.29 | .18 | -.06 | .25 | .39 | .37 | -.11 |
| 1. | Cost | .29 | | .03 | -.22 | .06 | .06 | .31 | .39 | 0 | .49 | .04 |
| 2. | Level of Effort | .33 | .22 | | .45 | .06 | .21 | .35 | .40 | .25 | -.12 | .52 |
| 3. | Educational Level | .10 | .10 | .54 | | -.04 | -.19 | .30 | .23 | .15 | -.52 | .20 |
| 4. | Time in Analytic Design | .38 | .18 | .51 | .19 | | .15 | -.20 | 0 | -.38 | -.35 | .49 |
| 5. | Time in Literature Search | -.05 | .11 | .15 | .14 | .38 | | -.20 | .15 | .06 | .19 | .37 |
| 6. | Team Size | .08 | .42 | .30 | .11 | .54 | .31 | | .35 | .31 | .03 | .17 |
| 7. | Laboratory Size | .29 | .58 | .42 | .13 | .29 | -.08 | .51 | | .64 | .28 | 0 |
| 8. | No. of Technical Personnel | .41 | .45 | .53 | .32 | .30 | -.08 | .39 | .82 | | .37 | -.40 |
| 9. | Time with Laboratory Specialists | .55 | .09 | .11 | .06 | .52 | -.02 | .27 | .18 | .18 | | -.16 |
| 10. | Time with Outside Consultants | -.29 | -.08 | -.10 | 0 | .21 | .42 | .26 | -.08 | -.14 | -.02 | |

* Intercorrelations for Problem A lie above the diagonal, those for Problem B below. For Problem A, $p < 0.10$ when $T \geq .39$, $p < 0.05$ when $T \geq .47$, for Problem B, $p < 0.10$ when $T \geq .26$, $p < .05$ when $T \geq .37$.

<u>Number of Alternative Approaches Considered</u>

To permit further analysis, Problems A and B were divided into four sub-problems and a comparison was made of the problem-solving processes leading to a laboratory's two best and two worst solutions among the sub-problems. These comparisons make it possible to assess one more variable: the number of alternative approaches considered in solving each sub-problem. When tested statistically, this proved to be a significant factor ($p=.02$) influencing success in the solution of the sub-problems. More extended analysis of the role of prior experience and of problem-solving tactics is presented in another report (Allen and Marquis, 1963b).

## CONCLUSIONS

In two proposal competitions for government R & D contract, ten characteristics of the proposal effort have been related to evaluated technical quality of the proposal. Results show that:

1. Technical quality is unrelated to the size of the proposal preparation team.

2. Technical quality is positively related to the size of the laboratory and especially to the total number of engineers and scientists in the laboratory.

3. Total man-hours of technical effort in proposal preparation is positively correlated with technical quality.

4. Time spent consulting specialists in the laboratory contributes definitely to technical quality, but time spent con-

sulting outside the laboratory shows no (or a negative) relation.

5. On the problem calling for a great deal of analytic design (Problem B), the time spent in analytic design was positively related (T=.38) to technical quality. On Problem A, which required little analytic design, the relation was negative (T=-.29).

6. Time spent in literature search was unrelated to technical quality.

These results are based on a very small sample of research activities and should be interpreted only as demonstrating the feasibility and potential usefulness of a new research design for the comparative study of factors in research success.

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