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THE MANAGEMENT OF DOD LASER RESEARCH CONTRACTS

William A. Davis, Jr.+ and Edward B. Roberts*

September 1967 #286-67

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INTRODUCTION

In recent years the impetus of government objectives and programs has been a major factor in the emergence of science and technology as a "critical activity" of private institutions. The "research revolution" of the past decade has in large measure been nourished and channeled by national space and defense programs. The largest single source of Federal R&D expenditure is the Department of Defense (DOD). Based on DOD budgets for R&D during the past four to five years, about one-third of the total national R&D effort is controlled by this agency.

In view of the major R&D role of the Federal Government, and of DOD in particular, it is relevant to raise the question of how productive this R&D is and how effectively it is being managed. The widely accepted necessity of security-related R&D and its shroud of secrecy have led to relatively little tendency for the general public to question this facet of public expenditure. However, in the past several years, Federal agencies have become increasingly interested in how efficiently they are conducting R&D. A notable example of this is the study effort going on in the Alfred P. Sloan School of Management at the Massachusetts Institute of Technology started in the spring of 1962 with financial support from the National Aeronautics and Space Administration (NASA). The broad objectives of this study

are "...understanding and improving the effectiveness of R&D activities and the utilization of science and technology in the general welfare."[1] This program of "research on research" has been concentrated on the problems of organizing and managing large-scale technology-based enterprises.

The objective of the study described in this paper was to investigate the effectiveness of DOD Research and Exploratory Development, two formal categories of DOD R&D, based on a small sample of contracted effort in a selected technology. The technology chosen was lasers, an area of considerable current activity and well documented as a field of military research. The study focuses on the performance of contractors, but the influence of government contract monitors and contracting agencies is also considered.

Despite the difficulties of meaningfully analyzing and assessing Research and Exploratory Development activities their long range importance to national defense demands a continuing effort to devise analytical methods of gauging their progress and improving their effectiveness. As most defense R&D is performed by contractors the factors affecting contractor performance and the character of government-industry relations at all levels are particularly relevant to the question of effectiveness.

The principal questions addressed in this study are: (1) How did the research projects get started? (2) How were they executed and

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[1] Annual Report, Research Program on the Management of Science and Technology 1964-65. Alfred P. Sloan School of Management. Cambridge, Massachusetts: Massachusetts Institute of Technology.

monitored? and (3) What were the results? An effort is made to depict the DOD procurement process, or scheme for "buying" research, as it actually exists and operates at the working level of defense agencies. Using a "representative" sample of contracts, the process is typified, a profile of the government contract monitor is drawn, a cross section of contractors is described and evaluated, and the "end product" is assessed.

Based on personal experiences with government contracted R&D, the following hypotheses were tested in the study. They are stated in such a manner as to permit the use of one-tailed probability levels for hypothesis testing.

1. Better performance is achieved on larger dollar volume contracts.
2. The larger contractors perform better than small contractors.
3. Oriented research is more successful than non-oriented research.
4. The higher the potential for large scale follow-on contracts, the better will be the contractor performance.
5. Higher educated contractor investigators will perform laser R&D more effectively.
6. The greater the related experience of the contractor, the better the contract performance.
7. A contractor's overall past performance on other R&D contracts will correlate with his performance on the laser R&D contracts studied in the sample.
8. The higher the educational level of the contract monitor, the higher the contractor performance.
9. The greater the experience of the contract monitor, the higher the contractor performance.

10. Close monitoring of the contract leads to better contractor performance.

11. Laser contracts are generally awarded as a result of single-source procurements.

12. Laser research tasks are seldom initiated in response to a formal military requirement.

METHOD

A random sample of 30 completed laser contracts, from a documented population of about 300 contracts, ranging in dollar amount from $3000 to $550,000 was selected for study. The sample contracts were representative of the total population with respect to the range of dollar amounts, the three military services, the various types of contractors, and the relevant categories of Research and Development. Data on the sample contracts were collected principally from in-depth, semi-structured interviews with the contract monitors. Additional data were obtained from the contractors via questionnaires. Past performance records of the sample contractors were obtained from Air Force files for comparison purposes.

The method chosen for evaluating the performance of the laser contracts was an assessment by the contract monitor of technical, schedule, and cost performance. Technical performance was evaluated on a 5-point scale and schedule and cost performance were evaluated in terms of percent slippage or overrun. In addition, an evaluation of the difficulty of the research objectives was performed by the contract monitor, using a 5-point interval scale. As the monitors' ratings are

an important part of the research, it should be noted that there is probably a certain amount of unavoidable bias in these ratings.

RESULTS

A number of general observations resulted from the interviews with contract monitors. (1) There is no uniform system or commonly accepted body of principles for selecting Research and Exploratory Development tasks within the services. (2) Of the two categories of research, Exploratory Development (the more oriented research) and Research (more towards basic research), the oriented work is contracted on the basis of greater initiative on the part of the contracting agency. On the other hand, non-oriented research is characterized by greater contractor initiative, unsolicited proposals, and broader work statements. (3) The performance of laser research contractors, as seen by the contract monitors, is relatively low. In fact, despite the mounting enthusiasm within the services concerning military applications of lasers, the average level of laser contractor performance has been seen as less effective than for other technical fields. This may be explained in part by the difficulties inherent in this new advancing technology.

Observations also indicate that the more successful government organizations in the laser R&D field have several characteristics in common.

1. They had significant in-house competence, and they did substantial preparatory work before awarding outside contracts.

2. They were conservative in that they leaned toward achieving modest improvements rather than quantum jumps in technology.

3. They were cautious and skeptical in their approach to industry, refraining from "buying" unsupported proposals and "jumping on bandwagons" before thorough investigations were conducted.

4. They exhibited pride in their performance record and reputation for achievement.

Although these general observations treat important aspects of DOD research management, they have been largely subjective in nature. In the next section more objective analyses of the data gathered will be presented concerning the nature of the work, the nature of the contract, the nature of contract monitoring, and the nature of the contractor. The focus of the findings described, as shown in Figure 1 below, is the relationship between laser research performance and the numerous factors investigated.

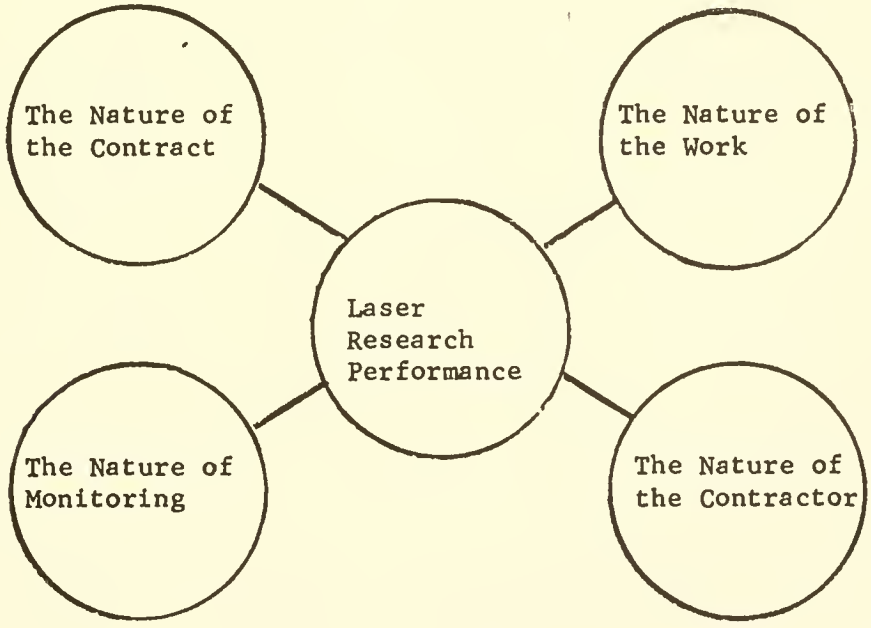

Figure 1. Organization of the Research Findings

Each of these four general areas of influences on the laser research studied is in turn subdivided into a number of specific features. For example, findings relating to four characterizations of the nature of work are reported: the degree of end-object orientation; the potential follow-on business; hardware versus non-hardware results; and technical difficulty of the work. For each of these characteristics, statistical tests have been used to attempt to find relationships with the variables of interest.

The statistical relationships reported will be represented by a figure in parentheses at the end of a statistically validated statement. The figure represents the number of times the reported relationship could have occurred by chance. For example, if the authors found that oriented research correlates significantly with higher performance (.002), this means that the two variables, oriented research and high performance, are strongly correlated and that the strength of the relationship observed could have occurred by chance in only 2 out of 1000 cases.[2]

The Nature of the Work

It was found that projects oriented toward specific end objectives rather than non-oriented research studies received higher performance ratings (.002) and that non-oriented research was rated relatively low in general. The finding that oriented research results in higher performance than non-oriented research is in general agreement with the findings of Project Hindsight.[3]

[2]Sidney Siegel, Nonparametric Statistics for the Behavioral Sciences. New York: McGraw-Hill Book Company, Inc., 1956.

[3]C.W. Sherwin and R.S. Isenson, First Interim Report of Project Hindsight (Summary). Washington, D.C.: Office of the Director of Defense Research and Engineering, October 13, 1966.

Since oriented work is typically involved with larger scale programs than non-oriented research, it is not surprising that the dollar amounts of the contracts in this area are greater and that this work generally goes to experienced contractors having large established laser teams.

The perceived potential of laser contracts in terms of the likelihood that they will develop into large dollar volume programs was positively related to performance (.073). Therefore perceived potential of projects serves as incentive for high performance. Contractors with large potential programs received about twice as many supplements. Contractors who receive these large potential contracts generally have a good reputation for innovation and contribution to laser technology, and they have large established laser teams.

Contracts requiring the delivery of hardware do not necessarily result in better performance than others. But if the delivered hardware meets specifications, then they are evaluated as high performance contractors. Contracts with good hardware are associated with contractors rated high in reputation for innovation and performance and in attitude toward performance.

The technical difficulty of the contract objectives did not correlate directly with performance. However, difficulty correlated positively with the educational level of the contract monitor, which in turn correlates negatively with performance. In other words, the more difficult contracts are associated with higher educational level monitors, and these monitors are generally associated with low performance contracts. This indirectly reflects the fact that Research work (which

is generally more abstract and difficult than Exploratory Development work) does not score as highly in performance. This may, however, mean that the higher educational level monitors, generally associated with Research, merely impose higher standards of performance.

The Nature of the Contract

Contract dollar amount is not significantly related to performance, but there is a trend for larger awards to have higher performance. (.209). Dollar amount is indirectly related to performance through size of laser team and educational level of monitor. The former is a positive relationship, indicating that the large contracts are awarded to contractors with large established teams. The latter is a negative relationship, which points to the fact that the larger laser contracts are not usually monitored by PhD level monitors.

Detail of the scope of the work does not relate directly to performance, although it does relate positively to contract dollar amount. The relation between contract dollar amount and performance, however, is not strong enough to infer any more than a tenuous relationship between detail of the scope of the work and performance.

Competitively awarded contracts do not necessarily result in higher performance. However, they go to experienced contractors with large laser teams, variables which do relate positively to performance.

The number of contract supplements awarded to a contractor is directly related to performance (.039). The probable cause for this relationship is that better performance leads to supplemental work assigned to the contract team. Contractors judged to

have a good reputation for total contribution and sharing information receive the highest number of supplements. As would be expected, those contracts which were deemed significant to DOD receive a relatively large number of supplements.

The Nature of the Contract Monitoring

The educational level of the contract monitor is negatively related to performance. It is also negatively related to the mode of monitoring; the PhD level monitors typically follow a more liberal mode of monitoring. This was explained before as due to the fact that the higher educated monitors handle more research-oriented jobs which in turn have poorer performance than the exploratory development contracts.

The experience of the contract monitor has a strange set of relationships to contractor performance. It has a weak direct correlation with performance. Indirectly, extensive monitor experience is tied to high technical performance through the number of contract supplements. However, the more experienced contract monitors are significantly associated with both cost overruns (.079) and schedule slippages (.087).

The mode of contract monitoring, classified as liberal, nominal, and close, is negatively correlated with communications in the form of frequency of meetings. This, too, is an anomalous result since monitors who see their mode of monitoring as close have fewer meetings with the contractor. The type and frequency of communications between monitor and contractor have no apparent effect on performance.

How can these monitoring relationships be interpreted? The data present a perplexing picture, but it is felt that this study did not probe deep enough to clarify the true role and influence of the contract monitor. From impressions gathered during the interviews, it is felt that

the most plausible explanation for these relationships is the fact that the more experienced monitors place a higher priority on technical performance than on cost and schedule performance. This explanation seems particularly applicable to these types of short duration, low dollar volume contracts where the principal objective is to advance the technology.

The Nature of the Contractor

Of the variables investigated concerning the nature of the contractor, four out of seven correlated positively with performance. The size of the contractor's laser team can be seen to have a number of positive correlations with other variables, including performance (0.22). The number of prior laser contracts correlates with size of laser team, as would be expected, and shows a trend with performance (.126). The attitude of the contractor toward technical performance. is related to four contractor strengths, including performance.

Past or general performance measurements were taken from Air Force files for the sample contractors and they were found to be unrelated to present laser performance. This suggests that past performance records should be used cautiously in the contractor selection process.

The educational level of the contractor team showed no significant relationship to performance. It seems noteworthy that this variable had neither a positive nor negative relationship to performance; by comparison monitor educational level correlates negatively with performance.

The contractor attitude variable is tied to performance through size of laser team and significance of work to DOD. Contractor attitude (as judged by the monitor) relates negatively to the educational level of the monitor, indicating that the PhD level monitor is more severe in his assessment of attitude. As was mentioned before, the PhD monitor seems to rank performance relatively low also.

The number of prior laser contracts is positively related to performance.

In summary it might be said that the related experience, attitude and reputation of the contractor are the things that count the most in performance. As the latter two factors are judgments of the monitor and subject to his biases, probably the most significant relationship is the objective finding that more extensive prior laser R&D contractual activity leads to better present laser R&D performance. The complexity of these findings is illustrated in Figure 2 on the next page, where the several contractor relationships are presented. The solid lines reflect the statistically significant relations, the plus signs indicating that the correlations were all in the positive direction.

RESULTS OF HYPOTHESES TESTING

The following section will be devoted to the results of the tests performed on the hypotheses stated at the beginning of the paper. There are a number of cross-currents and apparent conflicts which require thoughtful interpretive analysis. This is not an unusual or peculiar circumstance for a study of this nature. The complexity of the subject, the nature and diversity of the statistical tests used, and the relatively small sample size all combine to create an unavoidable residue of uncertainty. However, a number of statistically significant relationships and interesting trends do emerge from an analysis of the 12 hypotheses.

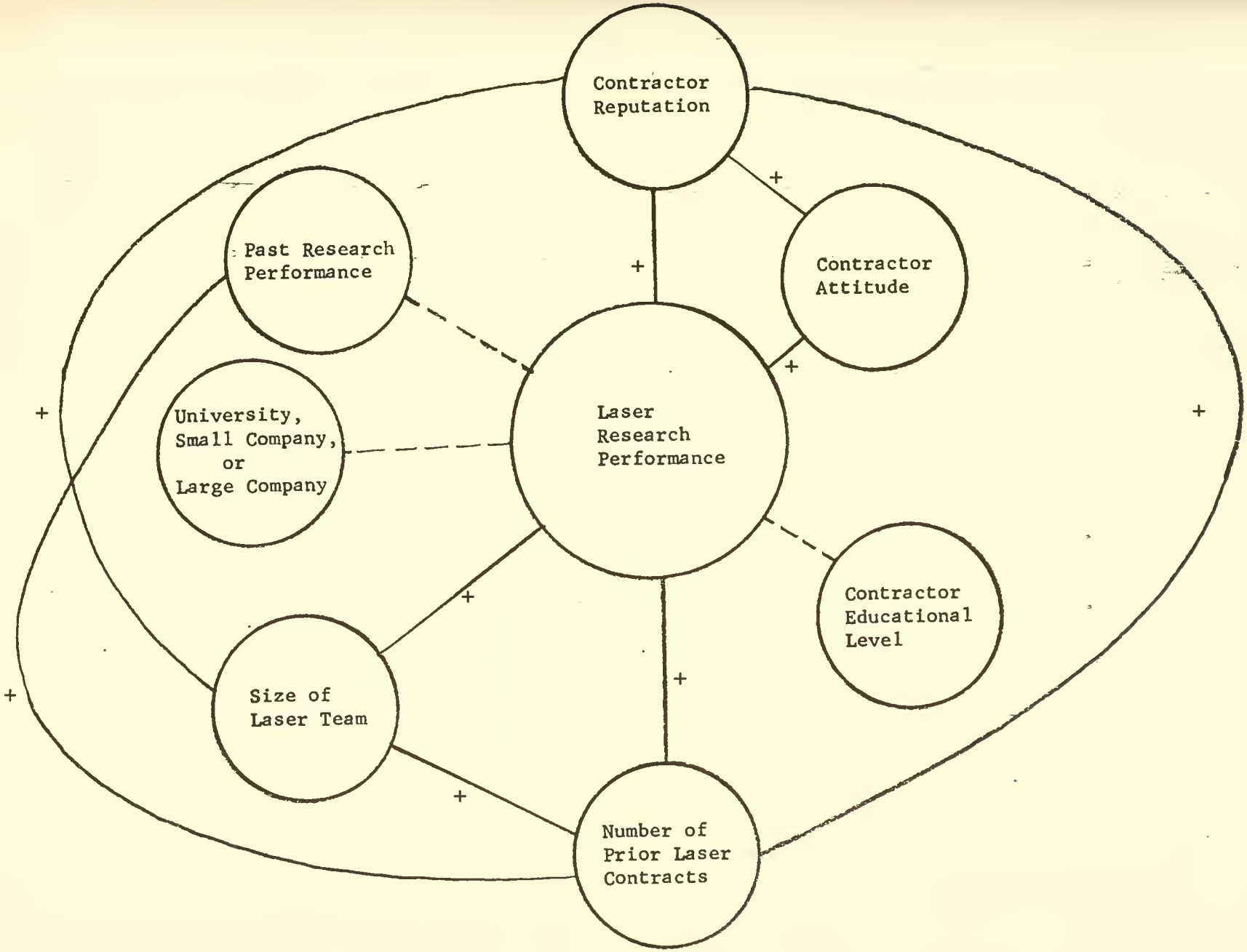

Figure 2. Performance and the Nature of the Contractor

The significance level selected as a basis for rejection of the hypotheses was a one-tail computed probability equal to or less than 0.10. Its meaning may be interpreted as a 90-percent level of confidence in the finding. In many cases, far greater confidence levels were achieved in the statistical computations. Confidence levels between 80 and 90 percent were accepted as evidence of a trend, though not strong enough to warrant confirmation of a hypothesis. The overall "box score" on the 12 study hypotheses as stated earlier was: 7 hypotheses were confirmed, the converse of the hypothesis was confirmed in one case, and no clear relationship could be found in 4 of the cases. The following brief comments summarize the statistical results for each hypothesis:

1. Better performance is achieved on larger dollar volume contracts. Both the Fisher Exact and Kendall Tau tests indicated positive trends at about an 88 percent confidence level. Thus, while the hypothesis is not strongly confirmed, it can be observed that contractors receiving large dollar amount laser contracts generally perform better than those receiving small contracts.

2. Larger contractors perform better than small contractors. This hypothesis was rejected by the Fisher Exact and Mann-Whitney tests. There was a high degree of randomness in the results of both tests.

3. Oriented research is more successful than non-oriented research. This hypothesis was confirmed with 99.9 percent confidence on the Mann-Whitney test. This was the strongest confirmation obtained. It can therefore confidently be stated that contractor performance on laser

research, as seen by the contract monitors, is better for those contracts aimed at an **end-application** than those devoted to non-oriented, basic research objectives.

4. The higher the potential for large scale follow-on contracts, the better will be the contractor performance. This hypothesis was confirmed with 94 percent confidence on the Fisher Exact test. Those contracts judged to have a big potential were also judged to have resulted in good performance.

5. Higher educated contractor investigators perform laser R&D more effectively. This hypothesis could not be supported by either the Fisher Exact or Kendall Tau test.

6. The greater the related experience of the contractor, the better the contract performance. This hypothesis was strongly supported at the 99 percent confidence level by the Mann-Whitney test.

7. A contractor's overall past performance on other R&D contracts will correlate with his performance on the laser R&D contracts studied in the sample. This hypothesis could not be supported by the Kendall Tau test. There appears to be no relation between general past R&D performance and specific laser R&D current performance.

8. The higher the educational level of the contract monitor, the better the contractor performance. This hypothesis was rejected with 98 percent confidence on the Kendall Tau test. In fact the converse of the hypothesized relationship was confirmed, meaning that the higher educated monitors were associated with the lower-rated contractor performances.

9. The greater the experience of the contract monitor, the higher the contractor's technical performance. This hypothesis was supported with 95 percent confidence on the Fisher Exact test.

10. Close monitoring of the contract leads to better contractor performance. This hypothesis was neither supported nor rejected by either the Fisher Exact or Kendall Tau test.

11. Laser contracts are generally awarded as a result of single-source procurements. This hypothesis was supported on the basis of the fact that about 68 percent of the sample contracts were awarded as a result of single-source negotiations, only 32 percent being issued after formal competitions were conducted.

12. Laser research tasks are seldom initiated in response to a formal military requirement. This hypothesis was confirmed on the basis of the finding that about 96 percent of the research tasks were initiated without an explicit military requirement.

DISCUSSION

Research Versus Exploratory Development Performance

It is clear that the results of this study point particularly to greater contract monitor satisfaction with laser Exploratory Development results than with laser Research results. No doubt part of the explanation lies in the fact that the results of Exploratory Development work are more visible and easier to measure. It might be further reasoned, with some support from the data of this study, that Exploratory Development is simply easier to perform than Research. By their very na-

ture, Research tasks involve higher risk objectives. But these reasons, it is believed, fall short of getting at the heart of the problem.

Research contracts are almost always let as a result of an unsolicited proposal. They are generally small dollar volume contracts, written with broad technical requirements and monitored in a liberal, "hands off" manner. The impressions gathered from the interviews indicated that there is no strong incentive for the contractor to perform well. In fact, a case might be built that a disincentive exists in the form of the prospect of continuing research through contract supplements on the same objectives. The data show that Research contracts are more frequently supplemented than Exploratory Development contracts. There appeared to be relatively little commitment to the research goals on the part of the Research contract monitors. On the whole, they did not seem to identify with the research effort to the extent that Exploratory Development monitors did.

In the area of Exploratory Development, the contract objectives were frequently generated by the contracting agency. Competitive procurement was more often used to select the contractor. In many cases, a built-in economic incentive existed in the form of potential growth of the project into a large dollar volume development program. There was relatively strong contract monitor commitment to the goals of the contract. It is not unreasonable to speculate that some of their greater generosity in evaluating contractors derived from the shared responsibility in defining objectives. In any event, this area of work was found to be marked by a higher degree of desire and motivation for good contractor performance on the part of the contract moni-

tors. Within the area of Exploratory Development, there was an apparent correlation between conservatism of technical goals and performance. The higher risk type of research contracts were generally evaluated more severely.

The foregoing comments apply closely to the classifications of oriented and non-oriented research which correspond to Exploratory Development and Research, respectively. With very few exceptions these two classifications are perfectly correlated.

These observations on the contrasting flavor of Research and Exploratory Development are admittedly vague and inconclusive. It is a formidable challenge to even describe the existing picture of these two elements of R&D, and a far more imposing task to identify any keys to improvement. It is difficult to escape the conclusion, however, that laser Research could be infused with greater zeal for achievement. Ultimately, the contract monitors who decry the performance of Research contractors must assume the burden of improvement in the selection, monitoring, motivation, and evaluative processes.

General R&D Performance Versus Laser Performance

The fact that the mean laser performance was less than the mean performance of the same contractors on prior Air Force R&D contracts may be attributed to a number of factors. It might be reasoned that performance on laser contracts is lower because it is a relatively new technology. Or, the reasons might be connected with the conditions under which the monitors made the ratings. In this study, they were anony-

mously contributing to an unofficial survey, and they were urged to be frank and objective. In making the Air Force ratings, they were preparing official signed records for Air Force files, which are widely distributed and freely accessible. It may be that the more official nature of the Air Force system was a strong deterrent to giving low ratings.

The study also indicated that the larger laser contracts were awarded to companies with the poorer record of past performance and that smaller contracts go to contractors with higher past performance. However, once the laser contracts are awarded, the contract performance is roughly proportional to the dollar amount of the contract.

It is interesting to note, concerning the split between universities, small companies, and large companies on general and laser performance, that universities range from the highest general R&D performers to the lowest laser performers. Small companies are only slightly under universities in general performance and highest in laser performance. Large companies are the lowest in general performance and in between in laser performance.

The relatively poor laser performance of universities reflects the generally low level of performance in research, or non-oriented work. The fact that universities score highest in general performance which is also predominately in the Research category, further suggests that laser research represents an atypical situation. It would seem that the comments made in the preceding section comparing Research unfavorably with Exploratory Development applies particularly to the laser field.

Influence of the Contracting Source on Laser Performance

It was noted that there is considerable difference in the degree of "success" achieved by various government offices and laboratories in their contracted laser research. It was further observed that the more successful contracting sources have in-house technical competence and generally pursue conservative contracting policies. This is an impression gathered from a small sample and it may be an over-generalization. However, the evidence was strong in the few offices visited, and it is a trend which is consistent with a number of other studies.

One other facet of the above observations is that success seems to breed success. Those sources which establish relatively high standards and a reputation for superior work generally attract the higher performance contractors. In a typical situation, a competent contractor research organization will seek out a competent government source to whom to present unsolicited ideas and proposals. The contractor will, in turn, receive a more critical and professional evaluation and feedback on his ideas. The weaker proposals which get funded are likely to be with the offices with less technical competence and lower standards. Whatever incidence of contractor misrepresentation and deception exists, and it is believed to be small, is likely to be concentrated in the less experienced government offices.

As far as individual contract monitors are concerned, the statistical evidence showed a positive correlation between performance and years of experience and a negative correlation between performance and educational level. However, the experienced contract monitors may be asso-

ciated with high performance not because of actual performance, but because they tend to rate their contractors higher. It is not known how to separate out these possible influences. On the apparnet anomaly with respect to education, this may be explained plausibly by the more severe performance ratings of PhD monitors on Research contracts and further by the hypothesized lower performance on Research (as contrasted with Development) contracts.

VARIABLES GROUPED ACCORDING TO PERFORMANCE

The variables used in the study cannot be rated on an absolute basis or in a rigid order of priority, but the natural "clustering" of the variables can be indicated. The following list presents those factors which relate positively to high performance on laser contracts (negative factors would be the converse):

Oriented research
Exploratory Development
Hardware delivered
Lower monitor educational level
More experienced contract monitors
More detailed scope of work
Good contractor reputation
Small number of contractor PhDs
Large number of contractor B.S.s and subprofessionals
High contract dollar amount
Companies rather than universities
Lower past performance in other fields
Close contract monitoring
More prior laser contracts
Larger laser teams
Work significant to DOD
More competitive procurement
Lower probability of continuation
Less difficult research objectives

Many of these positively associated factors drop out of any significant relationship when partial correlation analysis are performed.

MANAGEMENT IMPLICATIONS

Since Research, or non-oriented work, was discovered to be the weaker of the two categories of R&D studies, this is the area which merits the greatest management attention. Perhaps the most salient management implication here is the need for some reforms in the monitoring process. Generally, the number and diversity of Research contracts per monitor should be reduced to permit adequate surveillance. Beyond this there is an apparent need for more involvement in the programs by the monitors. This does not mean interference so much as it does expressed interest and concern for the outcome. Passivity in monitoring should be replaced by more active expression of expectation and desire for positive results. The need for heightened contractor incentive is evident; perhaps additional emphasis on recognition of excellence in performance could be instituted. A comprehensive record of R&D contractor performance evaluations could serve as a mechanism for establishment of a more widely known system of recognition of contractor achievement. Conceivably, official letters of commendation could be furnished to Research contractors based on a sustained record of high performance.

Laser performance is generally better in the area of Exploratory Development, or oriented research, than it is in non-oriented research, but improvements are obviously needed. The most critical management need is believed to be improved planning at the agency level. Exploratory Development tasks should be planned within the framework of "specific military problems" as specified by the R&D ASPRs. A

common management transgression is the formulation of contract tasks which are not clearly relatable to military problems. Often, the contract is on some idea or approach which was "bought" more on the basis of its scientific appeal or intriguing cleverness than on potential military application. There appears to be no substitute for pre-contract in-house applications studies, to establish, at least within broad boundaries, "what you are in the market for." Beyond this, a parallel in-house research effort is seen as a valuable adjunct to the contractor effort; a significant by-product of in-house competence is the ability to check out and use the products of contracted Exploratory Development work. The bulk of the planning for laser Exploratory Development must reside at the agency level; higher level coordination cannot correct for deficiencies in agency planning. It is probably a sound management practice to have one man in each affected government agency who is chiefly responsible for all laser planning for his agency; a staff of several knowledgeable technical personnel should be available to this central coordinator for reviewing proposed laser contracts in the context of a general plan or application area.

Several exogenous factors were identified by the contract monitors as serious management problems. The large amount of time and effort required to secure R&D procurement approval (especially the Determinations and Findings needed from the Service Assistant Secretary) was a universal complaint. The extent of laser coordination required by service and DOD-level review bodies was felt by many monitors to be an undue hardship which provided few benefits. These perennial pro-

blems of excessive procurement paper work and lead time were widely cited as sources of inefficiency. Problems associated with contract periods being out of phase with the budget cycle also concerned many monitors. All of these problems have management implications for the agency and higher level administrators. They are generally familiar and well-known problems for which quick and easy solutions cannot be presented here. (Suggestions for reducing several aspects of these problems have been proposed in an earlier paper by Roberts.[4]) The main point which should be emphasized is that the net value of all these constraints on the Research and Exploratory Development areas is open to question.

[4]Roberts, E.B., "Questioning the Cost-Effectiveness of the R&D Procurement Process", in M. Yovits, et al., editors, Research Program Effectiveness (New York: Gordon and Breach Publishers, Inc., 1966).

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