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Letters to the Editor

A SAMPLE SURVEY OF INDUSTRIAL OPERATIONS-RESEARCH ACTIVITIES II

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IN 1958 HOVEY AND WAGNER* reported on a survey of operations-research activities. It provided a snapshot of activities at that time. Since then the profession of operations research has grown. But growth is not the only change that has taken place. What trends are underway in organization and size of operations-research groups? What are the trends in the characteristics of the operations-research staff personnel? Are there changes in the areas of application?

To provide partial answers to these questions a second survey has been conducted. Mail questionnaires were sent to 168 companies. These were selected by cross-indexing *Fortune* "top 500" industrial corporations with firms listed in the 1964 *College Placement Annual* as seeking engineers and/or mathematicians. Companies ranged in size from less than 2,000 to more than 500,000 employees (median 15,000). This is the method used in the earlier survey. It did not provide a random sample but rather one biased in favor of the company being engaged in operations-research activities. 65 questionnaires were returned, of which 49 (or 75 per cent) were engaged in operations-research activities. All the statistics reported below pertain to the latter group of 49 companies. In certain instances answers were not given when the respondent believed these to be confidential. The number of companies included in any particular group of data will, in general, be somewhat less than 49.

OPERATIONS RESEARCH IN THE COMPANY ORGANIZATION

THE TREND now seems to be towards defining the philosophy of an operations-research program. Four points were made by many practitioners:

1. Operations research is an interdisciplinary science,
2. Operations research is problem-oriented,
3. Operations research is involved with implementation not just problem formulation and solution,
4. Operations research is a continuing effort not a 'one shot' project.

While considerable agreement may exist as to philosophy, there remains the problem of determining just what activities are to be included in a measurement. Even

* R. W. HOVEY AND H. M. WAGNER. "A Sample Survey of Industrial Operations Research Activities," *Opns. Res.* 6, 876-881 (1958).

with the differences in interpretation, we believe the following results to be meaningful.

Some idea of the change in the organization of the operations-research activities is obtained from Tables I and II. In 1958, 42.6% reported their operations-research staff to be organized as a separate activity. In 1964, 61.5% of the staff were so organized. Recognizing the difficulties of comparison, it does seem that

TABLE I^(a)
SIZE OF FULL-TIME OR STAFFS

Full-time OR staff	0	1-2	3-4	5-6	7-8	More than 8	Totals
Separate section	0 (0)	3 (3)	7 (6)	7 (5)	2 (0)	5 (9)	24 (23)
No separate section	4 (6)	5 (13)	2 (6)	0 (2)	0 (0)	4 (4)	15 (31)
Totals	4 (6)	8 (16)	9 (12)	7 (7)	2 (0)	9 (13)	39 (54)

^(a) Figures in parentheses are from the 1958 survey.

there is a trend toward organizing operations-research as a separate section. Will the trend continue?

OPERATIONS-RESEARCH PERSONNEL

Table III gives the past and anticipated growth of operations-research staffs for both surveys. A continuing steady rate of growth is apparent.

TABLE II^(a)
SIZE OF TOTAL OR STAFFS (INCLUDING PART-TIME STAFF)

Total OR staff	1-5	6-10	11-15	16-20	21-25	More than 25	Totals
Separate section	9 (8)	10 (6)	2 (1)	2 (3)	1 (0)	0 (5)	24 (23)
No separate section	9 (17)	1 (8)	1 (2)	1 (1)	0 (1)	3 (2)	15 (31)
Totals	18 (25)	11 (14)	3 (3)	3 (4)	1 (1)	3 (7)	39 (54)

^(a) Figures in parentheses are from the 1958 survey.

Information was obtained on the educational backgrounds of 464 operations-researchers in 37 companies as compared with 276 persons in the 1958 survey. These responses are summarized in Table IV. Of particular interest to the authors is the increased use of business and economics majors, particularly at the master's level. The increase in the number of industrial engineers is also noteworthy. Both of these reflect the changing emphasis in curricula in these areas. Social scientists still are not present in significant numbers.

The same 37 companies provided information on the age distribution for 472

operations-researchers. The results are given in Table V. Despite the apparent decrease in the number between 20 and 30 and the apparent increase in the number between 40 and 50, the average age increase is roughly only one and one-half years.

One significant difference should be noted. While in 1958 only 35 per cent (19 out of 54) indicated that they had used outside consultants during the preceding

TABLE III^(a)
PAST, AND ANTICIPATED FUTURE, ADDITIONS TO OR STAFFS

New OR personnel	0	1-2	3-4	5-6	More than 6	Totals
Hired, 1961 to 1964	6 (15)	14 (22)	6 (5)	6 (7)	6 (6)	38 (55)
Plan to hire, '64, thru '65	9 (21)	9 (8)	12 (6)	3 (2)	5 (10)	38 (47)

^(a) Figures in parentheses are for 1956 to 1958 and 1958 to 1960, respectively, for row 1 and 2.

2 years, in the present survey 68 per cent (26 out of 40) indicated that consultants *had* been used during the preceding two years. It is tempting to speculate as to the cause of this apparent change in attitude. Does it represent a division of

TABLE IV^(a)
EDUCATIONAL BACKGROUNDS OF OR PERSONNEL

Major field of study	Percentage of those with each degree			
	Bachelor's degree	Master's degree	Doctor's degree	All degree levels
Mathematics and statistics	26 (19)	33 (34)	37 (45)	30 (27)
Industrial engineering	15 (9)	14 (4)	6 (0)	14 (7)
Mechanical engineering	19 (15)	8 (8)	0 (6)	13 (12)
Business administration	5 (7)	14 (8)	2 (2)	8 (6)
Economics	5 (4)	9 (4)	12 (4)	7 (4)
Aeronautical engineering	8 (11)	4 (12)	8 (2)	6 (10)
Chemistry	6 (12)	3 (0)	22 (10)	6 (8)
Electrical engineering	3 (7)	2 (6)	0 (6)	2 (7)
Other	13 (16)	13 (24)	13 (25)	14 (19)
Percentage of total	48.3 (61.2)	41.2 (28.2)	10.5 (10.6)	

^(a) Numbers in parentheses are from the 1958 survey.

labor with consultants being used to do theoretical work while implementation is left to company personnel? Our data does not provide an answer.

OPERATIONS-RESEARCH APPLICATIONS AND TECHNIQUES

APPLICATIONS were reported in many areas, as shown in Table VI.

The increased activity in almost every area of application is encouraging. It

suggests that operations research is having a more pervasive impact in the various areas of management.

Virtually all companies had EDPE in their plants, and every company that

TABLE V
AGE DISTRIBUTION OF OR PERSONNEL

Age group	Per cent of employees in group	
	1958	1963
Under 20	1.5	0.0
20-30	36.0	22.7
30-40	44.0	42.0
40-50	14.	30.7
50-60	4.0	3.8
Over 60	0.5	0.2
	100.0	100.0

reported an OR program also reported that they used EDPE in their program. In addition, about half of the participating companies reported that they found it necessary to contract for the use of outside facilities for their OR program.

TABLE VI
AREAS OF APPLICATION OF OR TECHNIQUES

Area of application	Percent of companies reporting activity	
	1958	1964
Forecasting	57%	73%
Production scheduling	47	00
Inventory control	45	90
Quality control	33	51
Transportation	26	54
Advertising and sales research	20	27
Maintenance and repair	16	32
Accounting procedures	16	17
Plant location	15	32
Equipment replacement	15	27
Packaging	13	7
Capital budgeting	11	39

THE OUTLOOK: PROBLEMS AND PLANS

ONLY TWO companies reported no major problems in the implementation of the operations-research program. The problems ranged from relatively small, isolated

technical difficulties to a determined resistance on the part of management. The problem most frequently mentioned was that of gaining the confidence of management. For example, one individual listed as his biggest problem obtaining "management approval to go ahead and attack problems without a guaranteed, detailed, provable savings in dollars. (Even then there is great inertia.)" Another respondent complained of a "lack of positive continuing top management" support.

While a third summed up his biggest problem in one word: "people."

A second major problem area was similar to the first. Nearly as many researchers reported problems with line management. This problem was frequently described as "lack of effective communication with operating personnel." One wrote: "Sometimes the line organization wishes to get the results of the OR study, but resists any assistance in implementation of the results."

Taken at face value, one might conjure up the image of the operations researcher isolated from all levels of managerial authority. While some respondents felt that they both lack the approval for making recommendations, and the authority for seeing them carried out, most identify the problem as internal to the group. Invariably the solution offered to the external problems is the education of management in operations research.

Despite the problems experienced, most practitioners indicate satisfaction with their group's progress, and virtually all indicate that their company is planning to continue its programs.

NOTE ON A COVERAGE PROBLEM

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LAURENT^[2] discusses some applications of multivariate statistical techniques to bombing problems. He assumes the target fixed and the coordinate vector $X' = (x, y)$ of the impact follows a bivariate normal law $n(Bz, \Sigma)$, where B is a $2 \times q$ matrix and z is $q \times 1$. Let N observations on X' be denoted by the $2 \times N$ matrix $Y = (X^1 X^2 \dots X^1 \dots X^N)$, and the corresponding N observations on z by the $q \times N$ matrix $Z = (z^1 z^2 \dots z^1 \dots z^N)$. Then $\hat{\Sigma} = (Y - BZ)(Y - BZ)' / N$ is the maximum likelihood estimator of Σ when B is known.

Now if ξ is one of X^i vectors, then the conditional, given $\hat{\Sigma}$, density of ξ is

$$f(\xi / \hat{\Sigma}) = (2\pi N)^{-1} (N-2) | \hat{\Sigma} |^{-1/2} [1 - (\xi - Bz^i)' (N \hat{\Sigma})^{-1} (\xi - Bz^i)]^{(N-4)/2}. \quad (1)$$

The conditional probability of a hit within a circle of radius R centered at the point Bz^i is

$$\hat{p} = P \{ (\xi - Bz^i)' (\xi - Bz^i) \leq R^2 \}. \quad (2)$$

Setting

$$(\xi - Bz^i) = (t_x, t_y), \hat{\Sigma} = \begin{pmatrix} \sigma_x^2 & \sigma_{xy} \\ \sigma_{xy} & \sigma_y^2 \end{pmatrix}, r = \sigma_{xy} / \sigma_x \sigma_y, \quad (3)$$