A CORRELATION OF R&D LABORATORY

PERFORMANCE WITH CRITICAL FUNCTIONS ANALYSIS

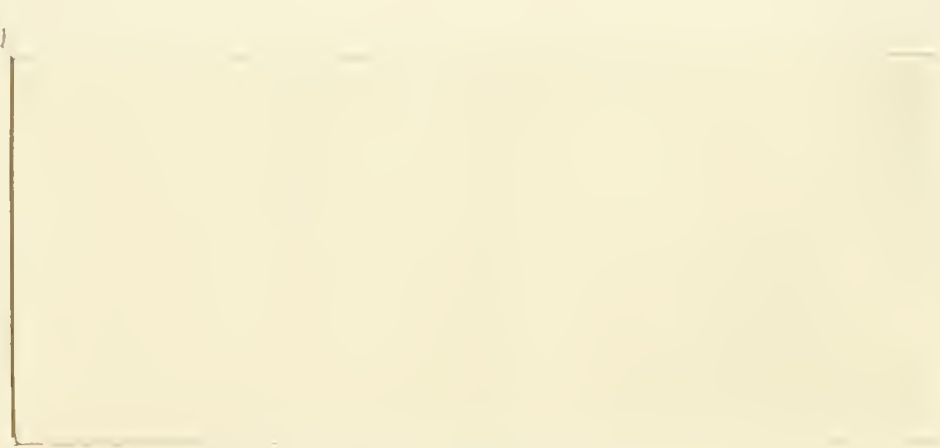Richard G. Rhoades,[1] Edward B. Roberts, [2]
and Alan R. Fusfeld [3]

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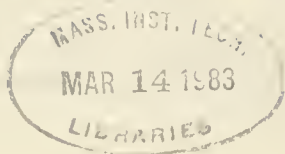and Alan R. Fusfeld [3]

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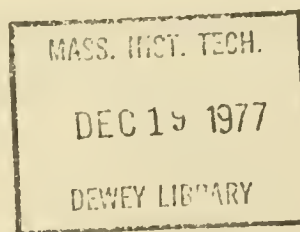
ABSTRACT

Five similar government R&D laboratories have been studied
using "Critical Functions Analysis" to determine the relative
fractions of their staffs performing one or more of seven critical
functions; a profile was developed for each laboratory. In order
to test the hypothesis that variations in these critical functions
profiles would be recognized by laboratory users, fifteen different
customers of these laboratories— weapons system project managers
and headquarters staff technology managers— were asked questions
designed to determine their perceptions of the relative performance
of the five laboratories.

Significant variations were found in role profiles among the
several laboratories; important variations were also identified in
customers' perceptions about laboratory performance. In general, the
three laboratories that had higher percentages of their professional
staff performing the critical functions also were rated higher in
performance by their customers. This difference was particularly
striking when an aggregate performance parameter, which summed the
numerical values of several performance-sensitive customer
questionnaire responses, was used. Customers were found to be
especially sensitive to the strength of the laboratories'
manufacturing/marketing gatekeeper functions.

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I. INTRODUCTION

The processes that occur within research and development organizations have been studied rather extensively over the past two decades, with many researchers focusing on a particular function performed by key person(s) in a successfully innovative organization. For example, Roberts and Wainer (1971) studied the key role played by the technical entrepreneur in recognizing and championing a new technical idea, product, or process. Marquis and Rubin (1966), on the other hand, chose to concentrate on the integrative and coordinative role played by the project manager. Allen (1970) has studied the critical part played by "gatekeepers", those individuals within the organization who collect and distribute information about changes in the internal and external technical environments. Others, notably Pelz and Andrews (1966), have documented the idea generating and problem solving functions of the creative scientist or engineer. Finally, Buddenhagen (1967) has identified the role of the "coach" or "sponsor" in providing guidance and development for less experienced personnel.

It can be argued that these referenced studies were often carried out within an organizational and technological environment such that focus on a single dominant role or critical function was appropriate. However, more usually, particularly when changes over

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time are considered, a mix of activities (and related critical functions) must be performed within the innovative research and development organization. Frohman (1974) and Fusfeld (1976) have described the innovation process as encompassing several common critical functions defined in Table 1.

Insert Table 1 Here

Pugh-Roberts Associates, Inc., a management consulting firm in Cambridge, Massachusetts, has developed a series of interrelated questionnaires that are designed to measure the number of professional staff members within an R&D organization who are performing these various critical functions. The approach used in the several questionnaires has been described by Frohman and Fusfeld in the previously cited references and it will not be repeated in detail here. In brief, each professional employee in the organization under study is queried to obtain that individual's assessment of his preferences, job requirements, and skills in performing the critical functions. Data are also obtained from several co-workers of each professional to determine their perceptions regarding the amount of time that professional devotes to performing the various critical functions. Correlation of the data from these two sources results in an inventory of the current and potential strengths within the organization for each critical function. In addition, data provided by the organizations' management regarding goals and objectives for the organization allow the relative balance or imbalance of critical function performance versus those goals and objectives to be assessed.

TABLE 1

CRITICAL FUNCTIONS DEFINITIONS

1. Problem Solver - develops, sets up, and runs experiments; solves technical problems that develop as a project progresses

2. Idea Generator - contributes to knowledge in technical field; finds opportunities for technical solutions to marketing, technical, or customer service problems

3. Technical Information Gatekeeper - keeps abreast of technical developments both inside and outside of the organization; serves as a source of technical information for colleagues

4. Marketing/Manufacturing Information Gatekeeper - maintains familiarity with existing and potential markets, whether outside customers or inside manufacturing divisions; communicates market information to R&D so that products or processes under development appropriately consider marketplace and manufacturing requirements

5. Entrepreneur - the real motivator behind a project; possesses the drive and determination to sell a new product to management and obtain resources to get the project started

6. Project Manager - coordinates, plans, and schedules work for a project; serves as the link between management and R&D who balances the company's goals with those of R&D

7. Coach - provides less experienced staff with credibility, support and guidance

II. RESEARCH APPROACH

The hypothesis to be tested in this research was that significant differences in performance among research and development organizations could be related to significant differences in their skill inventories (as determined by critical functions analysis). To test this hypothesis, one had to find research and development organizations with sufficiently similar responsibilities and functions, inventory skills of their staffs, and also obtain independent performance measurements for the same organizations. Differences in these attributes could then be examined for correlation and significance, and conclusions drawn.

It is suggested that such an experiment could be difficult to structure in the private sector due to the problem of finding several R&D organizations with similar external relationships, while, at the same time, finding a way to objectively measure their performance. Fortunately, it was fairly easy to find this situation in the federal government.

DESCRIPTION OF ORGANIZATIONS STUDIED

The organizations chosen for this study were five U.S. Department of Defense in-house laboratories. These five laboratories vary considerably in the size of their professional work force, as shown in Table 2, but are similar in internal organization design, and in their relationships with the outside world.

Insert Table 2 Here

TABLE 2

LABORATORY CHARACTERISTICS

LAB	% PROFESSIONALS	# OF PROFESSIONALS	# IN THIS STUDY	% PARTICIPATION
A	63	149	129	87
B	74	81	65	82
C	74	69	63	91
D	71	110	99	90
E	57	47	47	100
TOTALS	---	456	403	88

Each of the laboratories is responsible for work (predominantly applied research in nature) in a particular technology area; each of these areas encompasses the technology underlying a major component of a weapons system. Approximately one-half of each laboratory's multi-million dollar annual cash flow is devoted to in-house and contracted effort to advance technology in its area of responsibility to meet future U.S. defense needs. The "customers" for these R&D technology efforts are senior technical managers within the Defense Department (and, ultimately, Congress).

The other half of each laboratory's funds come from a second set of "customers", the managers of weapons systems under development or in production. For these customers, the laboratories provide research and development services. The laboratories studied had customer relationships with as many as eleven different weapons system managers.

Each laboratory is managed by a Director who is supported by a small administrative staff. Reporting to the Director are several supervisors, each of whom is responsible for the direction of a group of professional (and non-professional) employees in a functional area. When warranted, employees can be moved from one functional area to another. At any time, many tasks are underway in a laboratory, frequently involving more than one functional area. As a consequence, the laboratories operate primarily in a matrix management mode; designated project leaders have responsibility for the direction of individual research and development tasks within the laboratory. These project leaders might also be functional supervisors, but frequently

are not; they are usually senior professional personnel, however. In addition to the similarities described above, the relative fractions of junior and senior professional employees are approximately the same for each laboratory. As shown in Table 2, the ratio of professionals to total laboratory personnel does vary from laboratory to laboratory, reflecting primarily the specific demands of the technology area for technicians and other sub-professional personnel.

CUSTOMERS AND LABORATORY PERFORMANCE

The customers of the laboratories were chosen as the appropriate judges to provide perceptions on laboratory skills and performance. All the laboratories had four R&D technology customers in common, as well as at least seven of the eleven R&D services customers. The questionnaires developed by Pugh-Roberts Associates, with minor modifications to make the terminology consistent with the government laboratory environment, were used to determine the laboratory role profiles. A new questionnaire, entitled "Customer Perceptions Instrument", was designed and used to gather customer data. It consisted of eleven questions and was designed based on the following concepts.

First, the questionnaire was designed to focus in main on those laboratory attributes which could be related to the relative performance or lack of performance of one or more of the critical functions. For example, customers were asked, "How well does this laboratory understand the needs of your organization?" Laboratories receiving a high score on this question (i.e. that understood the customers' needs very

well) would be expected to exhibit relative strength in the manufacturing market/gatekeeper function. A total of five questions were designed based on this philosophy.

A second major area for focus concerned overall laboratory performance measures.

Four questions were used to explore laboratory innovativeness, to address the issue of usefulness and importance of the laboratory's output (or "products"), and to obtain a comparison of the laboratory with other research and development organizations.

Finally, two questions were designed to provide data for comparison with that obtained from the laboratory management teams on the status of their technology areas and the emphasis and focus of their professional staffs.

ANALYSIS OF RESULTS

Customer Perceptions

The responses received to the eleven questions of the Customer Perceptions Instrument indicate that the several customers of the laboratories did recognize significant differences between them. For example, the responses to the "understand your needs" question (Question 2) are given in detail in Table 3, with the customer sub-groupings varied. This variation was carried out for each question in

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Insert Table 3 Here

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order to investigate whether the two classes of customers ("R&D services" and "R&D technology") had significantly different perceptions. A second variation was accomplished to investigate the

TABLE 3

CUSTOMER RESPONSES TO QUESTION NUMBER TWO

"How well does this laboratory understand the needs of your organization?"

RESPONSES FOR LABORATORY

	A	B	C	D	E
All Customers (15)	3.90	4.73	3.82	3.62	2.75
In-Common Customers (8)	4.00	5.00	4.25	3.62	2.75
In-Common R&D					
Services Customers (7)	3.86	4.86	3.86	4.43	2.29

NOTES:
1. The responses for E are significantly different from those for B, with 99+ percent confidence.

2. The responses for E are significantly different from those for A and C, with 95+ percent confidence.

3. The responses for D are significantly different from those of B, with 95+ percent confidence.

4. Differences based on Aspin-Welch two-sided t-test.

5. Scores could range from 1 (good) to 7 (bad). Mean values are reported here.

possible effects of the asymmetry in customers among laboratories. Recalling from the rationale previously presented that responses to Question 2 were expected to reflect differences in laboratory marketing gatekeeper role performance, the data in Table 3 would lead us to anticipate with high confidence that laboratory E would have a higher percentage of market gatekeepers than laboratory B. With somewhat lower confidence we would predict E to have a higher percentage of market gatekeepers than A or C, and about the same number as D. Similarly, D is expected to have more market gatekeepers than does B.

As a second example, Question 4 was designed with the idea that differences would reflect the degree to which entrepreneurial role players were present. Table 4 presents the results for this question in the same format as was used in Table 3. Here the differences are not

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Insert Table 4 Here

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so consistently significant; about all we can expect is that laboratory E will have a somewhat higher percentage of entrepreneurs than do laboratories B or C. It may be that customers in responding to this question are sensitive to more than just entrepreneurial (the willingness to undertake unfunded effort) performance; for example, the quality of the effort performed may influence the response.

Four of the questions asked each customer can be regarded as different ways of asking the same question about the laboratories' overall performance in innovation; an aggregated approach to analyzing these responses was selected. A simple "effectiveness parameter" was

TABLE 4

RESPONSES TO QUESTION NUMBER 4

"Evaluate the responsiveness of this laboratory in conducting programs that are not funded by you to meet your needs."

| | RESPONSES FOR LABORATORY | | | | |
	A	B	C	D	E
All Customers (11)	4.67	5.50	5.00	4.00	3.50
In-Common Customers (7)	5.14	5.71	5.57	4.00	3.50

NOTES: 1. In this case, the "in-common customers" and the "in-common R&D services customers" are identical.

2. The responses for E are significantly different from those of B or C with 90+ or 95+ percent confidence.

3. Differences based on Aspin-Welch two-sided t-test.

4. Scores could range from 1 (good) to 7 (bad). Mean values are reported here.

devised to provide this aggregation, and was obtained by subtracting the (numerical) mean responses to the four questions from a constant. The constant used was the maximum value the aggregated responses could take on and was introduced to compensate for the choice of response scales, which would lead to "low effectiveness is good" results without this adjustment. Values of this effectiveness parameter are plotted in Figure 1 for several combinations of customers. The results are

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Insert Figure 1 Here

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consistent and show that, independent of the sub-grouping of customers that is selected, the parameter values for laboratories A, D and E are not significantly different. The same can be said for the values for laboratories B and C. However, the values for these two groupings of laboratories are significantly ($p \leq .01$) different, with the A-D-E grouping rated as considerably higher in effectiveness.

One additional result from the customer perceptions data is worth noting. Question 1 was identical to a question asked the laboratory management teams; the results from these two groups of respondents are given in Table 5. We observe no significant difference between the

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Insert Table 5 Here

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perceptions of customers and laboratory management for laboratories A, D and E concerning the status of their technology. (While not statistically significant, it is interesting to note that the managements of these three laboratories in general regarded their technology areas as less dynamic or less advancing than did their customers). However, in the case of laboratories B and C, the difference is strongly significant. These two laboratory management

FIGURE 1
LABORATORY EFFECTIVENESS PARAMETER COMPARISON
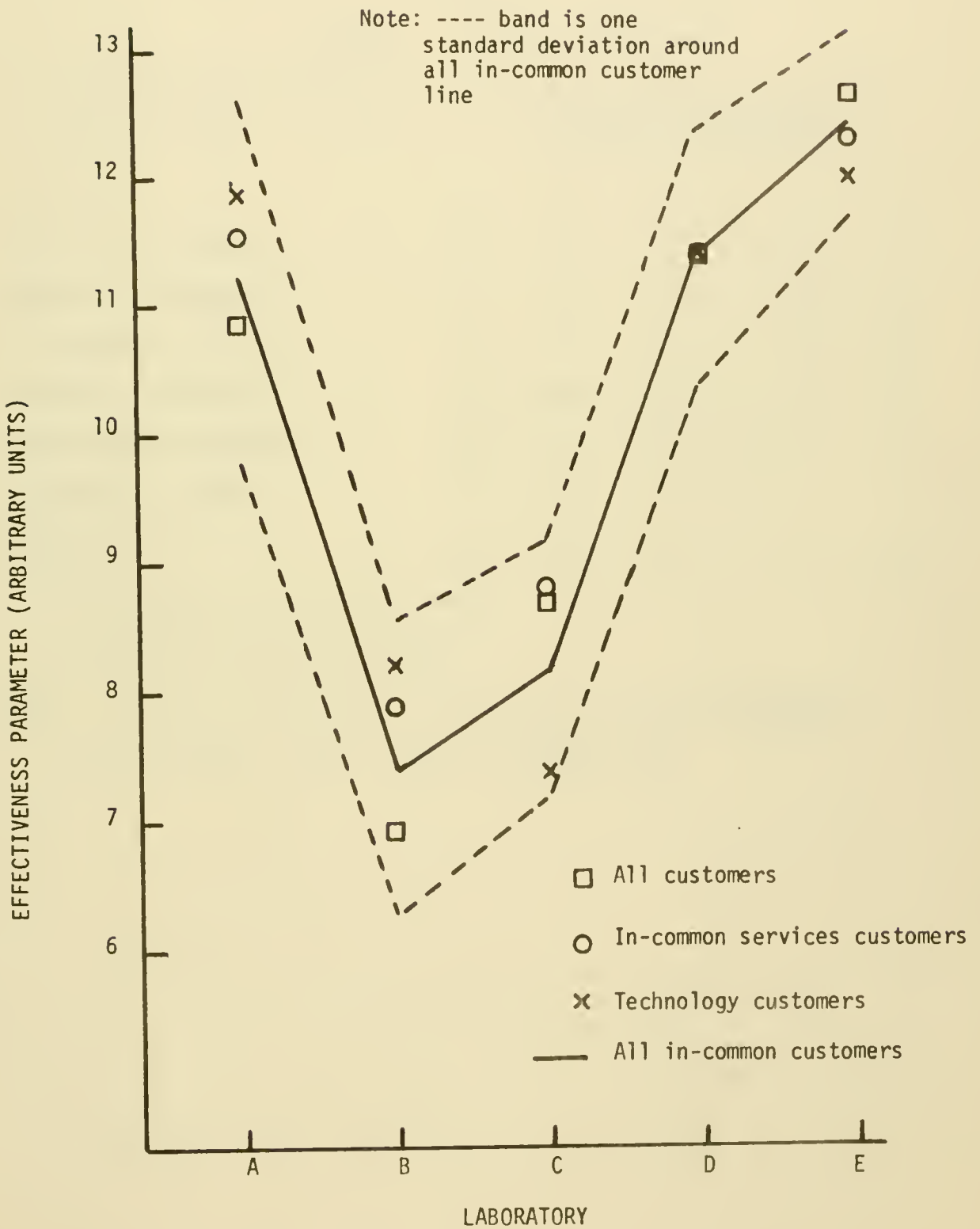
TABLE 5

RESPONSES TO QUESTION NUMBER ONE

"Describe the rate of change in the technological area in which this
laboratory works."   RESPONSES FOR LABORATORY

	A	B	C	D	E
Laboratory Management	4.79	4.50	5.50	5.16	3.71
(Number of Respondents)	(9)	(2)	(4)	(6)	(7)
All Customers (15)	5.38	2.43*	3.21*	5.55	3.87
In-Common Customers (11)	5.18	2.45*	3.09*	5.55	3.91
R&D Technology Customers (4)	5.00	2.25*	2.75*	6.25	3.50
In-Common R&D Service Customers (7)	5.56	2.50*	3.40*	5.14	4.00

*Significant at 99+ percent level

(Aspin-Welch two-sided t-test)

NOTE: The higher the score from 1 to 7, the more rapidly advancing
the technology. Mean values are reported here.

teams regarded their technology areas as considerably more dynamic and advancing than did their customers. A caveat regarding these results is appropriate, however; the number of laboratory management respondents for these two laboratories is small, even though the variance of these few responses is also small.

LABORATORY ROLE PROFILES

Inter-laboratory comparisons are shown in Figure 2. Note that

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Insert Figure 2 Here

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in general the "curves" for laboratories A, D and E lie above those for B and C. In particular, laboratory E shows a stronger marketing/ manufacturing gatekeeper function (twice the percentage) than laboratories B or C. These profiles were developed using a screening criterion of one standard deviation above the mean, following Swain (1971). That is, a professional was counted as performing a particular critical function if analysis of the several questionnaires showed that he performed it to a greater degree than (approximately) 85 percent of his peers. Profiles were also developed using two standard deviations above the mean and one-half standard deviation above the mean as screening criteria. The same trends (between laboratories) were observed as with the one standard deviation criterion shown here.

IV. CONCLUSIONS

The results of the preceding data analysis provide the basis for several conclusions. First, a significant correlation was found between differences in laboratory role profiles (as shown in Figure 2) and differences in customer perceptions about laboratory performance

FIGURE 2
ROLE PROFILES - INTER-LABORATORY COMPARISON
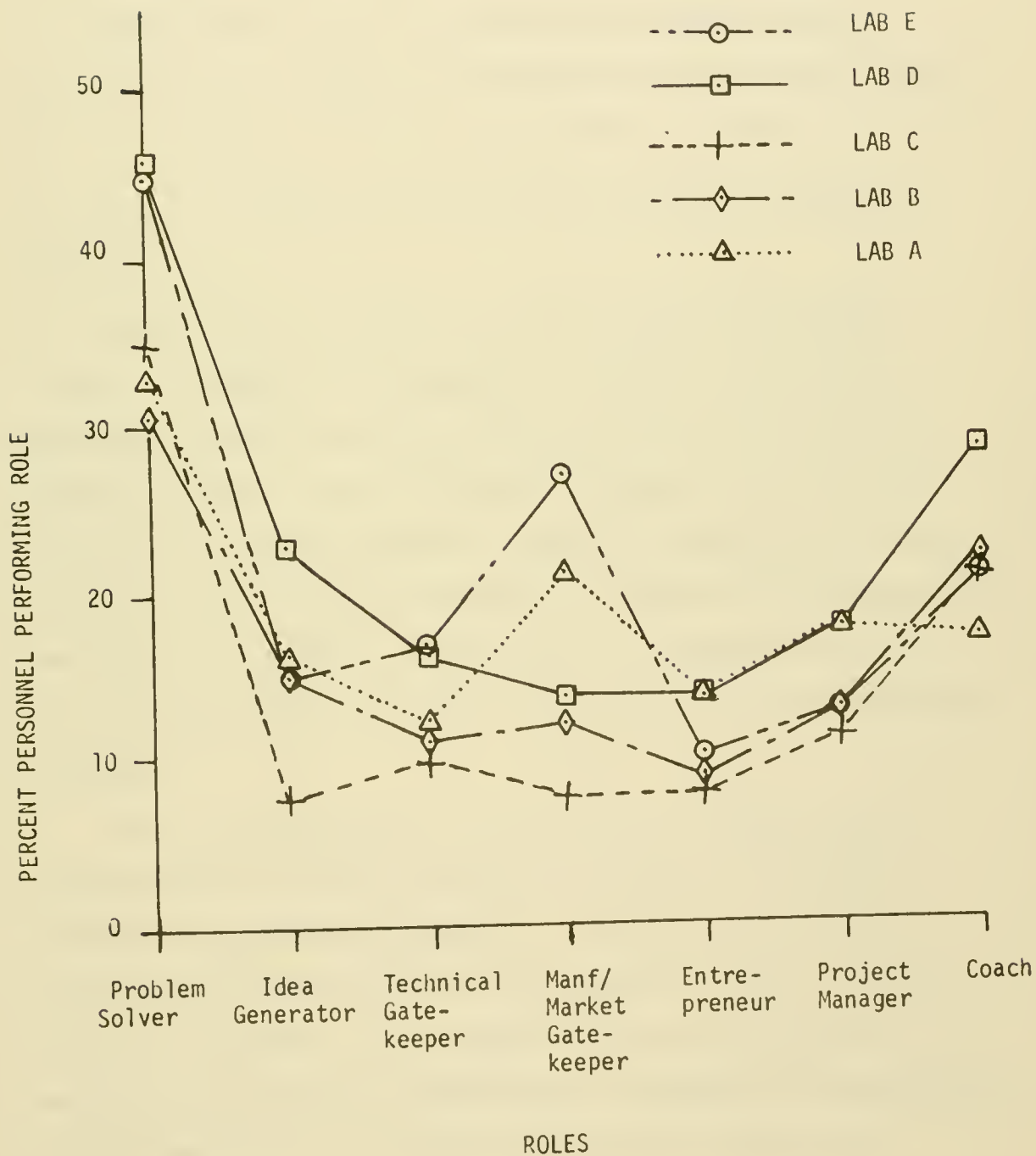
(Figure 1). Those laboratories that show consistently higher percentages of professionals performing each of the critical functions have significantly higher values of effectiveness, at least as measured by the simple effectiveness parameter devised for this study.

A significant correlation also was found between customer perceptions and the strength of the manufacturing/marketing gatekeeper role -- the higher the percentage of individuals performing the role, the better the customers perceived that the laboratory understood their needs.

Another facet of performance of the manufacturing/marketing function surfaced when the responses of customers and laboratory management to the (identical) question of status of the technology area were compared. Very significant differences were found between laboratory and customer perceptions about that status for those two laboratories which have low percentages of manufacturing/marketing performance; specifically, in these cases the customers felt that the technology area was much more slowly advancing than did laboratory management.

Two of the laboratories (A and D) work in technology areas in which advances are occurring rapidly (as perceived by both their customers and laboratory management). One might expect to find a significantly greater fraction of entrepreneurs in such a situation; such was in fact found. These laboratories had one and one-half to two times the percentage of professionals performing the entrepreneurial function compared with the laboratories working in more slowly

advancing areas.

The two subsets of laboratory customers— "R&D Technology" and R&D Services"— did not significantly vary in their perceptions concerning laboratory performance. In some cases, the statistical significance varied, but in no case did the trends change; in short, both classes of customers saw the laboratories in the same light.

In summary, there are significant correlations between differences in laboratory role profiles and customer perceptions concerning laboratory performance, as hypothesized. These results strongly suggest that if one uses critical functions analysis to determine staffing balance and needs, one can do so with assurance that the organization's customers are in fact sensitive to balances or imbalances in critical functions performers. The underlying assumption here is that customers are vital to the economic and professional well-being of innovative research and development organizations.

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