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Operations Research Society of America—Fourteenth National Meeting, St. Louis, Missouri, October 23–24, 1958

Operations Research Society of America

FOURTEENTH NATIONAL MEETING

St. Louis, Missouri, October 23–24, 1958

THE Fourteenth National Meeting of the OPERATIONS RESEARCH SOCIETY OF AMERICA was held in St. Louis on October 23 and 24, 1958 at the Statler-Hilton Hotel. This being the first meeting of the SOCIETY held in the Mississippi Valley, the meeting was sub-titled "The Four-Flags Meeting" in recognition of the geography and history of the area which at various times was under the flags of Spain, France, Great Britain, and the United States. There were 271 registrants, including 178 members, 85 non-members, and 8 students.

There were six sessions of invited papers including one all-day session and one half-day panel discussion, and three half-day sessions for contributed papers. There were 22 invited papers, 29 contributed papers and one still and one moving picture—a photograph taken at the luncheon and a film on Air Force Logistics. There was one half day devoted to small working parties for discussion of special subjects of interest. The subjects of the individual sessions, and their chairmen, were:

A. *Working Parties*	DAVID B. HERTZ Arthur Andersen & Company
1. Strategic Business Decisions	ROBERT S. WEINBERG International Business Machines Corporation
2. Logistics Data Processing	CHARLES A. PHILLIPS Department of Defense
3. Progress and Prospect in Queue Theory	HERBERT P. GALLIHER Massachusetts Institute of Technology
4. Marketing and Distribution Problems	ROGER CRANE Touche, Niven, Bailey and Smart
5. Military Transportation	ALLEN R. FERGUSON Northwestern University
6. Intuition, Conviction, Action	THORNTON PAGE Wesleyan University
B. *Case Histories Five Years After*	C. WEST CHURCHMAN University of California

C. A Decade of Military Operations in Perspective	A. W. Boldyreff University of California, Los Angeles
D. Methodology and Applications	George E. Nicholson, Jr. University of North Carolina
E. Contributed Papers	Richard A. Fitzgerald McDonnell Aircraft Corporation
1. Military	William F. Blaylock Headquarters Air Defense Command
2. Industrial	David B. Hertz Arthur Andersen & Company
3. New Development, Organization and Communications	E. Leonard Arnoff Case Institute of Technology
F. Military Logistics Research	Charles J. Zwick The Rand Corporation
G. Applications in Extraction Industries	Ernest Koenigsberg Touche, Niven, Bailey and Smart
H. The Lunar-Base Problem	E. W. Paxson The Rand Corporation

In Session C the following three papers were given in addition to those listed in the abstracts:

C2.1 *Operations Research for the Air Force*—Robert D. Specht, The Rand Corporation
C2.2 *Operations Research for the Secretary of Defense and the Joint Chiefs of Staff*—George Pugh, Weapons Systems Evaluation Group
C2.3 *Operations Research in the Canadian Department of National Defence*—Ronald H. Lowe, Defence Research Board (Canada)

These papers were followed by a panel discussion led by Omond M. Solandt, Canadian National Railways.

Other papers given but not listed in the abstracts were:

F.2 *A Simulation Model of Air Force Maintenance Operations*—Richard B. Rainey and Robert A. Levine, The Rand Corporation
F.3 *Time-Phasing Relationships in Determining Merchant Ship Requirements for Requirements for Overseas Cargo Lift*—Erling F. Rosholdt and Ralph B. Hunt, George Washington University

Social functions consisted of mixers on the evenings of October 22 and 23 and luncheons on October 23 and 24. An address of welcome was given at the luncheon on Thursday, October 23 by The Very Reverend Paul C. Reinhart, s.j., President of St. Louis University. At the luncheon on Friday, October 24, Thomas M. Ware, President, International Minerals and Chemical Corporation, spoke on "The Executive Viewpoint."

Members of the Program Committee for the Fourteenth National meeting were: Oliver G. Haywood, Jr., *Meeting Chairman;* Seymour T. R. Abt, *Arrangements Chairman;* James H. Batchelor, *Program Chairman;* Alexander W. Boldyreff,

C. West Churchman, W. P. Cunningham, Richard A. Fitzgerald, Herbert P. Galliher, Murray E. Geisler, David B. Hertz, Ernest Koenigsberg, R. B. Ladd, George S. Little, George E. Nicholson, Jr., E. W. Paxson, Donald H. Schiller, and Omond M. Solandt. The St. Louis Convention Bureau and Stix, Baer & Fuller provided registration clerks for the meeting.

REPORT OF THE SECRETARY

At its meeting in St. Louis on October 22 and 23, 1958, the Council of the Society took a number of actions of general interest to members of the Society:

1. Upon the recommendation of the Publications Committee, the Council voted to begin a new publication in 1959: *The Bulletin of the Operations Research Society of America.* The purposes of the *Bulletin* (to be published initially twice a year) will be to publish programs and abstracts for forthcoming meetings; material concerning the administration of the Society, such as the reports of the Secretary, Treasurer, meeting chairmen, and committees; and other material of general interest to the Society's membership. The desired result is to free the pages of Operations Research from material of this kind. The *Bulletin* will be edited by the Secretary of the Society, and it will be mailed to all members of the Society and subscribers to Operations Research; the first issue will appear early in April of 1959.

2. Also upon the recommendation of the Publications Committee, the Council authorized the publication of review volumes on operations research, to contain an appropriate selection of authoritative review articles. Dr. Russell L. Ackoff was selected as the editor of the first volume.

3. The Council agreed on the need for a comprehensive international review journal to publish digests and summaries of articles and books of interest to operations-research workers, and recommended that the International Federation of Operational Research Societies give this need its early attention.

4. The Organizing Committee for the International Federation of Operational Research Societies (with Dr. Thornton Page as ORSA's member) produced in September 1958 an agreed draft of proposed Statutes and By-laws for the Federation. The Council ratified these proposed Statutes and By-laws without change. Since the Operational Research Society of the United Kingdom has already ratified the Statutes and By-laws, the Federation will come into existence as soon as they are ratified by the Société Française de Recherche Opérationelle. (Further details will be published in the first issue of the *Bulletin* of the Society.)

5. The Council passed a motion extending its heartiest greetings and welcome to the newly founded Canadian Operational Research Society. The Council also directed that a new By-law be prepared, for presentation to the next Annual Meeting of the Society, to permit a 20 per cent reduction in ORSA membership fees for members of CORS. (CORS has already adopted a similar discount for members of ORSA who wish to join CORS.)

6. The Council approved the following sites for future meetings of the SOCIETY: Pasadena in November 1959, the New York area in Spring 1960, Detroit in Fall 1960, and Colorado Springs in Spring 1961.

7. The Council elected 39 new Members. (Their names will appear in the first issue of the *Bulletin*.)

8. The Council considered the present criteria for election to Membership in the SOCIETY and adopted some changes that will be brought to the attention of the membership in an early communication from the Membership Committee.

HUGH J. MISER

ABSTRACTS

B1 Review of: "Traffic Delays at Toll Booths," The Journal of the Operations Research Society of America, May 1954, Volume 2, Number 2, pp 107–138, LESLIE E. EDIE, *N. Y. Port Authority, 111 8th Ave., New York 11, N. Y.*

B2 Unsuccessful Case Studies and Why, An analysis of underlying difficulties in putting Operations Research recommendations to work. RUSSELL L. ACKOFF, *Case Institute of Technology, Cleveland 6, Ohio*

B3 Review of: "A Basis for Strategic Designs on Inventory Control Operations," Management Science, October 1955, Volume 2, Number 1, pp 69–82, GEORGE J. FEENY, *General Electric Company, New York City*

B4 Review of: "Can Scientific Sampling Techniques be Used in Railroad Accounting?", Railway Age, June 9, 1952, Volume 132, Number 23, pp 61–64. C. WEST CHURCHMAN, *School of Business Administration, University of California, Berkeley, California*

C1.1 Operations Research for the U. S. Navy Since World War II, JOSEPH H. ENGEL, *Operations Evaluation Group, Office of the Chief of Naval Operations (Op03EG), Navy Department, Washington 25, D. C.*

A review is presented of operations research done for and by the U. S. Navy since World War II, in an attempt to distinguish major trends which have occurred and major lessons which can be learned. Of particular interest are:

a. The manner and degree to which the Navy has adopted specific OR techniques and developed a capability for handling by itself many classes of problems originally assigned to the Operations Evaluation Group, thus freeing operations research workers to develop new fields.

b. The trend towards dealing with problems of continually increasing scope, involving greater difficulties in the selection of objectives and of measures of effectiveness.

c. The degree to which the Navy has made use of analytical studies, and the factors which determine their utility and manner of implementation.

d. The influences of the state of technology and of the worldwide political atmosphere on the type of research conducted, and the environment in which it takes place.

Specific examples are cited from the work of the Operations Evaluation Group and its sister organization, the recently organized Naval Warfare Analysis Group. Suggestions are presented concerning likely future trends in military operations research, and some key problems of the future are discussed.

C1.2 Operations Analysis in the Postwar Air Force, HUGH J. MISER, *Operations Analysis Office, Headquarters U. S. Air Force, Washington 25, D. C.*

This paper discusses the activity of the Operations Analysis Offices in the postwar Air Force. After discussing the organization of these offices and their growth, some characteristics of their work are described. Finally, some current problems and difficulties attending this work are set forth.

C1.3 The Growth of Army Operations Research, W. L. WHITSON, *Operations Research Office, USA*

Current methodology and techniques in Army operations research will be reviewed and their progress over a period of years noted. The necessary balance between theory and experiment will be discussed in relation to interactions between men, equipment, and environments. A capability will be proposed for broad group syntheses with considerations progressing through weapons systems, tactics and strategy. The necessity for emphasis on long-range problems will be argued. Discussion will include operational gaming and its dependence on a computing machine laboratory; and the general dependence of analysis on the latter. Finally, some proposals will be made of the future growth, value and limitations of operations research applied to Army problems.

D3 Centralization or Decentralization of Case's Library Facilities, M. W. SASIENI & H. D. MERCHANT, *Case Institute of Technology, Cleveland 6, Ohio*

Case Institute is an engineering school with approximately 1500 undergraduate and some 700 graduate students. Many of the latter attend only on a part time basis. At the present time Case possesses a main library and six staffed departmental libraries. Since the building housing the main library is due to be demolished the administration is concerned to replan the entire library system with a view to providing better facilities for users while at the same time keeping costs to Case as low as possible. A sample survey was made so that current user requirements in the various libraries could be compared with their operating costs. By projecting requirements and costs it was possible to make recommendations about a future system.

E1.1 Optimum Properties for Defense Strategy of Equal Attack Against All Targets, JOHN E. WALSH, *Operations Research Group, System Development Corporation, 2400 Colorado Avenue, Santa Monica, California*

Mathematical models for offense-defense interactions often specify that each member of an offense force receives the same amount of attack from the defense. This equal attack condition is usually motivated by the assumption that the members of the raid are indistinguishable to the defense and randomly arranged in their exposure to attack. This paper shows that the equal attack per raid member procedure has desirable properties when viewed as a deliberate defense strategy. Namely, it is optimum in a game theory sense for an important class of situations even if the defense is considered to have more knowledge about the raid and more attack capabilities than would ordinarily be available. The additional knowledge consists of the ability to segregate the members of the offense force into groups which have the same route, payload, and payload destination. The additional capability consists of the ability to separately attack the members of a group without suffering kill degradation from the presence of the other members of the raid.

E1.2 Development and Applications of a Terminal Air Battle Model, **JAMES L. TAYLOR,** *Northrop Division, Northrop Aircraft, Inc., 1938 Lees Avenue, Long Beach 15, California*

The development of a Monte Carlo type Fighter-Bomber Terminal Engagement Model is presented. Sequential sampling techniques are applied to the Stochastic process of Fighter-Bomber duel, allowing realistic evaluation of the effects of airborne vehicle and equipment characteristics, bomber countermeasures, fighter tactics and counter tactics, and Fighter-Bomber intelligence exchange upon the outcome of Terminal Air Battle.

Procedures employed for IBM-797 and IBM-704 programming and check-out of model mechanization will also be discussed briefly. Finally, applications of the Fighter-Bomber Terminal Engagement Model are presented along with typical results of machine computations.

E1.3 Consideration of Subsystems Apart from the Total System, **WILLIAM W. FAIN,** *Aircraft Systems Analysis Group, Chance Vought Aircraft, Dallas, Texas*

Certain considerations are explored treating the conditions and restrictions sufficient for making decisions concerning portions of military operations or subsystems independently and apart from the total operation or system. If the operation or system is expressed in terms of game theory, the separation of the system or operation into independent subsystems can be related to the functional form of the payoff elements and independent decisions for the subsystems require that the payoff elements be functions of the subsystem elements such that dominant rows and columns result. Two examples are given to illustrate the theory developed.

E1.4 System-versus-System Analysis of the One-Stage Binary Decision Situation, **PHILIP L. STOCKLIN,** *U. S. Navy Underwater Sound Laboratory, Fort Trumbull, New London, Connecticut*

Strategies yielding extremum average outcomes are known for the cases of (1) no-system versus no-system, and (2) system versus no-system, for the one-stage binary decision situation. This paper develops such strategies for the case in which each side has a physical system yielding stochastic information of the opponent's decision. The strategy of each side is a Bayes solution on its own Receiver Operating Characteristic curve; consideration of the Receiver Operating Characteristic curves for both sides leads to the minimax solution to the problem. Reduction of cases (1) and (2) is given, and game-decision relations are indicated. The system versus system technique developed for the one-stage binary decision situation is basic to multi-stage or multi-decision problems.

E1.5 Analysis of a Ternary Decision and a Multi-stage Game, BENJAMIN F. CRON and CARLETON S. WALKER, *U. S. Navy Underwater Sound Laboratory, Fort Trumbull, New London, Connecticut*

A two sided (Attacker versus Defender) single-stage ternary decision situation is analyzed for the case of stochastic information. It is assumed that the defender has a system, and (1) that the attacker does not know this, and (2) that the attacker does know this.

A multi-stage game is constructed. An extension of the Attacker-Defender game is considered for the following cases: (1) no information, (2) complete information, (3) stochastic information to the defender, no information to the attacker. Case (1) admits a straightforward minimax solution of a two-person, zero sum, single-stage game with a large, but finite, number of strategies. By considering case (2) in terms of the Dynamic Programming approach to multi-stage games, a solution involving a recursive series of two-strategy games can be obtained. The solution to case (3) requires a combination of the above methods together with a posteriori information processing.

E1.7 An Analysis of Parameters which Affect Readiness Probability, JAY B. HEYNE and LEWIS BROTMAN, *Systems Analysis Laboratory, Hughes Aircraft Company, Culver City, California*

A population of N equipments was considered. Utilizing the queuing theory, it has been possible to obtain relationships from which variations in readiness probability may be determined as the following basic parameters are varied.

(1) N population size
(2) λ average breakdown rate of equipment
(3) γ number of repair channels
(4) μ average repair rate for equipments

Graphs are presented which illustrate these relationships.

E1.8 Statistical Isolation of Learning and Other Phenomena in the Man-Hours for Overhauling Aircraft, KENNETH W. WEBB, *Corporation for Economic and Industrial Research, 1200 Jefferson Davis Highway, Arlington 2, Virginia*

A workload planning tool for the Overhaul Process of the Navy, Bureau of Aeronautics is developed, taking into account the complexity of phenomena at work in the overhaul process. The time-dependent mathematical expressions for the elements of "learning", obsolescence and deterioration are isolated, and combined to provide models of overhaul lines. These models provide man-hour predictions of increased accuracy over previous methods. Specific applications to engine and airframe overhaul are discussed.

E1.9 Performance of Certain POL Transport Systems under Conditions of Atomic Warfare, ROBERT E. JOHNSON and WILLIAM H. WILSON, *Technical Operations Inc., Combat Operations Research Group, Fort Monroe, Va.*

The transportation of bulk petroleum products to ground forces in combat has long been a major task. Within a combat zone, heavy reliance is placed on pipeline and vehicular systems. In addition to differences in cost, flexibility etc., these two modes of transportation differ in terms of vulnerability to atomic weapons. Simple deterministic models have been built to compare the performance of pipeline and vehicular systems under varying levels of atomic weapons and varying customer demands for fuel. Damage to a pipeline is in the form of a break, with an associated repair time during which the link is inoperable. Damage to a vehicular system includes damaged or destroyed vehicles, driver casualties and circumvention of contaminated or blow-down areas. Because of a large number of computations required, the model has been programmed for a digital computer.

E1.10 Range Programming with Application to Telemetry Frequency Assignment, J. A. JOSEPH, *Operations Analyst, Hq USAF, Washington 25, D. C.*

The conflicting demands of missiles for the simultaneous use of a limited number of telemetry frequency channels, during research and development firings, can cancel missile launchings. In a theoretical example, 28 available channels are assigned, in an optimum manner, to 19 missile types that together require 74 channels for operation. Any one missile type requires at most 6 channels. To conflict, two missile types will have to be on the range simultaneously and have the same frequencies assignment. Missiles are programmed several years in advance and it is not known precisely when the missile will arrive at the range. Frequencies, once assigned, can not be changed during the life of the missile type. A measure of effectiveness is developed which is the expected number of hours of conflict over a four year period; also an optimizing "technique" is developed which gives a reasonable frequency assignment. Unfortunately, no rigorous method of solution has been found; the problem is offered to analysts to seek a precise method. However, in a practical application, conflicts due to telemetry interference were reduced considerably after this assignment technique was used as compared to previous experience of haphazard assignent. This approach has many other important applications.

E1.11 Some Logistic Models for Missile Support Systems, RICHARD SCHWARTZ, *Advanced Weapon Systems Engineering Subsection, General Electric Advanced Electronics Center, Ithaca, New York*

The function of a missile support system is to insure a high probability of successful operation on demand. This is accomplished through maintenance, test and repair; the performance of these functions constitutes a major item of cost. A necessary first step in the analysis of missile support systems is the derivation of the functional dependence of the support system's performance on the parameters that characterize it. For example, performance might be measured by the average number of available missiles. Among the important parameters characterizing the support system are: 1) the period between inspections, 2) the reliability of inspection, and 3) the probability distribution of repair times. Several models have been constructed that relate these parameters to the overall performance of the missile support system in terms of asymptotic probability distributions on the number of missiles in various functional states. These results are preliminary and no extensive computations have been based on them.

E1.12 A Zoned Target Model, JANICE FAIN, *Chance Vought Aircraft, Dallas, Texas*

This paper describes a method of calculating "kill" probabilities in those cases in which a "kill" can be defined and the requirements for a "kill" are known. The concept of a *zoned* target is introduced. A *simple* target is defined as one which can always be "killed" (or totally destroyed) by one shot which falls close enough to the target center and is unharmed otherwise. A *zoned* target is one which may be destroyed by n_1 shots falling within a circle (centered at the target) of radius R_1, or by n_2 shots falling within a circular zone of outer radius $R_2, \cdots$ or by n_q shots falling within a zone of outer radius, R_q. The fact that the n_i and the R_i are arbitrary should make it possible to adapt the model to a wide variety of problems.

E2.1 Guides to The Financial Management of Inventories, ROBERT G. BROWN, *Arthur D. Little, Inc., 35–208 Acorn Park, Cambridge 40, Massachusetts*

Economic-lot and safety-factor models can be combined with the distribution of item annual sales rates in dollars to derive estimates of total inventory, costs and service for overall control. The distribution of usage rates is usual log-normal with a standard deviation of 2.303. Examples of uses and misuses of turnover are discussed.

E2.2 The Scheduling of a Barge Line, GEORGE G. O'BRIEN, *Touche, Niven, Bailey & Smart, 1292 National Bank Building, Detroit, 26 Michigan*

After a preliminary study of the operations of the Ohio Barge Line it was decided that the biggest payoff was in instituting a schedule for shipping, and in balancing the number of tugs and barges in the fleet. By applying the Monte Carlo technique to a simulation of the operation it was possible to make recommendations for scheduling and to predict the results to be obtained by varying the number of tugs, using the predicted optimum number of barges in each case. These recommendations were followed, first using the number of tugs in the present fleet and later adding a tug and the suggested number of additional barges. Data was accumulated in the ensuing years and a comparison was made between the predicted and actual results.

E2.3 Economic Batch Size Determination for Multi-Product Scheduling, SAMUEL EILON, Ph.D., *Associate Professor in Industrial Engineering, Israel Institute of Technology, Haifa, Israel*

In the determination of batch-sizes in batch production, different criteria can be used as guiding principles, depending on the specified objectives. In a production schedule consisting of several products, an optimum solution for the whole production schedule is sought, in which each product may still conform to its individual production range. Solutions for an overall optimization of the schedule with respect to maximum profit or maximum return have already been published. This paper suggests a method for determining the economic batch-sizes when a different criterion is used, namely when the maximum rate of return is sought for the multi-product schedule.

E2.4 The Measurement of Productivity in Industry, HAROLD W. MARTIN, *Management Engineering Department, Rensselaer Polytechnic Institute, Troy, New York*

The various types of human work involved in producing and distributing usable products are identified and defined and their relationships to the effectiveness and profitability of productive functions are examined. A suggested statistical sampling approach to the measurement of the productivity of an industrial organization or any department thereof is developed therefrom. Data emanating from experimental applications of the suggested measurement method is presented and analyzed, thereby enabling identification of work relationships and other pertinent factors which affect productivity and profit.

E2.6 Linear Programming Applications in Personnel Allocation, JOHN M. ALLDERIGE, *Technical Advisor, Industrial Engineering Division, Eastman Kodak Company, Rochester, New York*

Three studies are discussed: (1) The minimization of expensive cross-trained personnel in a "flying squad"—this specialized group is available to move with the peak receipts work load through the successive operations of a photographic processing activity; (2) The minimization of labor cost in scheduling 5-day people to a 7-day operation having different daily needs and extra costs for Saturday and Sunday work; (3) Determining the minimum transportation crew size to move unequal numbers of loads back and forth between major plant areas.

E2.7 Procedures for Forecasting Aircraft Engine Maintenance Removal Quantities, JOSEPH J. MODER and WILLIAM W. HINES, *School of Industrial Engineering, Georgia Institute of Technology, Atlanta, Georgia*

This paper is concerned with the determination and application of maintenance removal rates of aircraft engines, for use in a forecasting routine designed to predict removal quantities on which overhaul schedules are dependent. These problems are treated in two parts. Part I deals with the collection of the data and development of engine removal rates as a function of the flying hours on the engine. Part II deals with the utilization of these rates to forecast removals for a specified set of engines and flying schedule. Finally, a comparison is made of these forecasts with those developed by present commercial airline methods, and the values actually experienced during the forecast period.

E2.8 Decision Rules for Managing Finished Inventories Utilizing an Integrated E.D.P.-O.R. System, WILLIAM H. SMITH, *Distribution Center, Eastman Kodak Company, 343 State Street, Rochester, New York*

The decision rules described are applicable to an integrated E.D.P.-OR system so constructed as to utilize a large-size computer efficiently in automating the processing of incoming order data into production schedules for finished goods. Optimum results depend on construction of mutually compatible decision rules which are designed to guide computer-processing of the data at each stage of its transformation from incoming orders into production schedules. A data flow chart shows the points at which the decision rules apply, together with a listing of the 16 decision rules, broadly defined in general terms. The type of decision rules and their related sequence of operation on the flow and processing of data are the points stressed in this paper, rather than a detailed definition of the decision rules, which is expected to come with further research in these areas.

E2.9 An Inventory Model for Repair Parts, MARTIN J. BECKMANN, *Cowles Foundation, Yale University, New Haven, Connecticut*

The following inventory problem is analyzed in terms of continuous time: Demand is for one unit at a time, and Poisson. Alternatively, the demand density depends on the time elapsed since the last demand only. Delivery time is a random variable of known distribution. The order size is specified at the time of delivery (that is, approximately, at the time of production). Storage cost is proportional to stocks, the shortage penalty is proportional to the size and length of the shortage. There is a fixed cost in addition to the proportional cost of ordering. The optimal policy is of the s,S type. Simple approximations are found to the optimal order size and the reordering point.

E2.10 In-Process Inventories, KENNETH F. SIMPSON, JR., *Arthur D. Little, Inc., 35-206 Acorn Park, Cambridge 40, Massachusetts*

Many manufacturing operations can be looked upon as chains of operations separated by inventories. In any real case, there is a question about how inventory investment should be balanced between these various in-process inventories. Investigation of this situation for a very general control system—the base-stock system—leads to some general results which enable one to answer this question by examining a (generally small) finite number of possibilities. The conclusion may be stated: "The service time for any inventory should be zero." An important corollary of the method is that it answers the question of what points in the manufacturing operation should be inventory points and what points should not.

E3.1.1 "A Theorem in Convex Programming", WILLIAM KARUSH, *Operations Research Group, System Development Corporation, 2500 Colorado Avenue, Santa Monica, California*

An optimization problem which frequently arises in applications of mathematical programming is the following:

$$F(A,B) = \min_{A \leqq x_1 \leqq \cdots \leqq x_n \leqq B} [f_1(x_1) + f_2(x_2) + \cdots + f_n(x_n)].$$

where f_i are convex functions. In this paper, the function F is studied and shown to satisfy $F(A, B) = M(A) + N(B)$ where M and N are increasing and decreasing functions, respectively. Also, the functional equation $F(A, C) = F(A, B) + F(B, C) - F(B, B)$ is established. These results generalize to the continuous case

$$F(A,B) = \min \int_0^T f(t,x(t))\, dt,$$

with $x(t)$ increasing and $A \leqq x(0) \leqq x(T) \leqq B$. The results obtained in this paper are useful for reducing an optimization problem with many variables to one with fewer variables.

E3.1.2 An Algorithm for Solving "Travelling-Salesman" and Related Network Optimization Problems, FREDERICK BOCK, *Armour Research Foundation, Technology Center, Chicago 16, Illinois*

The algorithm has two complementary phases which are applied alternately in the solution of network optimization problems of the "travelling-salesman" type. Phase 1 proceeds from circuit to circuit by one-step transformations, always decreasing the circuit value, until either a relative or an absolute minimum value is attained. Phase 2 combines conditionally minimum circuit fragments in a systematic and exhaustive search for a complete circuit having a value less than the value previously attained in phase 1. The algorithm terminates when phase 2 fails to find an improved circuit. The algorithm has been programmed for a digital computer. Computational experience will be reported.

E3.1.3 A Solution to the Travelling Salesman Problem by Combinatorial Programming, MORTON J. ROSSMAN and RAYMOND J. TWERY, *Peat, Marwick, Mitchell & Co., 10 So. LaSalle Street, Chicago 3, Illinois*

An algorithm is presented in this paper which can be shown to lead to an optimal solution to all travelling salesman problems. Articles concerning the Travelling Salesman problem have previously appeared in the literature of mathematics and operations research. None to our knowledge has been shown to produce an optimal solution in every problem. The general approach is that which was presented in the paper "Combinatorial Programming" at the Sixth Annual ORSA meeting. Some mathematical demonstrations of the validity of the concepts used in this paper were also included in the earlier paper. Some indications of this algorithm's efficiency as well as a general statement of the spirit of the algorithm is presented in the paper proper. The detailed algorithm which we used to solve, by hand, an order 13 matrix is presented in an appendix. The Combinatorial Programming approach requires the explicit *or implicit* enumeration of all possible combinations (size m) of elements that can be drawn from the matrix (order m) which defines the problem. However, it also provides rules which reduce the number of combinations which must be considered *explicitly* to, relatively, a handful.

E3.1.4 On the Use of the Simplified Simplex Tableau for the Solution of Systems of Linear Equations, VALDEMARS PUNGA, *Rensselaer Polytechnic Institute*

Given a linear system $A_1x_1+A_2x_2+\cdots+A_nx_n=A_0$, where $A_1,\cdots, A_n,A_0$ are n-dimensional column vectors. Suppose $I_1,I_2,\cdots, I_n$ are n-dimensional unit base vectors. As initial simplex tableau write only the columns $A_1,A_2,\cdots, A_n,A_0$. This amounts to expressing A_i vectors in terms of unit base vectors I_i, $i=1,2,\cdots, n$. Then start to replace the base vectors $I_1,I_2,\cdots, I_n$ successively, one by one, by $A_1,A_2,\cdots, A_n$, respectively, using usual formulas for the change of basis $x'_{kj} = \frac{x_{rj}}{x_rk}$,

$x'_{ij} = x_{ij} - \frac{x_{rj}}{x_r k} x_i k$, where the subscript k stands for "coming in" and r for "going out." After a vector A_i is introduced into the basis, discontinue to compute the elements of the column A_i. The elements of the column A_0 in the final tableau will give the solution of the system. For the solution of n equations the method requires $n^3+\frac{1}{2}n^2-\frac{1}{2}n$ multiplications (including divisions) and $\frac{1}{2}n^3-\frac{1}{2}n$ subtractions and since it essentially uses only two formulas, it very easily yields to the programming on the digital computer. It is still longer than Crout method, but can be recommended as preliminary exercise for the mastery of the simplex method of the linear programming.

E3.2.1 Manpower Gaming on a Digital Computer, **MAURICE G. VACHEROT,** *Surface Communications Systems Laboratory, Field Systems Studies, Radio Corporation of America, Tucson, Arizona,* **and JOHN B. TEEPLE,** *Applied Psychology Corporation, APCO, ℅ Surface Communications System Laboratory, Field Systems Studies, Radio Corporation of America, Tucson, Arizona*

Manpower requirements for a system requiring more than three hundred technical operators were determined by simulating system operations on a digital computer. Men to be used to perform tasks were coded according to their occupational specialty, and these codes were stored in memory. Tasks were coded on punch card inputs. The program defined the way in which the tasks would be assigned to the men, and accumulated the amount of time each man worked on each kind of task. This enabled the determination of the efficiency of each man and skill specialty. A variety of tactical situations was simulated. Variables which resulted in different manpower assignments included the amount which tasks could be delayed, degree of cross-training of personnel, frequency of system movement, terrain, climatical conditions, length of tasks, number and kinds of extra duties, and equipment reliability. For each task input, the value for the variables above was selected from statistical distributions. Computer outputs presented a historical record of each man's work. Appropriate criteria applied to men and facilities simulated provided a measure of the efficiency of manpower utilization for each combination of variables. This was accomplished through the use of a data-reduction program based on a mathematical model. The future of realism in human factor simulation programs is discussed with special reference to such problems as human variability and experiential factors.

E3.2.2 Feasibility Analysis of Use of Television Remote Access to Library Card Catalogs, **FRANK R. BACON, Jr.,** *the Operations Research Department, Room 232C West Engineering Building, University of Michigan, Ann Arbor, Michigan,* **and ROBERT E. MACHOL,** *Associate Professor, Department of Electrical Engineering, Purdue University, West Lafayette, Indiana (address will be 1606 Granger, Ann Arbor, Michigan until September 10, 1958)*

This case study describes the nature and sequence of operations research techniques used to determine the feasibility of replacing divisional library catalogs with a closed circuit television system permitting viewing of catalog cards located in a central catalog from remote divisional libraries.

As a test case, the cost savings possible and the amount of equipment required to introduce such equipment in the University of Michigan library system was studied under contract with the Council on Library Resources, Inc.

The operations of the centralized Catalog Department were analyzed to determine the differential costs associated with the maintenance of divisional card catalogs. The distribution of arrival rates and holding times associated with the present use of card catalogs in 21 libraries in the University system were studied. The study describes the application of queuing theory to estimate the number of television monitors and cameras needed to meet the load requirements of the total system.

The cost of the equipment required, including installation and maintenance costs, were found to exceed, by a considerable amount, the savings anticipated, in this particular application.

E3.2.3 An Evaluation of the Models of Two "Business Decision Games." J. L. DILLINGER, *Associate Professor of Business Statistics, School of Business, Northwestern University, Evanston, Ill.*

The author has participated in two "business decision games:" (1) the UCLA Executive Game No. 2, and (2) the IBM Top Management Decision Making Model I. The purpose of this paper will be to analyse and compare the basic models of the two "games." The two models are similar in many respects, but different in several key concepts. Experience with different groups of participants and in the mode of presentation of the "games" will be cited. Generalizations as to the superior points and the weak points in each "game" will be explained.

E3.2.4 Simulation of a Unique Communication System on a Digital Computer, MAURICE G. VACHEROT, RALPH N. COOPER and JOHN R. HUNTER, *Surface Communications Systems Laboratory—Field System Studies, Defence Electronic Products, Radio Corporation of America, Tucson, Arizona*

Communication requirements for complex systems have been a major problem for many years, especially if the population is varying in numbers and constantly moving. This paper presents a method for simulating such a communication system. It is divided into three main parts: 1) Load Generation, 2) Simulation, and 3) Output.

1. The load is a statistically generated random number selection of individual call destinations, origination times, and conversation times. These factors are, of course, limited and controlled by past experiences as to their applicability and duration.
2. The one-one model in the simulation program in handling traffic is so designated that it can account for changes in routing, changes and displacements of population, changes in communication stability, equipment outages, displacement of communication centers, augmentation or reduction of trunk requirements, changes in connectivity pattern due to changes in system configuration,

automatic or manual switching, impasse corrections, automatic placement of comcenters, and sub-systems off the main communication centers.

3. The output from such a versatile computer program gives several parameters for adjudging the comparative merits of different communication configurations, properties, and conductivity patterns. Some of these parameters are as follows: System efficiencies, lost calls by reason of loss, average number of trunks per completed call, average number of switches per completed call, average connect time per number of switches, and number of trunks busy for each trunk group per interval.

E3.2.5 Realizability of Redundance in an Electronic System, S. NOZICK, *Hughes Aircraft Company*, Tucson, Arizona*

The analytical approach to redundant systems has been developed in a number of papers. They show the large theoretical reliability improvement that a fully redundant system† can give. The practical application of these theoretical analyses, however, is extremely limited. At best, most currently developed systems have only either partial redundance or functional redundance. This is true even in cases where the system's use is critical enough to justify the cost in dollars, weight, size, and logistics brought about by redundance.

The reason for this is that the state of knowledge of the art of building redundant systems is very limited. There is insufficient component and system failure data to allow the designer to effectively use the analytic tools that have been developed by the theoretician. The designer who attempts to build a redundant system often finds that redundance may reduce reliability, but the theoretician cannot yet isolate such cases. Therefore, the typical impasse often exists where the thoretician becomes more theoretical and the practical engineer becomes more practical, and no redundant systems are built.

Even though the state of knowledge is limited, it is possible to build truly redundant systems today, provided a working team of theoretical and design engineers is maintained throughout the system planning and prototype stages. This paper describes such an effort and its success. Although theoretical optimum was not found realizable, the reliability gains that were achieved could not have been realized by conventional system design.

The philosophy, thinking, and planning described overcame the need for the extensive material and systems information that appeared at first to be needed, but which was prohibitively expensive in time and money. The limitations found, which made different types of redundance unrealizable with the current state of the art, are presented for the guidance of anyone planning to follow this avenue in the future. The thoughts during the planning and their realizability are mentioned. Several circuitry techniques which were evolved during the development are presented for the use of others.

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* This work was done while the author was employed at Sanders Associates, Nashua, N. H.

† A fully redundant system is one where no single component failure can cause system failure, including such items as wires, etc. which are not normally considered as components.

E3.2.6 An Operational Approach to the Design of Work, A. R. MARKS, *Assistant Professor of Industrial Administration, Yale University, Consultant, The Martin Co., Denver, Colorado*

Productive work must be performed if an organization is to attain its goals. The job is the vehicle in the organizational structure which enables an employee to perform this work. The input to the job may be described as consisting of organizational requirements (including those of the technical process) and employee needs. The output is measured by a criterion of total costs. It has been theorized and confirmed experimentally that one important area of a job about which the input variables interact to influence the output criterion, total costs, is the work content of the job.

A "job-centered" approach to the design of jobs was tested in an industrial setting by means of controlled experimentation. This approach took into consideration the goals of the organization and the needs of the employees. The experimental results showed the approach to have merit. For example, there was an immediate seventy-five per cent decrease in defective items caused by poor workmanship.

The modifications in job design which brought about these benefits and the techniques which enabled the variables to be measured, will be described. An operational postulate of job design, developed as a result of this experimentation, will be offered to provide some basis for the utilization of this approach.

F1 Spare Parts Supply Control in Army Ordnance—An Interim Report, HERBERT P. GALLIHER, *Massachusetts Institute of Technology,* **RICHARD CHRISTENSEN,** *Frankford Arsenal, and* **BERNARD B. ROSEMAN,** *Frankford Arsenal*

(*a*) A Compound Poisson distribution (dubbed "stuttering Poisson") was fitted to recorded captive demand for spare parts in an integrated supply system. The probability distribution of total inventory under an S,s type reordering scheme was used to minimize costs subject to a specified probability of back-ordering. Available overall improvements over present supply performance were then estimated by Monte Carlo simulation and by statistical characterization of the entire catalog list of parts.

(*b*) Collection and analysis of the data necessary to support the S,s model was the most severe problem of implementation. The accuracy of much of these data was rather dubious. However, analysis showed that the reorder level was not too sensitive to cost errors. Reduction of errors in demand data, and development of operating procedures and methods for handling peculiarities in the character of demand comprised the other major problems.

(*c*) Management attitudes cannot be generalized; they differ at each administrative echelon. Of special interest are attitudes that exist as to the degree to which the model will augment or supplant existing decision-making techniques. Other attitudes of interest are those related to the model's demands for new types of data, to the use of simulation in evaluation of competitive systems and to financial implications involved in adoption of a new system.

G1 The Application of Statistics to an Iron Ore Deposit, PHILIP HERMANN, *Supervisor, Jones & Laughlin Steel Corp., 3 Gateway Center, Pittsburgh 30, Pennsylvania*

A particularly complex lean iron ore body is used as the basis for the application of mathematical statistics to iron ore deposit evaluation. Statistical analyses of the exploration, and ore metallurgy data are presented. These analyses are interpreted in terms or recommended modifications to present practices of data utilization. Future applications of the statistics of an iron ore body are outlined, along with their associated economic effect on the iron and steel making processes.

G2 Development and Evaluation of Production Strategies in a System of Mines and Plants, GERSHON COOPER, *Dunlap and Associate, Inc., 429 Atlantic Street, Stamford, Connecticut*

The paper deals with the analysis of a system of mines and plants which are interdependent. The study sought to assist top management in making major, current decisions with respect to: (a) investment in, and physical rearrangement of the system of mines and plants, for example, whether to add a new plant; (b) some of the ground rules under which lower levels of management should operate, for example, how far beneficiation of the ore should be carried; (c) construction of mechanisms (models) to assist in short-run production planning.

G3 Model-Building, Planning and Scheduling in an Integrated Oil Company, ERIC E. SORENSEN, *Supervisor of Operations Research, The British-American Oil Co., Ltd., 800 Bay Street, Toronto, Ontario*

Examples will be given to illustrate problems encountered in building relationships depicting operations within a company and how these problems are resolved. The speaker will describe how some of these relationships were used in the optimization of operating plans for the company and the subsequent suboptimization of departmental scheduling activities.

G4 The Economic Operation of Mixed Fleets of Oil Tankers and Other Bulk-Cargo Ships, GLEN D. CAMP, *Case Institute of Technology, Cleveland, Ohio,* **GEORGE P. HENDERSON and PATRICK J. ROBINSON,** *Institute of Business Administration, University of Toronto, Toronto, Ontario*

Tanker construction costs and short- and long-term charter rates undergo coupled quasi-periodic oscillations, under the influence of economic mechanisms similar to those which cause the beef and hog cycles, over a range of the order of $\pm 20\%$, $\pm 40\%$ and $\pm 70\%$, respectively, with quasi-periods of the order of several years. Lowest cost of a predictable ocean transport requirement therefore arises from using a mixed fleet of owned and long-term chartered tankers, together with short-term charters during periods of low rates, each in time-varying quantities. The total cost (discounted to the present owing to the long times involved) depends strongly on the timing of changes in the amount of each type of service, and this is accentuated by the large lump-sum investments required to buy new ships. A method for developing good long-term programs is outlined and its applicability to mixed fleets of other bulk-cargo ships is discussed; some aspects of the tactical operations of mixed fleets are also briefly discussed.

H1 A System Design Problem—Lunar Bases, **E. W. PAXSON,** *The RAND Corporation, Santa Monica, California,* **J. W. DUNLAP,** *Dunlap and Associates, Stamford, Connecticut,* **J. S. ROWEN,** *The RAND Corporation Santa Monica, California,* **DAVID A. KAHN,** *Cornell Aeronautical Laboratory, Buffalo 21, N. Y.*

This session is a round-table discussion which tries to formulate the essential structural features of a systems analysis of the lunar base problem. No attempt is made to 'solve' the problem nor even to come to any conclusions or recommendations about such bases. However, the various factors requiring quantitative study will be listed and many of the basic concepts of operations analysis will be illustrated.