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Fourth Annual Meeting of the Society

WASHINGTON, D. C., MAY 10–11, 1956

THE FOURTH ANNUAL MEETING of the SOCIETY was held at the Sheraton Park Hotel in Washington, D. C. on May 10 and 11, 1956. There were 54 contributed papers on the program, and 22 invited speakers participated in the sessions. There were 497 registrations, of which 280 were by members of the SOCIETY and 217 by nonmembers.

The Annual Business Meeting of the SOCIETY was held at 9:30 A.M. on May 10. At this meeting it was announced that the following officers had been elected:

RUSSELL L. ACKOFF, *President*	WILLIAM F. OFFUTT, *Treasurer*
BERNARD O. KOOPMAN, *Vice-President*	MERRILL M. FLOOD, *Council Member*
MARTIN L. ERNST, *Secretary*	ALEXANDER M. MOOD, *Council Member*

LEROY A. BROTHERS, retiring president of the SOCIETY, gave a résumé of the more important issues considered by the Council of the SOCIETY during the past year; this summary appears below.

The opening session of the program was devoted to discussion on the subject *Fallacies in Operations Research.* The principal address was given by BERNARD O. KOOPMAN, and CHARLES J. HITCH and GLEN D. CAMP presented prepared discussions of Professor Koopman's remarks. LEROY A. BROTHERS was chairman of this session.

The banquet on Thursday evening, May 10, was attended by 200 persons. ROBERT F. RINEHART was toastmaster. The Lanchester Prize for 1955 was awarded to GEORGES BRIGHAM, as reported later in this section. GEORGE SHORTLEY discussed the selection of the prize-winning paper and presented four letters of Honorable Mention. ELLIS A. JOHNSON presented the prize to Mr. Brigham on behalf of the Johns Hopkins University. Bronze plaques commemorating the awards of the Lanchester Prize were presented by WILLIAM J. HORVATH on behalf of the SOCIETY to MR. BRIGHAM and to LESLIE C. EDIE, last year's winner. The retiring presidential address by LEROY A. BROTHERS was on the subject *Education for Operations Research*; this address will appear in the August issue of OPERATIONS RESEARCH.

In addition to the opening session described above, there were eight sessions devoted to invited and contributed papers, as follows:

A. Cost in Operations Research	Chairman: FRANCIS P. HOEBER, Operations Research Office
B. Operations Research and the Firm	Chairman: ELLIS A. JOHNSON, Operations Research Office
C. Symposium on Potential Applications of Operations-Research Methods to Public-Health Planning and Evaluation	Chairman: J. A. RAFFERTY, Weapons Systems Evaluation Group

D. *On Congestion Theory, Queuing Theory, and Some Applications*	Chairman: GEORGE E. NICHOLSON, JR., University of North Carolina
E. *Contributed Papers*	Chairman: JEROME B. GREEN, Operations Research Office
F. *Operations Research in Medicine and Public Health*	Chairman: CHARLES M. MOTTLEY, Department of Defense
G. *Continuation of Session D; Contributed Papers on Other Subjects*	Chairman: S. K. SHEAR, Operations Evaluation Group
H. *Contributed Papers*	Chairman: FOSTER L. WELDON, Operations Research Office

The abstracts of the papers presented at these sessions are printed below, except for Session C, which was organized as a symposium with the following invited participants:

JOHN D. PORTERFIELD, Director, Ohio State Department of Mental Hygiene
CHARLES M. MOTTLEY, Planning Division, Assistant Secretary of Defense for Research and Development
JUSTIN ANDREWS, Associate Chief for Program, Bureau of State Services, Public Health Service
ROSS KANDLE, Assistant Commissioner of Health, New York City
MARK BLUMBERG, Health Conservation Section, Public Health Service
ANDIE KNUTSON, Behavioral Studies Division, Public Health Service
JEROME CORNFIELD, Office of Biometry, National Institute of Health

In addition to the three participants in the opening session and the seven contributors to the symposium in Session C, the authors of the following twelve papers were invited speakers: A1, A2, A3, B1, B2, D1, D2, D3, D4, F1, F2, and F3. The other 54 papers were contributed; of these the following were read by title: A9, D7, E7, E8, F7, H4.

The Program Committee consisted of DAVID M. BOODMAN, GLEN D. CAMP, WALTER E. CUSHEN, LAURENCE B. DEAN, JR., JEROME B. GREEN, DAVID A. KATCHER, ROY F. LAYTON, DANIEL LEIVICK, CHARLES F. MEYER, BERNARD B. WATSON, and HUGH J. MISER, *Chairman*. Daniel Leivick was in charge of arrangements.

There follow the President's report to the membership, the report of the 1955 Prize Committee, a report on the award of the Lanchester Prize, the report of the Education Committee, and finally the Abstracts of the papers presented at the Meeting. The reports of the Secretary and of the Treasurer will appear in the August issue of OPERATIONS RESEARCH.

PRESIDENT'S REPORT TO THE MEMBERSHIP

LeROY A. BROTHERS

THE COUNCIL, at its meeting in Ottawa last January, instructed me to give you, at the close of my term of office, an "outline of the problems and activities of the SOCIETY during the year." It is entirely fitting for the Council to inform you

of these matters and I am happy to act for the Council in this regard. My instructions were no more explicit than is indicated by the quotation from the minutes of the Council meeting I have just given you, and these remarks have not been reviewed by the Council. Therefore I take full responsibility for the judgments of what "problems and activities" to "outline" for you, and for the words used, which may sometimes represent my opinion rather than that of the Council.

THE AMENDMENT TO ELIMINATE ASSOCIATE MEMBERSHIP

DURING THE YEAR, the Council proposed an amendment to the Constitution which, if adopted, would eliminate the membership category, Associate Member. The amendment was submitted to the membership and was defeated decisively. Adoption would have required an "affirmative vote of two-thirds of the members voting" —the actual vote was 113 for and 147 against the amendment.

In connection with the defeat of this proposed amendment the following points are pertinent: (*a*) The decision by the Council to propose the amendment followed long and earnest debate, and was the result of a vote that was far from unanimous. (*b*) The discussion of the proposed amendment at the Annual Business Meeting of the Society in New York in June 1955 seemed to indicate a fairly even division of those present who were for and against. (*c*) In the decisive defeat of the proposed amendment only Members and Fellows were eligible to vote. Therefore it did not necessarily reflect the sentiments of those most affected, the Associate Members.

The defeat of the amendment requires that we continue to operate under the provisions of the Constitution that only Members and Fellows may vote and only Fellows may hold office. It is therefore urgently important that members be advanced to the grades for which they qualify as rapidly as possible. The Council and the Membership Committee have long recognized this and have urged the membership to nominate people to the categories for which they are qualified. But the rate at which people are advanced continues to be disappointingly slow.

I am sure I represent the Council when I urge you again to go through the lists of Members and Associate Members in the Directory and nominate people for the highest grade of membership for which they qualify.

AFFILIATION WITH THE DIVISION OF MATHEMATICS OF THE NATIONAL RESEARCH COUNCIL

JUST BEFORE the 1955 Annual Meeting, the Society received an invitation to become a member society of the Mathematics Division of the National Research Council for the three-year period 1 July 1955–30 June 1958, and to name a representative to the Division. The Council accepted this invitation and named Dr. Robert F. Rinehart as its representative. This is an important step in the Society's continuing growth in professional stature.

COMMEMORATIVE PLAQUE FOR THE LANCHESTER PRIZE

DURING THE YEAR, the Council decided to present to each winner of The Johns Hopkins University Lanchester Prize a bronze plaque commemorating his achievement. The Lanchester Prize goes to the author of the best operations-research paper pub-

lished in the English language and free of security classification. The Johns Hopkins University donated $1000 for this prize for the best paper published in the calendar year 1954, and $1000 for the best paper of 1955. MR. LESLIE C. EDIE received the 1954 award for his paper *Traffic Delays at Toll Booths*, published in OPERATIONS RESEARCH, vol. 2, No. 2, May 1954. The prize was presented to Mr. Edie at the Third Annual Meeting at Columbia University in June 1955. The winning paper for the year 1955 will be announced and the prize will be presented to its author at the dinner meeting this evening. Commemorative plaques will be presented to the winners for both years at the dinner meeting.

With great pleasure I announce that The Johns Hopkins University has informed the Council that it will provide $1000 for the best paper published in 1956. Also, I wish to take this opportunity to thank the University for its generosity, on behalf of the Council and the membership of the SOCIETY.

CONSIDERATION OF EMPLOYMENT OF FULL-TIME STAFF MEMBER

THE COUNCIL is giving consideration to the employment of a full-time staff member to make it possible for the SOCIETY to furnish greater service to the membership. For several years the SOCIETY has contracted with the Williams and Wilkins Company of Baltimore for managerial services. These services have made it practicable for the Secretary, the Treasurer, and the Editor to carry out their responsibilities to the SOCIETY without compensation. However, the Officers of the SOCIETY, the Editor of the JOURNAL, and the Chairman of the Education Committee are receiving an increasing number of requests for service from the members and from others interested in operations research. In spite of our willingness we are unable to provide the requested service adequately. Therefore a committee was appointed to study the needs for service and to make recommendations to the Council at this meeting regarding the possibility of the SOCIETY's employing a person to meet these needs.

Possible duties of such a staff member are: (*a*) to maintain a record of current employment opportunities for use by members; (*b*) to maintain a clearing house for information regarding education for operations research; (*c*) to maintain a bibliography of operations-research publications; (*d*) to work with libraries in establishing and maintaining a library classification system for operations-research publications. The fourth item listed is the most urgent, but the greatest volume of requests is in regard to the first three.

QUALITY OF PRESENTATIONS AT ORSA MEETINGS

THE COUNCIL has given earnest thought to possible ways to improve the quality of the presentations at our meetings. I am sure every one of you who has attended our meetings will agree that many of the presentations at the meetings leave much to be desired. Some of them have been of extremely poor quality, both as to the material presented and the method of presentation.

In the case of invited papers the solution is quite simple: just don't invite the speaker again. But in the case of contributed papers the problem is difficult. The By-Laws permit any member to contribute a paper at each meeting; he is

limited to fifteen minutes. Some of these fifteen-minute periods have been a waste of time for everybody, including the speaker.

The Council has considered many possible courses of action, including contributing a small prize for the best presentation at each meeting. But the difficulty of administering each procedure considered—for example, the very practical matter of selecting the best presentation—has, thus far, led to the rejection of each idea.

The Council will welcome your suggestions, and, above all, urges that each member preparing a paper for one of our meetings give careful attention to the quality of the content of the paper and of the method of presentation. ORSA members are busy people; don't waste their time.

PLANS FOR AN INTERNATIONAL CONFERENCE ON OPERATIONS RESEARCH AND MANAGEMENT SCIENCES

About a year ago, I received a memorandum addressed to the presidents of ORSA and The Institute of Management Sciences, signed by a number of people who are members of one or both societies, proposing that the two societies jointly sponsor an international conference on operations research and management sciences. During the year, each society has approved the idea of holding such a meeting, and has appointed a committee to investigate the problems relating to such a conference. Our committee was empowered to take initial actions as necessary.

Considerable progress has been made. The Operational Research Society of London is cooperating enthusiastically, and has agreed to be host to the conference. Contacts have been made also with operations-research groups in other European countries and in Japan.

PARTICIPATION IN MANAGEMENT OF THE SOCIETY BY MEMBERS FROM INDUSTRY

The Affairs of the Society thus far have been managed largely by people from the military operations-research groups. Perhaps this was inevitable in the beginning, since we from the military groups greatly outnumbered the members associated with industry and universities, and since we had been in the business longer than most operations analysts in industry. But it is important for the increasing membership from industry to participate more actively in the management of the Society.

One of the first tasks of the incoming president is to recommend committee assignments for the Council's approval. When I did this a year ago I tried hard to place people from industry on our committees. But I had limited success, principally because I knew so few people in industrial operations research. I recommended, and the Council approved, the appointment of five men to the important Nominating Committee as follows: the chairman and one member from industry, one member from a university, and two members from organizations doing operations research for the military services through contracts. Perhaps this accounts, in part, for the fact that only three out of eleven nominees for Officers and Council vacancies for the coming year were people in military groups. I believe this is a step in the right direction.

It would be helpful to the incoming president and the Council if you who are

practicing operations research in industry would let us know if you are willing to serve on committees. Although most committee assignments for the coming year will be made tonight, I assure you that it will be useful for you to let us know, today or even later, if you are willing to help. Other committees will have to be appointed during the year, and your willingness to help will be remembered by the Council in future years.

EXPRESSION OF APPRECIATION

AT THIS POINT in my report to you, the membership, I'd like to reverse directions and represent you. As your representative, and on your behalf, I wish to express appreciation to some of the 'unsung heroes' of the early years of the SOCIETY.

It might well be said that anyone who would be willing to attempt to list the people who deserve the special thanks of the membership for their outstanding contributions to the Society during its early formative years automatically categorizes himself among those who 'rush in where angels fear to tread.' So be it. I believe I can single out a few whose major contributions are unquestioned, even at the risk of leaving out some who should be included. At any rate, on your behalf and mine, I express sincere appreciation to the following:

JACK LATHROP, Secretary of the SOCIETY from its founding in 1952 through the first three years of its existence. It is not possible to measure Jack's contributions during these years when we were learning how to operate—but they were tremendous. Jack also was a member of the Founding Committee, practically wrote the Constitution and By-Laws, and served as Chairman of the Constitution and By-Laws Committee for three years.

ALFRED WATSON, Treasurer of the SOCIETY from its founding through its first four years. Al has done an outstanding job in developing our fiscal policies, and is largely responsible for the present sound financial position of the SOCIETY. I must report, however, that the Council received quite a shock at the Ottawa meeting when Al requested a 100 per cent increase in the Treasurer's budget for the year: from $10.00 to $20.00.

THORNTON PAGE, the first Editor of the JOURNAL. To establish a scientific journal, starting from scratch, requires a great deal of imagination, ability, and diplomacy plus a large amount of hard work. When Thornton resigned his post as Editor because he was going on a European tour for the Operations Research Office, he left the JOURNAL a going concern which had earned its respected place in the family of scientific journals. Thornton was also elected to the Council for a three-year term in 1953.

GEORGE SHORTLEY, who took over the Editor's job when Thornton Page went overseas. The continued growth of the JOURNAL, both in quality and quantity, under George's guiding hand, is eloquent evidence that George deserves our commendation. George also has done yeoman service on the Lanchester Prize Committee, on which he is, for obvious reasons, a perennial member.

GEORGE KIMBALL, Chairman of the Membership Committee for our first two years. The Membership Committee in the early years had a particularly difficult task. The criteria for the different grades of membership as stated in the Constitution proved difficult of practical interpretation. The procedures for qualifying people for admission to the SOCIETY and for advancement in grade had built-in delays. Despite these difficulties George and his committee developed sound operating procedures and did a very creditable job in moving people into the membership category for which they were qualified. George was a Council member for the SOCIETY's first three years and served as Chairman of the Professional Standards Committee for the fourth year.

JOSEPH MCCLOSKEY, Chairman of the Education Committee for the last three years. Joe has handled this arduous task excellently and deserves our special thanks. Some idea of the variety of difficult tasks with which the Education Committee is faced may be obtained by reviewing quickly the list of possible duties for a full-time staff member described earlier. The last three of the items listed are presently referred to the Education Committee. Joe has had a number of other committee assignments, all of which he has carried out efficiently and well.

DAVID KATCHER, Chairman of the Publicity Committee for the past two years and member of the committee the year before. Dave has handled this difficult assignment superbly, during the period when it was necessary for him to develop policy as well as carry it out.

IN A LISTING such as this, it is necessary to name one or two others who have made major contributions to the Society and who deserve special thanks, even though they hardly qualify as 'unsung': (*a*) PHILIP MORSE, first President of the SOCIETY and member of the Founding Committee, for the excellent job he has done as Chairman of the Membership Committee for the past two years. (*b*) ROBERT RINEHART, second President of the SOCIETY, member of the Founding Committee, and member of the Council since the SOCIETY was founded, for the pioneering job he did as first chairman of the Lanchester Prize Committee.

REPORT OF THE 1955 PRIZE COMMITTEE

THE 1955 PRIZE COMMITTEE of the Operations Research Society of America followed the procedure evolved by the 1954 Prize Committee which was approved by the Council at its meeting on November 19, 1954. The 1955 Committee found the procedure comprehensive and logical and its consensus was that there was no need to alter the scheme.

This procedure consisted in referring each paper appearing in operations-research publications (or publications that contain occasional operations-research contributions) in 1955 to at least two members of a screening group for review and recommendation. This group consisted of the twelve Associate Editors of OPERATIONS RESEARCH and twenty-three additional members selected by the Committee.

Without the assistance of this group, whose names follow, the formidable task presented to the Committee could not have been accomplished in responsible fashion:

J. W. Abrams, Department of National Defence, Canada
R. L. Ackoff, Case Institute of Technology
E. L. Arnoff, Case Institute of Technology
R. A. Bailey, Lockheed Aircraft Corporation
J. H. Batchelor, Consultant, St. Louis, Missouri
A. A. Brown, Arthur D. Little, Incorporated
Glen D. Camp, Melpar, Incorporated
T. E. Caywood, Caywood-Schiller, Associates
L. S. Christie, Operations Research Office
R. R. Crane, Touche, Niven, Bailey and Smart
J. M. Danskin, Institute for Advanced Study
D. E. Debeau, Battelle Memorial Institute
J. M. Dobbie, Operations Research Group
J. W. Dunlap, Dunlap and Associates
L. C. Edie, The Port of New York Authority
William R. Fair, Stanford Research Institute
S. C. Frey, Lockheed Aircraft Corporation
Charles Goodeve, British Iron and Steel Research Association
J. O. Harrison, Jr., Operations Research Office
W. J. Horvath, Airborne Instruments Laboratory
B. O. Koopman, Columbia University
J. B. Lathrop, Lockheed Aircraft Corporation
Michael Leyzorek, Case Institute of Technology
J. F. Magee, Arthur D. Little, Incorporated
D. G. Malcolm, Operations Research Office
Thornton Page, Operations Research Office
E. W. Paxson, The Rand Corporation
William J. Platt, Stanford Research Institute
T. L. Saaty, Operations Evaluation Group
Andrew Schultz, Jr., Cornell University
W. L. Swager, Battelle Memorial Institute
G. H. Symonds, Esso Standard Oil Company
R. M. Thrall, University of Michigan
R. S. Weinberg, Operations Evaluation Group
L. A. Young, Consultant, Los Angeles, California

Each member of the screening group was requested to evaluate as to prizeworthiness the six or so papers referred to him, or the entire proceedings of a symposium, according to the criteria the Committee published in the November 1954 issue of Operations Research, namely:

For a research paper representing new results

1. The magnitude of its contribution to the advancement of the state of the art of operations research.
2. The originality of its ideas or methods.
3. New vistas of application opened up by it.
4. Expository clarity.

For a primarily expository paper

1. The degree of unification or simplification of existing operations-research theories or methods.
2. Expository clarity and excellence.

Each screener was requested to nominate the one, or, at most, two papers of his list which he deemed most prizeworthy, and was asked to state which paper of his list was best, even when he considered that none deserved nomination for the prize. In addition, each screener was invited to recommend to the Committee for their consideration any other operations-research paper published in 1955. In addition, in a note on page 551 of the November 1955 issue of OPERATIONS RESEARCH, the Committee invited all interested persons to make nominations from whatever source. A copy of the final report of each screener was distributed to each member of the Prize Committee as it was received.

The 1955 publications that were systematically screened were the following:

1. *Operations Research*
2. *Management Science*
3. *Proceedings—What is Operations Research Accomplishing in Industry?* (Case Institute of Technology)
4. *Proceedings—Operations Research Conference, 29–30 September 1955* (Society for Advancement of Management)
5. *Journal of Industrial Engineering*
6. *Naval Research Logistics Quarterly*
7. *Mathematical Models of Human Behavior—Proceedings of a Symposium, 1955* (Dunlap and Associates)
8. *Linear Programming—Second Symposium, vol. 1* (National Bureau of Standards)
9. *Osaka Prefectural Institute for Industrial Management, Industrial Administrative Research Memoranda*
10. *Proceedings—Institute for Business and Industry* (University of California)
11. *Operational Research Quarterly*

The Prize Committee met on March 25, 1956, in Washington, D. C., to arrive at a final recommendation to the Council. The members of the Committee selected a paper by Georges Brigham, "On a Congestion Problem in an Aircraft Factory," which appeared on p. 412 of the November 1955 issue of OPERATIONS RESEARCH. The members were unanimous in their decision that the paper contains all of the salient features of good operations research. Unlike the situation last year, the Committee's selection was not arrived at easily. There was a good deal to be said for each paper in a group of about five. None of these papers, including the prize winner, was outstanding with respect to every one of the criteria which were employed. Joint consideration, however, soon led to a decision on Brigham's paper.

Because the margin of choice between the winner and the remaining papers was not as large as last year, the Committee feels that at the presentation in May, the following papers (listed alphabetically) should receive Honorable Mention:

RUSSELL L. ACKOFF, "The Allocation of Sales Effort," *Proceedings of the Conference on What is Operations Research Accomplishing in Industry?* Case Institute of Technology, April 1955.

JACK W. DUNLAP AND HERBERT H. JACOBS, "Strip Mining Phosphate Rock with Large Walking Draglines—A Problem in Operations Research," *Operations Research*, February 1955.

CHARLES HITCH, "An Appreciation of Systems Analysis," *Operations Research*, November 1955.

JOHN D. C. LITTLE, "The Use of Storage Water in a Hydroelectric System," *Operations Research*, May 1955.

This year the Committee was reluctantly obliged to eliminate from final consideration a number of excellent operations-research reports which dealt with work which gives every indication of having been of great importance and competently executed. These reports, however, had not been primarily addressed to the professional operations analyst and were difficult to judge by the standards which the Committee adopted last year and confirmed again this year. Such papers were therefore at a disadvantage in that they lacked analytical details and scientific proofs and justifications, although they were undoubtedly well suited for their original purpose of expositions to management.

March 29, 1956

R. F. RINEHART
GEORGE SHORTLEY
JACINTO STEINHARDT, *Chairman*

AWARD OF THE LANCHESTER PRIZE

THE COUNCIL of the Operations Research Society of America accepted the recommendations of the Prize Committee contained in the above report and notified the President of The Johns Hopkins University of the choice of winning paper.

At the banquet of the Fourth Annual Meeting of the SOCIETY on May 10, 1956, the President of the SOCIETY, on behalf of the Council, presented letters of Honorable Mention to the authors of the four papers recommended for Honorable Mention in the preceding report of the Prize Committee.

DR. ELLIS A. JOHNSON, representing the President of The Johns Hopkins University, then presented MR. GEORGES BRIGHAM with the Prize of $1000, together with the following letter from the President of the University:

> Dear Mr. Brigham:
>
> In accordance with the terms under which it was offered, the Council of the Operations Research Society of America has informed me that you are the second recipient of The Johns Hopkins University Lanchester Prize.
>
> I am, therefore, honored to transmit the Prize to you and to congratulate you, not only because you have won the Prize, but still more because you have made a significant contribution to the profession of operations research.
>
> The establishment and award of such a prize is of course meant to stimulate achievement in this new field. But the medium of a prize is meant also, and more, as a symbol of recognition and esteem for work identified as of distinguished excellence. Such work is needed as the fulfillment of the promise of operations research for the greater value of

human actions, and it is needed in order to assist by example in the setting and maintaining of high standards in this new profession, and it is needed further as an increment to the body of knowledge available for the teaching which must be the life source of the profession.

Once more my congratulations to you for having made a fine contribution to these purposes, and my thanks to the SOCIETY and its Council for having chosen a worthy recipient for the Prize.

Sincerely yours,
LOWELL J. REED
President

May 3, 1956

GEORGES BRIGHAM made the following speech in accepting this award:

SPEECH OF ACCEPTANCE, BY GEORGES BRIGHAM

TO RECEIVE THE LANCHESTER PRIZE is, in the personal sense, a verification of one's work. I have been studying and working in operations research for the last two or three years and have had the opportunity to investigate a variety of problems. However, I have been pretty much on my own except for occasional discussions with Dr. Gaskell, who encouraged me to work in this field, and with one or two other mathematicians; my only outside contacts with operations research have been the meetings and the literature. What I needed was some independent check on what I was doing.

When I was working on the problem which was described in my paper, one of the things I needed to derive was the distribution of the waiting times of the clerks. After several attempts, I found what I believed was the correct distribution. At this point I wanted to test its correctness. By comparing its mean, a very simple expression which can be derived independently, and by considering an extreme case which is equivalent to one derived many years ago by A. K. Erlang, I could check that I was on the right track. Similarly, when I received Dr. Brothers' announcement, I felt that perhaps I am on the right track in my work.

I felt many other things too—all very hard to express adequately: pleasure and pride at receiving such an honor, wonder at my being the one to receive it. Certainly I felt some unworthiness, for I am sure there must be some better qualified than I, but who for a variety of reasons beyond their control were not eligible this time. I wish that I could share this experience with them, and hope that somehow they can derive some pleasure and encouragement from my good fortune.

Beyond and above this personal aspect, the Johns Hopkins Lanchester Prize is a high honor established to encourage the development of the profession—not merely to reward one man. A man's knowledge, his ability, the opportunity, help, and encouragement given him, all come more or less from sources outside himself. It would be presumptuous for him to claim the prize as an exclusive achievement. I owe a great deal to the profession of operations research and to the people around me for winning this prize. I receive it with this in mind, deeply grateful for the

honor bestowed on me and keenly aware of the responsibility that goes with it. I shall do my utmost to be worthy of the one and to fulfill the other.

REPORT OF THE EDUCATION COMMITTEE (1955–56)

IN JUNE 1955, the Director of the Operations Research Office, The Johns Hopkins University, enlisted the aid of the SOCIETY in selecting the publications that should be supported out of the royalty fund created when the authors of *Operations Research for Management* (both volumes) agreed to forego royalties in the interest of creating a fund for the encouragement of publications on operations research. This led to a proposal for joint publication *for* the SOCIETY *by* The Johns Hopkins Press, and the Education Committee was charged with study of the matter. By the January meeting, sufficient progress had been made to justify a separate committee to carry out the steps necessary to Council action. The Secretary's report* contains the results of that action.

Plans were made for a Conference on Operations Research Education to be sponsored by The Johns Hopkins University and the Education Committee of the SOCIETY. The Conference was held in Baltimore on March 22–23, 1956. The general conclusions of the Conference are summarized in the Appendix to this report.

A determined effort was made to obtain a complete listing of institutions of higher learning offering curricula or courses in operations research, whether or not under that name. The Appendix on Operations-Research Education is the result of that effort. The outgoing Committee is sure that the new Committee will appreciate receiving information respecting additions, deletions, or corrections that should be made in this listing.

DR. E. LEONARD ARNOFF proposed that a series of articles on OR education in the various institutions be published in the JOURNAL. The Editor having agreed, the reaction of those responsible for curricula in OR was solicited. The response was favorable and the first such article should appear in the October issue of OPERATIONS RESEARCH. The Editor has designated Dr. JOSEPH F. MCCLOSKEY as editor of the series.

As a means of facilitating responses to inquiries about OR and the Operations Research Society, the Education Committee was charged with preparation of a brochure analogous to that prepared in 1951 by the Committee on Operations Research of the National Research Council. Several drafts were prepared and circulated to the Council prior to the current meeting. The Secretary's report includes the action taken by the Council on this matter.

Some preliminary work was done on the matter of establishing scholarships or fellowships, but no concrete proposals were developed.

Some preliminary work was done on the matter of developing a library classification scheme as a preliminary to establishing abstracting and bibliographic services

* The report of the Secretary will appear in the August 1956 issue of OPERATIONS RESEARCH.

under SOCIETY aegis. Definite recommendations were deferred until the possibility of a cooperative effort with the Operational Research Society can be explored, inasmuch as this society is considering similar action.

E. LEONARD ARNOFF
MAX ASTRACHAN
GLEN D. CAMP
GILBERT W. KING
EDWARD S. LAMAR
ANDREW SCHULTZ, JR.
HERBERT SIMON
JOSEPH F. MCCLOSKEY, *Chairman*

CONFERENCE ON OPERATIONS-RESEARCH EDUCATION

ON MARCH 22 AND 23, 1956, a conference on operations-research education was held at The Johns Hopkins University under the joint sponsorship of the Department of Industrial Engineering of the University and the Education Committee of the Operations Research Society of America.

Invitations were extended to representatives of about forty educational institutions interested in operations research. Those who attended are listed below.

The first day's sessions were devoted to a description of the activities under way and planned at the schools represented, a discussion of the place of on-the-job training, and a consideration of the general structure of courses. MR. LEROY BROTHERS, President of the SOCIETY, spoke at dinner on the background that he, as an employer of OR scientists, looks for in applicants. The second day's sessions dealt with requirements in mathematics and statistics and general curricular concepts.

From the first day's sessions, an emphasis on three major 'lacks' emerged: There is a lack of monographic materials to be used in teaching. There is a lack of fully developed case histories, including discussion of blind alleys, failures, implementation, and payoff. There is a critical lack of time: many of those attending the conference are 'on their own' with respect to OR activities; anything they do is in addition to an otherwise full schedule.

On the positive side, there emerged virtually unanimous agreement that on-the-job training, whether as member of an organized group or as an independent worker on appropriate 'live' problems, is essential to an educational program in operations research. The demands placed on the student's time by the combination of classroom and practical work generates some problems that require careful consideration by administrators and teachers.

There was general agreement that the 'case method' of instruction, as practiced in some business schools and in most law schools, is unsuited to the requirements of operations research (in part because there are insufficient good case histories to sustain such an approach and in part because the case method is relatively slow). Rather, courses properly balanced as to method, theory, and application were favored by the conferees.

There was, on the other hand, no clear position among the conferees on the relative merits of methodological *vs.* functional courses. In point of fact, courses in probability and statistics, linear programming, and so forth predominate; while courses in planning and programming, production and inventory control, and the like are sparsely represented. Some interesting experiments are under way and it is to be hoped that the results of these experiments will receive wide publicity through the JOURNAL and other media.

So far as mathematical training is concerned, there was general agreement that the student entering a graduate program in operations research should present, as a minimum, a knowledge of differential equations. As is true of most graduate programs, the mathematics required of the individual student should be fitted to his interests and requirements, but there was fair unanimity among the conferees on three points: The student should receive a fair exposure to higher algebra. Derivations and proofs should receive only that emphasis required by the interests and capabilities of the students. Great emphasis should be placed on model construction (setting up the problem) so that the student may become fully familiar with abstraction and the way mathematics works in the solution of problems.

With respect to probability and statistics, a minimum sequence was felt to be a term each on the equivalent of the unstarred chapters in FELLER and of DIXON AND MASSEY, followed by a term on sampling and a term on design of experiments and the associated analytical tools.

Several experimental 'survey' courses were reported on. These acquaint the students with some or most of the mathematical techniques and tools in wide use in operations research in order to provide the student with an opportunity to develop his particular interests and appreciate his deficiencies. It is to be hoped that full reports on these courses will soon become available.

Any attempt to take a position on the relative merits of including standard courses offered by the mathematics department as against the development of special courses, under either mathematics or operations research, was stymied by the diversity of attitudes at the institutions represented at the conference; some of both appeared as the predominant pattern, however, even where departmental lines are sharply defined.

The discussion of curricula brought out the fact that a very healthy situation exists in the diversity of approaches. Thus, M.I.T. continued to grant degrees in a particular subject matter, with a thesis on OR under the supervision of an interdepartmental committee. Several schools have carried the interdepartmental committee a step further by permitting or otherwise encouraging more crossing of established departmental lines. Several others are basing their operations-research curricula on industrial engineering and are adding or substituting operations-research courses as student requirements and faculty capability develop. Finally, Case Institute continues to move in the direction of a fully developed curriculum within the context of operations research, adding courses developed out of the subject matter of operations research as rapidly as such courses prove feasible; meanwhile, it continues to require or encourage considerable work in the departments of mathematics and the basic sciences.

The basic debate on curriculum hinged on the question: Is physics or statistics (or some other established discipline) the best training for operations research, or is the physicist valuable on an OR team because of his training and experience in model building and is the statistician valuable because of his training and experience in data reduction, design of experiments, etc., all of which can be extracted and taught as such? If the former position is taken, then the M.I.T. approach is valid; if the latter position is taken, then the Case approach is valid; if a position somewhere between is valid, then the approaches of most of the schools represented at the conference are valid.

Preliminary plans were made for another conference to be held at Case Institute in about 18 months. It is to be hoped that the unresolved questions will have moved closer to solution as a result of the experience that will have been gained in the interim.

The conferees and the Education Committee of ORSA wish to express their appreciation to Johns Hopkins, and particularly to DEAN ROBERT H. ROY and DR. CHARLES D. FLAGLE, for the hospitality extended to the group, and to MR. LEROY BROTHERS for taking time from his busy schedule to address the dinner meeting of the group.

PARTICIPANTS IN CONFERENCE ON OPERATIONS-RESEARCH EDUCATION

DR. RUSSELL L. ACKOFF, Director, Operations Research Group, Case Institute of Technology
PROF. WYETH ALLEN, Chairman, Department of Mechanical Engineering, University of Michigan
DR. E. LEONARD ARNOFF, Assistant Director, Operations Research Group, Case Institute of Technology
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DR. E. H. BOWMAN, Assistant Professor of Industrial Management, Massachusetts Institute of Technology
DR. J. G. BRAINERD, Director, Moore School of Electrical Engineering, University of Pennsylvania
DR. EDWARD P. COLEMAN, Professor of Engineering, University of California at Los Angeles
DR. SIDNEY DAVIDSON, Associate Professor of Accounting, The Johns Hopkins University
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DR. EMIL JEBE, Statistician, Iowa State College
DR. A. W. R. JONES, Associate Professor of Mathematics, Rensselaer Polytechnic Institute
DR. R. E. LANGER, Director, Mathematics Research Center, U. S. Army, University of Wisconsin
PROF. E. P. MARTINSON, Head Professor, Department of Industrial Engineering, University of Florida
DR. JOSEPH F. MCCLOSKEY, Operations Analyst, Operations Research Office, Johns Hopkins University
DR. ALEX ORDEN, Director of Mathematical Analysis, Burroughs Corporation, Philadelphia
DEAN ROBERT H. ROY, School of Engineering, Johns Hopkins University
DR. ANDREW SCHULTZ, JR., Professor in Charge, Dept. of Industrial and Engineering Administration, Cornell University
DR. SEYMOUR SHERMAN, Visiting Professor of Electrical Engineering, University of Pennsylvania

OPERATIONS-RESEARCH EDUCATION

THIS IS A LIST of accredited colleges and universities offering curricula or courses in operations research. It is based on information available to the Education Committee of the Operations Research Society of America. Because of the rapid growth of interest in OR education, the list cannot hope to be complete. Errors and omissions should be reported to the new Chairman of the Education Committee (DEAN ROBERT H. ROY, School of Engineering, The Johns Hopkins University, Baltimore 18, Maryland).

The following schools have *curricula leading to graduate degrees*:

Carnegie Institute of Technology
Graduate School of Industrial Administration

Case Institute of Technology
Department of Engineering Administration

Columbia University
Department of Industrial and Management Engineering

Cornell University
Sibley School of Mechanical Engineering
Dept. of Industrial & Engineering Administration

Massachusetts Institute of Technology
Interdepartmental Committee on Operations Research

The Ohio State University
Department of Industrial Engineering

Purdue University
Department of Industrial Engineering

The Johns Hopkins University
School of Engineering

University of Michigan
Department of Industrial Engineering

University of Pennsylvania
Moore School of Electrical Engineering

Other schools with *one or more courses* in their curricula devoted to or oriented toward operations research include:

American University
George Washington University
Harvard University
Illinois Institute of Technology
Iowa State University
Northwestern University
Oregon State College
Pennsylvania State University
Rensselaer Polytechnic Institute
Stanford University
University of California
University of California at Los Angeles
University of Minnesota
University of North Carolina
University of Pittsburgh
University of Southern California
University of Tennessee
University of Toronto
University of Washington
Wayne University
Yale University

The U.S. Naval Postgraduate School, Monterey, California, has a curriculum in operations research. The U.S. Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, has courses devoted to and oriented toward operations research.

Of the schools listed above, Case, M.I.T., and U.C.L.A. offer short courses, usually of two-weeks' duration, in operations research.

Interested persons should write directly to the schools, rather than to the Operations Research Society of America, for specific information on curricula and courses, including short courses.

ABSTRACTS

Fallacies in Operations Research, B. O. KOOPMAN, *Columbia University, New York 27, N. Y.*

A1. The Relevance of Costs in Operations Research, MALCOLM W. HOAG, *The RAND Corporation, 1700 Main Street, Santa Monica, California.*

Operations research may be divided into studies in which (1) costs are largely irrelevant, because the problem is the maximizing of one objective subject to specific fixed constraints; (2) a measure of real cost internal to the analysis is required, because multiple objectives compete for specific inputs whose supplies are fixed; and (3) real costs must be approximated by money costs, because the form and amount of many inputs can be altered. The scope of the analysis undertaken and the time available for adjustment of the operations in question determine into which group a particular study falls. As an illustration, the context of a hypothetical allocation problem is changed to make it fall successively into each group. Gross misuse of cost measures can result from a failure of operations analysts to discriminate among these groups and to apply tests of efficiency appropriate to each.

A2. Development of Costs for Comparisons Involving Government Activities, REGINALD V. HOBBAH, *Operations Analysis Office, Hq U. S. Air Force, Washington 25, D. C.*

This paper is concerned with developing cost data which permit cost comparisons of government enterprises, one with another, or with private enterprises. First, it discusses the problem of converting expenditures data to figures which reasonably compare with the data yielded by business accounting procedures. Conversion is effected by classifying expenditures to provide memorandum accounts which in turn permit ascertainment of "annual costs." Second, it offers some principles bearing upon the allocation of indirect costs. Unless an activity can be costed on a marginal basis, it is necessary to resort to arbitrary formulas for allocating indirect costs. Consequently, the task confronting the analyst is to develop a formula which is *reasonably* or *judicially* arbitrary—which will appeal, that is, to a *reasonable man* as being *fair* (such qualities as reasonable and fair having substantially the same connotations as they have acquired in regulatory-commission law).

A3. Weapon-System Cost Analysis, G. H. FISHER, *The RAND Corporation, 1700 Main Street, Santa Monica, California.*

A method of estimating cost inputs for weapon-systems analyses is presented and discussed. The major characteristics of the method are:

(1) Total-cost concept, which provides for accumulation of "support" as well as "direct" costs to the tactical unit of capability (e.g., wing or squadron in the case of the Air Force).

(2) Distinction between investment and annual operating costs.

(3) Incremental costing, which provides for taking into account "inheritance value" of existing assets when a new weapon system is phased in to replace an existing one.

(4) Time phasing of weapon systems and the costs related thereto.

(5) Emphasis on consistency in costing alternative weapon proposals, which, for purposes of systems analysis, is perhaps more important than striving for a high degree of accuracy.

In addition to the application to formal weapon-systems analysis, use of the method as a tool in Air Force planning and programming of future weapon systems is also discussed.

A4. A Model of the Cost of Varying Production Rates, ROBERT G. BROWN, *Arthur D. Little, Inc., 30 Memorial Drive, Cambridge 42, Massachusetts.*

A model is developed for the expected costs of excess labor premiums as a function of the variability of production rates scheduled. For a simple model of costs, and normally distributed production rates, it is shown that the expected cost is strictly proportional to the standard deviation of the distribution of production rates. For a more general cost model, the costs are approximately proportional to the standard deviation.

A5. Price and Strategic Considerations in Marketing a New Airplane, GEORGES BRIGHAM, *Operations Research Group, Mathematical Services Unit, Boeing Airplane Company, Seattle, Washington.*

The price to be set on a new airplane is an important variable in the struggle for a position in the air transport market, for two reasons: because it has such an important effect on the whole problem, and because it is a variable over which the manufacturer has some control. Hence, this study attempts to relate the other major variables in the problem to the variable of price and to determine a strategy to be followed in setting the price. We investigate successively (1) the general market background and the assumptions from which it seems reasonable to start, (2) the costs, both to the manufacturer and to his competitors, as a function of price, (3) the potential market, i.e., the number of airplanes which might be sold at different prices, (4) the element of risk involved in getting into this business, how it may be measured and how the price may influence it, (5) criteria for judging what is a "good" price, and (6) possible variations away from the optimum price to gain or maintain a strategic advantage over the competitors.

A6. Some Operations-Research Models for Measuring the Economic Feasibility of Large-Scale Airlifts, ROBERT STANLEY WEINBERG, *Division of Defense Laboratories, Massachusetts Institute of Technology, Cambridge, Massachusetts (Operations Evaluation Group, Navy Department, Washington 25, D. C.)*

Two widely different problems in military air transport economics are considered. The first is concerned with the economies which may be gained through the use of an airlift-oriented logistical support system for overseas supply in peacetime. The second deals with the feasibility of operating a world-wide or global airlift in the event wartime control of the seas should be lost.

The first problem considers the nature of the impact that an airlift logistical support system will have on the total costs incurred in supplying an overseas supply activity with its material requirements. The second problem considers the resource costs, in terms of aircraft, fuel, personnel, and air base construction, generated during the operation of a global airlift. Two simple aggregate models constructed from a minimum amount of available input data provide results of interest and value.

A7. The Role of Cost in Formulating Merit Criteria for Communication Systems, A. HAUPTSCHEIN and L. S. SCHWARTZ, *College of Engineering, New York University, Bronx, N. Y.*

Merit criteria are formulated for the efficient transmission of information through noise. The anticipated operational problem is one of determining the "cost" required to transmit a message over a particular communication system with a specified degree of reliability for given noise and loading (traffic density) conditions. The better system transmits the information at less cost. A technique for establishing this cost for any communication system is described. This technique permits allowance to be made for message importance, and depends upon assigning cost values to the basic merit parameters of power, bandwidth, and time, and to the operational loading conditions. In this paper the method has been applied to a relative evaluation of the efficiency of binary and quaternary PCM (Pulse Code Modulation). The method is flexible, however, and can be applied to the evaluation of any modulation and coding system. Comparative evaluation of systems should result in performance indices which permit judicious choice of systems for use in various operational situations.

A8. The Changing Roles of Costs for Operations, ROBERT J. SCHUBACH, *Office of the Comptroller of the Army, 6129 Landover Road, Cheverly, Maryland.*

The roles described are: 1. The early role of costs as an aid in make-or-buy decisions and in preparing competitive bids. 2. The development by engineers of cost reports to warn them when their factory processes fell out of control. 3. The conversion by accountants of costing techniques from measurement of operations to support of balance-sheet values, generating a 50-year-long debate on the distribution of overhead. 4. The change in needs for costing operations arising from advances in process-control techniques. 5. Some needed research in costs of operations.

A9. A Scientific Approach to Accounting, BERNARD WHITNEY, *Whitney and Kornfeld, CPA's, 527 North La Cienega Boulevard, Los Angeles 48, California.*

Accounting should be a source of information for control and decision making. In order to achieve this, present accounting theories and techniques must be completely re-examined and revised. The following five functions of accounting are discussed in detail: (1) Minimizing income taxes, (2) recording money transactions, (3) supplying reports to creditors and stockholders, (4) providing basic information for management decision making, and (5) furnishing feed-back data for management control.

B1. On Staff Organization and Operations Analysis, ROBERT H. ROY, *School of Engineering, The Johns Hopkins University, Baltimore 18, Maryland.*

The first part of the paper deals with the convention that staff organization is supposed to be advisory to line organization and examines the forces which tend to make staff organization authoritative over subordinate line echelons. The reasons for this tendency are examined and the consequences of the growth of staff authority are analyzed. The second part of the paper deals with operations analysis as a special case of staff organization and sets forth the contrasts between this organization relationship and the organization relationship of other kinds of staff elements. The sources of hostility to operations analysis are examined and a means for coping with these forces is discussed.

B2. Operations-Research Models as a Basis for Action: A Case Study, ROBERT STANLEY WEINBERG, *Division of Defense Laboratories, Massachusetts Institute of Technology, Cambridge, Massachusetts (Operations Evaluation Group, Navy Department, Washington 25, D. C.)*

A generalized aggregate model of the over-all operations of an industrial corporation is developed. Two important planning and control problems are then discussed within the framework of this model. The first is the shorter term planning problem of determining an optimum marketing, advertising and sales promotion policy. The second is the longer term planning problem of developing a set of objective criteria for "capital budgeting".

Actual case studies drawn from the operations of two major manufacturing corporations are introduced to demonstrate how a generalized aggregate model may be used to provide a quantitative basis for executive action. Taking operating profits and net operating profits after taxes as a measure of operating effectiveness it is shown that the company's profits are determined by the interaction of four basic relations: (*a*) a relation between general economic activity and total industry sales, (*b*) a relation between total industry sales and company sales, (*c*) a relation between company sales and operating profits, (*d*) a relation between operating profits and net operating profits after taxes.

It is further shown that the individual company may, through various strategic expenditures, exercise a varying degree of influence over each of these relations. The model is used to demonstrate at what level these various strategic expenditures should be set to maximize the company's profit position.

B3. Competitive-Bidding Strategies in Simple Situations, LAWRENCE FRIEDMAN, *Operations Research Group, Case Institute of Technology, Cleveland 6, Ohio.*

Competitive-bidding situations are generally divided into two types, open bidding and closed bidding. These categories can in turn be subdivided by varying the following parameters: number of bidders, number of items up for bid, values of items up for bid, available funds of bidders, restrictions on the bidding and sequence of items in the case of open bidding. Some analytic solutions of the simpler situations will be discussed as well as some of the unsolved problems in the theory of competitive bidding.

B4. "Best Guess" Systems: A Harmonic Analysis of Some Problems in the Large, D. DAVID BOURLAND, JR., *Division of Defense Laboratories, Massachusetts Institute of Technology, Cambridge, Mass. (Operations Evaluation Group, Navy Department, Washington 25, D. C.)*

"Best Guess" systems may be defined as those having the following characteristics: (1) Large expenditures made by groups of concerns, who in some instances are in competition among themselves; (2) procedural guides for the outlays are usually retrospective analyses of past campaigns which supposedly have some degree of similarity to the campaign planned; (3) prediction of pay-off for a given campaign cannot be made accurately, either as to whether there will be a pay-off or how large it will be, and in some cases the pay-off cannot be measured in dollars.

Some outstanding characteristics of such systems are described in terms of a generalized harmonic series. The model so constructed is evaluated with data from the advertising industry and the field of military research and development. Finally, criteria are provided for the interpretation of departures from predicted logarithmic linearity and the attendant slopes.

B5. Mathematical Programming and Employment Scheduling, WILLIAM KARUSH, *Department of Mathematics, University of Chicago, Chicago 37, Illinois,* **and ANDREW VAZSONYI,** *The Ramo-Wooldridge Corporation, 8820 Bellanca Ave., Los Angeles 45, California.*

The conventional economic theory of production assumes that the cost of production is a monotonically increasing convex function. This theory is not explicitly applicable to the problem of employment scheduling which must take into account overtime and the cost of hiring and firing. The present paper presents a model which assumes that the cost is the sum of two terms: (1) a cost function of two variables $C(r, w)$, where r is the number of productive hours, and w is the number of people employed; (2) the hiring and firing cost $h(\Delta w)$, where Δw is the change in employment. The paper considers the following problem. Let a schedule of productive labor-hour requirements $r_0, r_1, \cdots, r_n$ be given: What is the employment schedule $w_0, w_1, \cdots, w_n$ that minimizes the total production cost? An explicit algorism to solve this problem is given under the conditions that (1) $C(r, w)$ is ditonic (composed of a monotonically decreasing and increasing function) in w, and (2) that $h(\Delta w)$ is proportional to Δw with different proportionality constants for hiring and for firing. The algorism is particularly adaptable to graphical techniques.

B6. The Development of the Basic Input Data in a Linear Programming Application, DONALD W. JENNINGS and FRANCIS G. WALKER, *Touche, Niven, Bailey and Smart, 1380 National Bank Building, Detroit 26, Michigan.*

This paper describes some of the practical considerations involved in the application of linear programming to a business problem and the manner in which the operating conditions are reflected in the basic input data used for computation. The paper relates experiences with a project being carried on at the Nekoosa-Edwards Paper Company, where linear programming is being applied weekly as an approximate method for optimum scheduling of the paper-making machines.

Basic to the paper-making industry, as in most process industries, is the diffi-

culty of establishing composite product profits and production rates suitable for practical linear programming purposes. It is particularly difficult where the application, as in this case, involves scheduling a primary product from which numerous end products are manufactured and where the product mix continuously varies. How realistic, usable profit and product rates were established and linear programming used as an integral part of the process of scheduling paper machines at Nekoosa-Edwards will be discussed.

B7. Use of the Transfer Function for Company Planning, GORDON K. JOHNSON, *Minneapolis-Honeywell Regulator Company, 2600 Ridgway Road, Minneapolis 13, Minnesota.*

The transfer function of servomechanism theory has been found to be a useful tool in certain phases of the company planning problem. The application of this theory to develop a relationship between sales and the required engineering effort in the aircraft equipment industry is described. Other potential uses of the transfer function in the overall planning problem are outlined.

D1. The Scope and Purpose of the Theory of Queues, WALTER L. SMITH, *University of North Carolina, Chapel Hill, North Carolina.*

An introductory account of the range of problems encountered in the theory of queues and an indication of some of the mathematical developments that have been made.

D2. The Rate of Production of a Group of Machines Subject to Irregularly Occurring Stops, DAVID R. COX, *University of North Carolina, Chapel Hill, North Carolina.*

Much work has been done to provide a basis for predicting the production expected from a group of machines under the care of one or more operatives. This work is reviewed with emphasis on the various complications that can arise.

D3. An Analogue Solution of a Machine-Minding Problem, E. D. PALMATIER, *University of North Carolina, Chapel Hill, North Carolina.*

A small electronic analog computer has been constructed as a pilot model to test the feasibility of using such devices to solve complex machine interference problems. Comparisons of results with certain theoretical predictions are given.

D4. An Artificial Realization of an Airline Operation by Means of a Digital Computer, JOHN COCKE, *Duke University and the University of North Carolina, Chapel Hill, North Carolina* **and JACK SILBER,** *Roosevelt College and Hq U. S. Air Force, Washington 25, D. C.*

The use of a digital computer to solve an airline scheduling problem is discussed and a particular application is described.

D5. A Priority Queuing Problem, J. Y. BARRY, *Division of Defense Laboratories, Massachusetts Institute of Technology, Cambridge, Massachusetts (Operations Evaluation Group, Navy Department, Washington 25, D. C.)*

Consider the following queuing problem. Priority one and two calls arrive at a single service channel in a Poisson manner with mean arrival rates λ_1 and λ_2 respec-

tively, where their service times are exponentially distributed with mean service rates μ_1 and μ_2 respectively. Each priority of call is served on a first-come first-serve basis. However, priority one calls are serviced before all priority two calls, and should a priority two call be in the service channel when a priority one call arrives it is replaced in the channel by the priority one call and reenters the queue.

Let P_n^m denote the probability that m priority two calls and n priority one calls are in the queue. By assuming that $\lambda_1/\mu_1 + \lambda_2/\mu_2 < 1$ and that the system is in a steady state, it becomes possible to derive (1) the generating function of P_n^m, (2) the probability that n priority one calls are in the queue, and (3) the expected number of priority one and priority two calls in the queue.

D6. Queuing with Preemptive Priority, HARRISON C. WHITE and LEE S. CHRISTIE, *Operations Research Office, The Johns Hopkins University, 7100 Connecticut Avenue, Chevy Chase 15, Maryland.*

Cobham's work on average waiting times for arrivals grouped into priority classes is extended to the discipline in which higher-priority items upon arrival actually interrupt service on any low-priority items. But further the need for finding the full distribution of waiting times is demonstrated. The differential-difference equation approach to waiting-line-length state probabilities is chosen for development. The preemptive discipline is found to be the simplest priority type to handle in this approach. An analysis in terms of the four basic two-dimensional difference equations is carried out for the equilibrium situation: we assume two preemptive priority classes at a single server, with assumed exponential arrival and service statistics for different mean rates. Models with indefinitely large and with finite waiting lines allowed are both discussed. Applications to communications systems and to machine breakdown are indicated.

D7. Two Queues with a Priority Rule and a Single Queue with Interrupted Service, FREDERICK F. STEPHAN, *P. O. Box 337, Princeton, N. J.*

The case of two queues served by a single server with priority of service to one of the queues is solved. The results are applicable to single-queue problems when the service is subject to interruption. Negative-exponential arrivals and departures are assumed but the results can be extended to certain other systems.

D8. Studies of the Characteristics of Queues in Tandem, A. W. MARSHALL, and EDGAR REICH, *The RAND Corporation, Santa Monica, California.*

The problem of analyzing the case when customers enter a second queue after having waited on a first queue involves examination of the arrival statistics at the second queue, and their effect on waiting time. Complications arise if the inter-arrival periods at the second queue are not independently distributed. Some characteristics of the system can be studied analytically. A further study is based on an application of Monte-Carlo techniques specially designed to take advantage of qualitative statistical properties of the situation.

D9. The QUEUEIAC: An Electromechanical Analog for the Simulation of Waiting-Line Problems, PAUL F. DUNN, *Operations Research Office, The Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase 15, Maryland,* **CHARLES D. FLAGLE,** *Department of Industrial Engineering, The Johns Hopkins University,*

Baltimore, Maryland, **and PHILIP A. HICKS,** *Naval Electronics Laboratory, San Diego, California.*

Of interest to ORO for several years has been the problem of improving the efficiency of Army communications systems. Involved in these studies, besides obvious problems of communications equipments, are problems of organization and human handling operations. To understand and offer solutions to these latter problems, electromechanical simulation equipment has been developed which displays the network of handling operations and provides estimates of congestion at any or all points in the system.

In the analog each node consists of a display and register unit upon which columns of lights represent items in a waiting line. Distributions of arrival times of input items and servicing times are programmed on standard teletype tape fed to the analog by teletype transmitters. The register unit at each point of the network displays the queue, computes state occupancy times, and provides estimates of state probabilities. Continuous records of the system states are maintained by pen recorders so that individual delay times and empirical estimates of their distributions may be obtained.

The register units may be connected in parallel or tandem, representing various sequential or parallel operations. Available as important queue disciplines are the handling of multiple inputs on a priority basis and the automatic adjustment of servicing rates according to transient loads.

(The research in this paper was done while the authors were at the Operations Research Office.)

E1. The Value of Information in Decision-Making, THORNTON PAGE, *Operations Research Office, The Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase 15, Maryland.*

An effort has been made to derive the value of military information empirically and semiquantitatively by reference to decisions actually made during a large ground-air field maneuver lasting 5 days. Input information, in the form of messages received at field army headquarters, was classified in 10 categories. Twenty-six major decisions by the army commander were identified, all considered of equal importance, and the categories of information were determined on which each decision rested. The inputs, compared with frequencies of such use (by category of information) showed deficiencies and excesses in the amounts of information available. The timeliness of the information received was analyzed in similar manner, and a combined figure of merit derived: The "sufficiency" of information available relative to the commander's decisions. These results were compared with those for a modified information-gathering system (only partly tested in the field) for which the sufficiency is estimated to be 50% higher than for conventional army reporting.

E2. The Effect of Background Information in Man-Machine Systems, ALDEN H. RYAN, *Naval Research Laboratory, Washington 25, D. C.*

Man-machine systems (such as a Navy CIC) function through the transmission and use of information. The messages carrying information frequently arrive at the user in incomplete and garbled state, due to noise in the system, and the user

must then reconstruct what he considers the most probable message. In making this reconstruction, the user is presumably aided by a background knowledge of the context of the message.

A preliminary experiment is reported which attempts to measure the degree to which the background information aids in the reconstruction of a garbled message. A very simple situation was chosen in which one group of subjects received messages with no context, and other groups received the messages with progressively more background information. It is shown that in some cases the effect of partial background may be to hinder the reconstruction of the message.

E3. Military Intelligence in War Games, JAMES HODGSON, *Technical Operations Incorporated, Combat Operations Research Group, Headquarters Continental Army Command, Fort Monroe, Virginia.*

A CORG model views intelligence in war games as a function of time. The function is assumed similar to that of a random event dependent on more than one independently variable "prerequisite event". As the number of prerequisite events increases the function approaches a delta function with all events occurring at mean time. Variation from the mean provides an index to the complexity defined as the number of "prerequisite events". An historical research program is in progress gathering empirical data on mean time lapses and variation from the mean of categories of military intelligence decisions and prerequisite information. Goals are (1) more realistic controls of intelligence injection in a sophisticated map maneuver called SYNTAC, and (2) the quantification of military intelligence for use in theoretical war games and combat operations analyses.

E4. Field Exercises and Maneuvers as Data Sources, JOHN C. BERNENS, *Technical Operations Incorporated, Combat Operations Research Group, Headquarters Continental Army Command, Fort Monroe, Virginia.*

A discussion of the problems encountered in attempting to collect operational data during regularly scheduled maneuvers and field exercises. The disadvantages are numerous—lack of combat realism, diverse objectives of data collection and training, and difficulties of control being the most serious. Among the advantages may be listed realistic space-time factors, ready availability of large numbers of troops, and the limited realism supplied by the tactical maneuver situation. Past experience in this type of field work is reviewed, and comparisons made with similar work conducted during the Korean conflict.

E5. Fractional Replication in Military Field Experiments, WILLIAM P. MURDEN, JR. and RAYMOND H. BURROS, *Technical Operations Incorporated, Combat Operations Research Group, Headquarters Continental Army Command, Fort Monroe, Virginia.*

Military field experiments are characterized by large numbers of independent variables, of which many are specifiable only qualitatively, and many are not subject to control. The availability of troops and equipment limits sample sizes and imposes a rigidity on test schedules. Rigid schedules are not compatible with sequential experimental methods, and small sample sizes frequently militate against complete factorial designs. The factorial experiment with fractional replication offers the possibility of reducing sample sizes while challenging the experimental

designer to use his knowledge of the subject under investigation rather than employ a routine design.

E6. Ship-to-Shore Lighterage: A Case Study from Military Logistics OR, WILLIAM H. SUTHERLAND, *Operations Research Office, The Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase 15, Maryland.*

A simple model of the operation of ship-to-shore cargo-ferrying lighters shows that the least cost per ton moved occurs with a relatively small-capacity lighter. The capacity of this lighter is considerably less than the size of the largest piece of cargo to be carried ashore. A frequency distribution of Army cargo size is used to determine an optimum cost-per-ton family consisting of members of two sizes, the larger being intended to carry the largest size piece of cargo and other pieces down to the capacity of the smaller lighter. The smaller lighter, of size to be determined by the computation, would take cargo sizes from its maximum capacity on down. Comments are made on validating the model by field experiments, the use of time-study data in operations research, and an exploratory investigation of the queueing of a group of lighters serving a number of hatches, the hourly output of which varies over a wide range.

E7. A Mathematical Model for Interdiction, JAMES A. RAFFERTY, CHARLES V. KREBS, and HOWARD MARTENS, *Weapons Systems Evaluation Group, Department of Defense, Washington 25, D. C.*

A mathematical model has been developed which describes certain aspects of two-sided warfare with special reference to build-up rates under logistic restrictions. The interaction of rail and highway logistical systems is included in the estimation of the logistical parameters. Under certain conditions of asymmetry the trade-off between interdiction forces and staying forces can be illustrated by the model. An example from the unclassified literature of World War II is included. The utility and limitations of the model are pointed out.

E8. Mathematical Modeling of Screw Worm Eradication Plans, R. A. LANGEVIN, *Technical Operations, Inc., 777 14th Street, N.W., Washington 5, D. C.*

E. F. Knipling (*Jour. of Econ. Entomology*, vol. 48 (1955), p. 459) appears to have been the first to suggest the possibility of eradicating an insect population by introducing sterilized males into the natural population. The feasibility of this procedure was demonstrated by the eradication of the screw worm population on the island of Caracao in 1954 (R. C. Bushland et al., *Science*, vol. 122 (1955), pp. 287–288). Clearly the effectiveness and cost of an eradication program of this sort are heavily dependent on the program adopted for the release of the sterile males. The present paper discusses the application of a mathematical model of an insect population to this cost-effectiveness problem. Typical results are presented for a variety of feasible release programs.

E9. Generalized Models in Operations Research, T. L. SAATY, *Division of Defense Laboratories, Massachusetts Institute of Technology, Cambridge, Massachusetts (Operations Evaluation Group, Navy Department, Washington 25, D. C.)*

In the course of development of any science, for example, physics and mathematics, knowledge is accumulated in small bits. When a certain amount of knowl-

edge is obtained, connections among the various pieces are perceived, a pattern becomes evident and a general picture or superstructure of the activity may be deduced.

The value of such a superstructure is two-fold: First, there is an esthetic appeal; and second, it permits a greater degree of understanding of a particular field of human activity. The activity is easier to teach, and problems are easier to solve when their general position in the superstructure is perceived.

It is felt that the activity which we call Operations Research is now sufficiently advanced that a first attempt at formulating a superstructure may be made.

E10. The Solution of a Certain Two-Person Game, RICHARD H. BROWN, *Division of Defense Laboratories, Massachusetts Institute of Technology, Cambridge, Massachusetts (Operations Evaluation Group, Navy Department, Washington 25, D. C.)*

Players I and II in a game each have one move to be made without the other's knowledge. Player II may move at any time, t_2, between 0 (now) and B (>0, a later time). Player I may move at any time, t_1, between 0 and $B + 1$. If $t_1 < t_2$, I receives an amount $1 - \theta, 0 < \theta < 1$. If $t_2 \leq t_1 \leq t_2 + 1$, I receives an amount 1. If $t_1 > t_2 + 1$, I receives nothing. It is shown that I and II have optimal mixed strategies, and that the value of the game to I is $(1 - \theta)/(1 - \theta^{n+1})$, where n is the largest integer not exceeding B.

F1. An Operations-Research View of Medicine and Public Health, WILLIAM J. HORVATH, *Airborne Instruments Laboratory, Inc., Mineola, New York.*

The organized practice of medicine affords many examples and opportunities for the application of operations-research methods. The three principal areas for such application may be described as technical, tactical, and strategic, by analogy with similar military categories.

The technical area has only recently been raised to prominence with the growth of quantitative measurement techniques in medical diagnosis. It covers a multitude of problems connected with data handling and analysis and their relation to the decision-making process of the physician.

By contrast, what we have called the tactical area is covered by the well-established sciences of epidemiology and medical statistics. Examples of problems solved by these methods will be cited, and the hazards and pitfalls of clinical surveys, mortality statistics and autopsy records will be dealt with.

Strategic problems in medicine, dealing generally with the distribution of effort in the different areas, suffer from the same uncertainties of sub-optimization and inadequate definition of goals and objectives as the analogous military problems, and consequently studies of these problems have equally inconclusive results.

F2. Mortality Study of Medically Impaired Lives, GORDON D. SHELLARD, *Metropolitan Life Insurance Co., One Madison Avenue, New York 10, N. Y.*

This paper describes a study made jointly by 27 large life insurance companies of the mortality associated with each of some 130 groups of medical impairments. The purpose of the study is stated and the records available are described. Techniques used in collection and analysis of the data are recounted and illustrative results are reported. The principal problems outstanding are listed and plans for a study of mortality by build and blood pressure are outlined.

F3. Evaluating Health-Screening Procedures, MARK S. BLUMBERG, *Public Health Service, Washington 25, D. C.*

The various objectives and means used in screening populations for disease conditions are briefly presented. Detailed consideration is given to the evaluation of screening done primarily to improve the health status of the screened community. Alternative numerical methods of measuring health benefits are given. The many variables which are subject to control by authorities directing the screening program are listed. A model is formulated for determining the optimum level at which the result of a test should be considered as positive (resulting in recall of the screened person for further diagnostic study). The proposed model is compared with other evaluation methods in use. Data from a diabetes survey are used as an example. The optimum level for screening is shown to depend not only on the biological characteristics of the test, but also on (1) the relative health value to the screened community of true and false positives and negatives, and (2) the prevalence of the disease condition in the population screened.

F4. The Joint Use of List and Area Sampling in Public Health Studies, HAROLD NISSELSON, *U. S. Bureau of the Census, Washington 25, D. C.*

The problem considered is the optimum design of a screening survey to provide a probability sample of all cases in a population for an experimental study to evaluate the costs and benefits of rehabilitation, certain cases in the population already being known to health, welfare and other agencies. Design theory for a survey based on joint use of a list (the "known cases") with area sampling, due to Hansen and Hurwitz, is extended slightly to the case in which an experiment is to be conducted on a subset of the sample. Since the theory involves certain prevalence rates, success rates and other parameters the values of which can only be guessed initially, the optimum design is searched in the course of the survey itself. The joint use of list and area sampling characterizes an optimum design for many public health studies. The survey discussed is a joint project of the U. S. Bureau of the Census and Community Studies, Inc., Kansas City, Missouri, undertaken as part of the total study being conducted by Community Studies, Inc.

F5. Logical Aid to Systematic Medical Diagnosis, ROBERT S. LEDLEY, *Operations Research Office, The Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase 15, Maryland.*

Textbooks and current periodical literature on medical diagnosis give the set of symptoms associated with a disease or else discuss the set of diseases associated with a symptom. The medical diagnostician must use this information, abetted by experience and insight, to determine the disease or diseases indicated by combinations of symptoms. Certainly it is difficult for a man to retain all this information and then to make mentally the logical sorting and combinatorial analysis necessary to deduce the disease associated with a combination of symptoms. Hence, as an aid to medical diagnosis the following system is suggested: A McBee sort card is associated with a disease and appropriately punched according to symptoms. By successive sorts on symptoms a deck of such disease cards can be reduced to one or several cards, thus aiding in the proper diagnosis. It is to be emphasized that

such a system is merely an aid to medical diagnosis and is not a mechanical substitute for experience, skill, judgment and insight. A demonstration will be given with a sample deck of disease cards.

F6. Application of Value Theory to Psychiatry, NICHOLAS M. SMITH, JR., *Operations Research Office, The Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase 15, Maryland.*

Value theory may provide a technical formalization particularly suited to the field of psychiatry. This viewpoint arises from a description of (1) conflict in decision and its means of resolution by dominance-suppression, schism, and concrescence, (2) the evolution of a value system by concrescences in an ever-widening area, (3) the structure of morale, and postulates of ultimate values relating to immortal and mortal systems. The therapeutical role of the psychiatrist may be formulated in terms of the aid he gives his patient in relieving embedded schisms by reviewing past experiences and performing new concrescences. A description of three states of fear reaction reveals that individuals whose values are based on postulates of their material immortality can result in a collapse of their value structure in the face of imminent probable death. A recovery of the value structure may result in a new system based upon postulates of mortality, or it may result in a new imprinting taken from the danger-fear situation. In this new imprintation all stimuli relevant or irrelevant to the danger situation become associated with the fear response, resulting in the state of anxiety continuously motivated by the everyday irrelevant stimuli.

F7. Operational Simulation in Medicine, ROBERT S. LEDLEY, *Operations Research Office, The Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase 15, Maryland.*

The methodology of operational simulation seems ideally suited for application to the analysis of many complicated and highly involved phenomena that occur so frequently in medicine and biology. When the formulation of such a simulation is aided by a systematic format (see abstract H13 by the author on A Format and Computational Aid) and the computations are performed on a high-speed electronic computer, the consideration of these phenomena becomes entirely feasible. These complicated biological phenomena with all their detailed feedbacks, interactions, and special considerations can be studied as entire entities. This method can be applied to the analysis of existing information and data about specific aspects of such systems as related to the whole, as well as to the planning and design of further investigations. As an illustration of such a simulation, the phenomena of the regulation of the heart and circulation of the blood will be discussed.

G1. Maintenance of a Group of Machines Utilized Intermittently and Subject to Several Types of Malfunctions: I. Operational Requirements and Resource Allocation, W. P. SEWELL, *The RAND Corporation, 1700 Main Street, Santa Monica, California.*

A group of machines must meet requirements of expected utilization rates and expected stand-by rates. The machines are subject to several kinds of malfunctions requiring different repair resources. The determination of preferred (in the sense

of lower cost) maintenance-resource mixes is considered. The cases of no substitution between resources, substitution with absolute advantage among resources, and substitution with comparative advantage among resources are considered. Several utilization scheduling policies are compared. Costing with special attention to the relation to requirements and to differences for the steady state and the transient cases is discussed. The explicit solution to some of the queuing problems involved is discussed in Part II.

G2. Maintenance of a Group of Machines Utilized Intermittently and Subject to Several Types of Unscheduled Malfunctions: II. Queuing Problems, D. S. STOLLER, *The RAND Corporation, 1700 Main Street, Santa Monica, California.*

The queuing problem for a group of machines is formulated so that account may be taken of both (1) machine utilization policies which set the activity level of those machines not requiring repairs as a function of the number of machines requiring repairs, and (2) maintenance scheduling policies which allocate resources to repairs in accordance with the numbers of machines requiring repairs of various types. Solutions in simple form are given for the steady-state probabilities of the number of machines requiring repairs of various types for some special classes of interest. One class of solutions contains the case of m_i repairmen of type i, $i = 1, \cdots, k$ as a special case.

G3. Priority Assignment in Waiting-Line Problems Involving a Single Channel, MAJ. SAM A. DRESSIN (USMC), *U. S. Naval Postgraduate School, Monterey, California, and The RAND Corporation, 1700 Main Street, Santa Monica, California.*

The study described assumes that units of each priority level arrive in accordance with independent Poisson laws and that all units possess the same exponential service-time distribution. Expressions are derived for the probabilities of the system states, the characteristic function and moments of the waiting-time distribution function, and an approximate solution for the waiting-time distribution function. The study's relation to the work of Cobham (*Jour. of the Opns. Res. Soc. of Am.*, vol. 2 (1954), pp. 70–76) is discussed.

G4. Estimation of Reliability Growth in a Complex System with Poisson-Type Failure, HERBERT K. WEISS, *Weapon Systems Analysis Department, Northrop Aircraft, Inc., 1001 East Broadway, Hawthorne, California.*

Many modern complex systems, especially those involving numerous electronic components, are subject to failures with operating time which follow a Poisson-type distribution. In the course of development of such a system engineering changes are made, with the object of improving system performance or reliability. As a result, no two successive assemblies are alike in all components, although only a few changes may have been made across assemblies.

It is nevertheless desirable to know at the earliest possible time in the development program (1) the level of reliability of the system, (2) whether reliability is increasing, and if so, how rapidly, and (3) the expected reliability at the end of the projected development program.

In this paper, methods are developed for fitting typical reliability growth curves to experimental data by the method of maximum likelihood. Simple mathematical models are also developed for the engineering development process to provide a logical basis for the selection of suitable growth curves.

G5. Methods of Optimum Assignment of Redundant Parts to Increase Reliability, W. R. ALLEN, *RCA Laboratories, Princeton, N. J.*, **and N. R. GOODMAN,** *New York University, New York, N. Y.*

The mathematical model considers a complex mechanism composed of n types of components which fail independently. It is possible to improve reliability of the mechanism by using $K_i \geq 1$ of the ith type of component where there are restrictions on the system as to total weight, volume, power requirements, etc. Two cases are considered:

For Case 1, assume items of type i fail with probability P_i and never return to life. Further, assume that the side conditions can be formulated as a set of linear inequalities. This problem is then a relatively simple nonlinear programming problem. An algorithm is given for making optimum assignments with certain restrictions on the nature of the side conditions.

For Case 2, assume that items of type i go out of operation at some time in accordance with a probability distribution F_i and return to life in a time t after failure with some distribution function G_i. This may be recognized as a problem in inventory analysis or in the theory of queues with many types of customers and specialized servers. A criterion for such assignment is given based on a simple cost function.

The research reported in this paper was done while both authors were members of the Analytical Research Group, Princeton University.

G6. Probability of Safe Approach of an Aircraft for Landing, Using Electronic Low-Approach Aids, WILLIAM GRODOWITZ, *Operations Analysis Office, Hq Air Proving Ground Command, Eglin Air Force Base, Florida.*

Data available on the accuracy of aircraft positioning with several landing approach aids have been analyzed statistically to deduce estimates of the probability of successful approach to varying size aircraft fields. The calculations of this study are based almost entirely on accuracy of approach positioning data for twin-reciprocating-engine-powered aircraft. The techniques involved, however, can be generalized to apply to jet aircraft. The basic types of approach aids considered, in descending order of complexity, were the Instrument Landing Approach System, the Flight Director System, and the Ground Controlled Approach System.

G7. A Monte Carlo Analysis of the Ground-Controlled Approach System, ALFRED BLUMSTEIN, *Cornell Aeronautical Laboratory, Inc., 4455 Genesee St., Buffalo 21, N. Y.*

The Ground-Controlled Approach (GCA) is an all-weather landing system in which a ground controller, watching the landing airplane on a radar scope, transmits maneuver orders to produce a proper approach path. By a Monte Carlo analysis of this system, it has been possible to estimate the distribution of airplane positions along the approach path, and the probability of a successful landing. Sample

flight paths have been simulated by using random numbers to represent the stochastic variations in initial position, wind, controller decisions, and execution-of-turn orders.

G8. Some Applications of the Monte Carlo Method to the Problem of Predicting Positions in Orbits, DAVID E. VANTIJN, *General Electric Co., Court Street, Syracuse, N. Y.*

The problem considered is that of predicting the position of an earth's satellite in its orbit, using as inputs radar observations, and as outputs the position of the satellite at some fixed future time. The first formulation is as a statistical problem, inputs and outputs all being random variables. In this form the problem is so intractable that only Monte Carlo methods can give an insight into the propagation of errors, and then only for one set of values of the parameters at a time. With the insight gained, successive parts of the process can be formulated approximately analytically, and Monte Carlo methods used to yield results of increasing generality.

G9. Bayes Solutions of Some Simple Statistical Decision Problems, THOMAS E. OBERBECK, *U. S. Naval Postgraduate School, Monterey, California.*

Solutions are obtained for some specific problems which may be stated in the following practical terms: The results of stochastically independent trials of a weapon system are valued as success (1) or failure (0) and the true probability of success, p, of the weapon system is unknown. It is assumed that any value of p in the interval [0, 1] is equally likely. As an estimate of p we choose p_e, the fraction of any finite number of trials which result in success. At the conclusion of testing the weapon system is accepted (terminal decision d_1) if $p_e \geq \theta$ and rejected (d_2) if $p_e \leq \theta$. A simple symmetric weight function $W(p, d_i)$, $i = 1, 2$, is defined; if the true p is such that $0 \leq p \leq \alpha \leq \theta$, then the cost of wrong decision when the weapon system is accepted is 1^* (one value unit), and if the true p is such that $\theta \leq 1 - \alpha \leq p \leq 1$, then the cost of wrong decision when the weapon system is rejected is 1^*; otherwise, there is no penalty attached to the difference between p_e and p for either terminal decision. The cost of one trial is c where $0 < c < 1^*$. The Bayes solution provides, prior to actual testing, values of N_m and N_M, the minimum and maximum number of tests which will be conducted before a terminal decision is reached. Such information is useful in planning and scheduling tests. The solutions obtained are for specific sets of values of α, c, and θ.

G10. Bombing Problems, ANDRE G. LAURENT, *Department of Statistics, Michigan State University, East Lansing, Michigan.*

Under the assumption that errors in range and deflection cause the coordinates of the points of impact to obey a bivariate normal distribution, the basic problems arising in bombing situations can be classified as follows:

(1) *The bomber's viewpoint*, in which the target and bombsight (and hence the distribution's parameters) are known. The problem is that of obtaining the probability that a bomb will drop inside a given area.

(2) *The opponent's viewpoint*, with a known or unknown target. The available information consists of the set of points of impact during a flight. The problems are (*a*) estimating the probability of a "hit" inside a given area, (*b*) testing hy-

potheses about such a probability, and (c) defining "safe" areas such that one can state with a given probability of being right that the probability of a "hit" will be at most equal to a given value.

Some of these problems are considered. The paper gives a method of obtaining the uniformly minimum-variance unbiased estimate of the probability of a "hit" inside a given area and illustrates it with a few examples.

G11. The Dynamics of Military Combat, HOWARD W. BRACKNEY, *Convair, A Division of General Dynamics Corporation, San Diego 12, California.*

A dynamics of military combat is presented which predicts theoretically certain classical characteristics of real warfare. Theoretical developments proceed from the early work of Lanchester who was concerned with the duel and with the symmetric assault for which he derived the so-called Lanchester "linear law" and Lanchester "square law", respectively. Alternatively, the present dynamics distinguishes three fundamental combat situations (or configurations) of practical interest by injecting into the theory a reconnaissance requirement and concept. Configuration I is Lanchester's "square law" case, the symmetric assault marked by a total lack of the reconnaissance requirement. Configuration II is a "linear law" case, the symmetric fire fight or barrage marked by the existence symmetrically of cover and the need for reconnaissance. Configuration III is a non-symmetric, mixed linear-quadratic case representing the most usual combat situation, in which one adversary openly attacks another occupying under cover a defended position or deployment. The fundamental requirements for decisiveness in combat are elucidated by the analysis.

H1. Predicting Penetration Distances for Guided Missiles—A Simplified Analytical Model, JOHN W. GOST, *Weapons Systems Evaluation Section, The Glenn L. Martin Company, Baltimore 3, Maryland.*

In evaluating future weapons systems, the evaluator desires to know whether the advanced-design project engineer has properly combined the various characteristics of payload and lethality, vehicle weight, speed, and range when considering the mission to be accomplished and the enemy's defensive capabilities in the time period involved. This paper points out some similarities between a guided missile approaching enemy territory and a neutron approaching a mass of material. Arbitrary potential capture cross-sections have been derived for an enemy's defensive capability against a friendly guided missile system. This data together with other pertinent probabilities has led to an analytical method for determining penetration distances. The results are then compared with the preselected specifications. Necessary specification adjustments are then made to the missile to ensure performance of mission at maximum vehicle efficiency and least weapons systems cost.

H2. A Linear Model for a Support-Personnel Calculation, JOHN D. C. LITTLE, *Combat Operations Research Group, Headquarters Continental Army Command, Fort Monroe, Virginia.*

An Army division can be considered to consist of combat troops and support troops. The combat troops man the various weapons whereas the support troops

provide the combat troops (and also themselves) with food, ammunition, communications, transportation, construction, medical service, etc. In considering possible changes in army organization, it is desirable to be able to determine rapidly what support troops would be required by various different numbers and kinds of combat troops. A simple model has been set up in which the number of a given kind of support personnel depends linearly on the number and kinds of personnel supported. The model and its manipulation will be discussed.

H3. A Method for Computing Survival Probabilities of a Group of Targets, JANE C. INGERSOLL, *University of Maryland, College Park, Maryland.*

Infantry squad weapons are evaluated against a background of a rifle squad attacking a position defended by riflemen. The behavior of the attackers and defenders is characterized by simultaneous action within each squad. The defenders fire as a group, volley by volley. There are T attackers initially. The set of probabilities that t attackers ($t = 0, 1, \cdots, T$) will survive the vth volley is computed for use as a basis for weapons comparison. Under certain restrictive conditions the set of probabilities forms a Markov chain. For certain ranges of the variables there are some simple approximations to the expected number of survivors. A method is outlined in which the survival probabilities can be calculated when the two groups fire at each other. (The research in this paper was done at the Operations Research Office.)

H4. A Model Technique for Analyzing Flow-Type Networks, S. NOZICK, *Combat Development Department, Army Electronic Proving Ground, Fort Huachuca, Arizona.*

A technique for analyzing complex networks is presented. This technique is applicable to telephone systems, highway nets and other similar systems. The example quoted as illustration is a communications net utilizing telephone, radio and VHF links. Analysis is possible of local and overall system capacity, including the effects of different tie-thrus at various subcenters. Figures of merit are obtained for message capacity and operating manpower efficiency at sub and main switching centers. The effect of relocating the system can be analyzed in steps as well as the effects due to communication channel or subcenter failure. It is possible to predict the effects of temporary rerouting on tie-thrus under such conditions. This analysis is basically one of a fixed system; however, the effects of moving a system by temporarily relocating different elements can be analyzed by a series of stationary-system analyses.

H5. The Analysis of War Gaming, P. R. NEWCOMB, *Operations Research Office, The Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase 15, Maryland.*

An experimental design for war gaming is recommended that will (*a*) determine the validity and internal logical consistency of the particular game and (*b*) assist in drawing inferences from the game.

For economic reasons, confounding is deliberately introduced into the design of the experiment. Multiple regression techniques are applied in the analysis. Each variable can be considered to contribute linear and other effects. With this method

the limits of the linear effects of each and every variable are determined in three plays of the game multiplied by the number of variables. Higher-order effects are detected and then solved for with no additional plays.

H6. Some Methodological Requirements for Experimentation on Organizational Concepts, DONALD W. MEALS and ROBERT P. GECKLER, *Technical Operations Incorporated, Combat Operations Research Group, Headquarters Continental Army Command, Fort Monroe, Virginia.*

The need is noted for experimental studies as a basis for decisions on organization where equipment and operating concepts are changing radically. Limitations in currently available methods are discussed. Attention is called to areas of methodological development required for research with large organizations. Suggestions are offered as a point of departure in each of these areas.

H7. CORG, A Scientist-Army Officer Operations Research Group, FRANKLIN C. BROOKS and COL. HORACE K. WHALEN, *Combat Operations Research Group and Combat Developments (respectively), Hq Continental Army Command, Fort Monroe, Virginia.*

The Combat Operations Research Group is operated jointly by Technical Operations, Incorporated, of Arlington, Massachusetts, and the Combat Developments Section of Headquarters, Continental Army Command. It performs theoretical and experimental operations research to develop criteria of good combat organization and tactics for the Army in the future.

Although both theoretical and experimental research methods are used, particular emphasis is being placed on experimentation in the field with troops and weapons to get those basic quantitative data necessary to test and support theory.

The concept of operation and general program of CORG will be discussed from both the civilian and military point of view.

H8. The Marginal Preference Model: An Approach in Operations Research, P. H. BENSON, *Division of Social Studies, Drew University, Madison, New Jersey.*

The measurement of preference by procedures involving a standard error of judgment as a metric unit enables operations research to be applied to situations where the objective is to satisfy human wants as fully as possible. These situations confront business management in finding the best product design or the most effective choice of merchandising methods, and confront government in optimizing the feeding, clothing, living arrangements, and recreation of institutional populations. The marginal preference model provides an approach to these problems. The model is based upon the principle of finding the optimal preference of consumers when preference is psychologically measured and expressed as an empirical function of variables of business or government procedures. The optimization problem involves the solution of simultaneous equations obtained by partial differentiation of the preference-cost function with respect to its independent variables under the restriction of limited cost outlay. An iterative procedure for solving simultaneous equations of higher degree is proposed. A research committee composed of Lawrence Abbott, P. H. Benson, H. O. Gulliksen, J. E. Karlin, and L. R. Tucker is investigating applications of the model.

H9. A Proposed Measure for Determining the Value of a Design, L. IVAN EPSTEIN, *Armament Section, The Glenn L. Martin Company, Baltimore, Maryland.*

Two proposed competitive designs, for example of aircraft, will generally differ in a variety of characteristics. It is desired to give a function of these characteristics which gives the over-all value of the design. The function proposed is a product of powers. The exponents are positive for desirable qualities, negative for faults, large (small) in absolute value for important (unimportant) characteristics. This form of function is proposed because the ratio of the values of two designs is then independent of the units of measurement.

With the aid of the proposed value function, the choice between competitive designs could be made more objectively than at present. The exponents in the function could be decided on jointly by customer and contractor before design work is begun.

H10. The Application of Flow-Chart Methodology to the Ground-Support Areas of Military Operations Research, STANLEY HAUER, *Tactical Engineering Group, Hughes Research and Development Laboratories, Culver City, California.*

The paper is a presentation of a specific flow chart and its relationship to the processes of operations research. It describes the columnar headings of the chart and how they have been designed to answer any who, what, where, how, or when question relative to the handling of a weapon on the ground. The stages of purpose of operation, measure of its effectiveness, and improving its effectiveness are then related to the information content of the chart.

H11. Stochastic Duels, TREVOR WILLIAMS and CLINTON ANCKER, *Operations Research Office, The Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase 15, Maryland.*

In most, if not all, small-unit tactical problems, the basic element is the duel. Analytic solutions of stochastic models of certain duels are presented here. The solution is the probability that a given side will win. Particular cases, considered in order of increasing complexity are as follows.

(1) Each round either kills or misses. Firing time is a random variable. Firing continues until a kill occurs on either side. The kill probabilities are (*a*) constant, (*b*) time-dependent, or (*c*) round-dependent.

(2) In addition to a kill or a miss we may admit the possibility of a near-miss which causes a temporary suspension of fire on one side.

H12. Some Applications of Simplified Analytic Drag Relations, KENNETH S. COOK, *Air Force Armament Center, Eglin Air Force Base, Florida.*

When weapon-effectiveness studies are based upon the selection of a proper model and upon the use of satisfactory analytic relations for the many parameters, then an investigator can retain a comprehensive picture of the physical problem under study. In general, ballistics data are not available in a sufficiently simple form. However, in the case of studies on gunnery armament for high-performance fighters, there is a useful method available which permits an adequate analytic estimation of time of flight and terminal velocity. This is based on work done at

Aberdeen by Sterne, Dederick, and R. N. Thomas over a decade ago; but, except for Type 5 projectiles at standard velocities, it does not seem to have been extended and utilized in general. The method becomes relatively more accurate as higher muzzle velocities and higher aircraft speeds are considered, and could be a useful tool, readily learned by flying personnel or adapted to an analog device. After describing the basis of the method, a few practical examples will be demonstrated.

H13. A Format and Computational Aid for Operational Simulation (Gaming), ROBERT S. LEDLEY, *Operations Research Office, The Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase, Maryland.*

Operational simulation (also called operational gaming or war gaming) appears in many instances to be the only method presently available for solving certain highly complicated operations-research decision problems. The method essentially consists in simulating the decision or sequence of decisions under consideration. A detailed discussion of the rationale behind the method can be found elsewhere; however, operational simulation promises to become an important operations research method in many fields of industry, government and science. The format for operational simulation is designed to (*a*) help the translation of an intuitive game concept into specific events, (*b*) aid the formulation of each event by isolating it from other events, and (*c*) present the completely compiled game in a format best suited for playing on a high-speed computer. Associated with this format is a program which prepares a computer so that any game may be compiled directly on and then played automatically by the computer. This program is designed so that (*a*) preliminary coding of a game is reduced to a minimum, (*b*) any event can be changed, replaced, or omitted directly on the computer independently of the other events of the game, (*c*) the computer automatically determines the next event and performs the proper calculations, (*d*) the players' decisions are put directly into the computer, and (*e*) trial decisions can be calculated by the computer on the basis of imprecise data such as those obtained from intelligence in war games.

NOTE: Copies of the above papers are not available either through the SOCIETY or the EDITOR. Persons interested in obtaining copies of the papers presented should contact the authors directly.

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