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THE THIRD NATIONAL MEETING OF THE SOCIETY

Hotel Statler, Boston, Mass.
Nov. 23–24, 1953

IN SUMPTUOUS SURROUNDINGS, far from the Department of Defense, the Third National Meeting turned more toward operations research in business and industry than previous Society meetings. One half-day session of four invited papers was devoted to inventory control and production scheduling, six of the eighteen contributed papers concerned direct application to business and industry, and one of the three invited papers presented in the session on search theory, an erudite and generally highly mathematical subject, was on the earthy topic of consumer shopping!

Altogether, 197 members and 150 nonmembers attended. The Program Committee, whose efforts were appreciated by all who attended, consisted of

PHILIP M. MORSE, *M.I.T., Chairman*
SHERMAN KINGSBURY, *Arthur D. Little, Inc.*
GEORGE P. WADSWORTH, *M.I.T.*
MUNROE A. MALLER, *Minneapolis-Honeywell Co.*

The following abstracts appear in the order in which papers were presented, except for the contributed papers on the last day when two sessions ran simultaneously.

The Theory of Search and Its Applications, three invited papers under the chairmanship of BERNARD O. KOOPMAN, *Columbia University.*

The Distribution of Searching Effort, BERNARD O KOOPMAN, *Columbia University*

The case is considered in which the continuous probability distribution of an object being searched for is known before the start of the search, and the probability of finding it, if it is in any small given region, obeys an exponential saturation law in terms of the amount of search applied to this region. The problem is to distribute the search density so as to maximize the probability of finding the object. This is the prototype of a class of problems of finding the optimum distribution of effort among a continuum of different tasks The irregular problem in the calculus of variations to which the formulation leads is solved It is shown that in some regions no search is warranted and a quantitative criterion for this is given In the region where searching should occur, a logarithmic law for its intensity is derived.

A Particular Class of Generalized Search Problems, E. BRIGHT WILSON, JR , *Harvard University.*

Search as a generalized procedure applicable to adjusting apparatus, finding the roots of an equation, locating faults in equipment, seeking causes, etc., will be discussed. Such problems can be classified according to the number of dimensions

involved (e.g., the number of dials to be adjusted), the types of search paths permitted (e g., continuous or discontinuous, parallel to axes or not), the nature of the point or region sought (e.g., a maximum of a function of the space coordinates), the nature of the functional relationships (continuous, multipeaked, etc.) and the nature of the criterion used to define the 'best' search path.

The problem of selecting a good search path will be discussed for one case, in which the unique maximum of a continuous function z of two variables x and y is being sought. It is assumed that x, y, and z can be read off at each point on the search path but no other information, and that only zigzag paths parallel to one or the other of the x, y axes can be traversed. Such a situation often occurs in tuning a two-control apparatus with an indicator to maximum indicator reading. The contour lines near the maximum will approximate ellipses and the search problem is minimized if the x and y axes are parallel to the principal axes. Possible paths to follow when the x, y axes are not parallel to the principal axes will be described.

Search Theory in the Analysis of Consumer Shopping, WROE ALDERSON, *Massachusetts Institute of Technology*

Marketing may be regarded in one of its aspects as a double search in which producers are looking for consumers who can use their products, and consumers are looking for goods which will satisfy their needs. Shopping by consumers is often an arduous search with an uncertain outcome as to consumer satisfaction Application of search theory to an investigation of shopping might contribute both to more effective consumer buying and to a lower cost of selling on the part of producers attempting to reach the consumer. Several models of searching procedure have been considered in relation to shopping records obtained from representative groups of urban consumers A trip is regarded as a series of choice points, and the problem is to measure the probability that the trip will be terminated at any given point. The consumer starts the trip with some specifications as to the product wanted and some state of knowledge as to what the market affords. Both factors may change during the course of the trip, and thus affect the cumulative probabilities of termination by purchase or nonpurchase

Harmonic Analysis, Causation, and Operations Research, NORBERT WIENER, *Massachusetts Institute of Technology.*

(An entertaining, extemporaneous address on the philosophical aspects of causation and decision theory, to which no abstract could do justice.)

State Probabilities in Congestion Problems Characterized by Constant Holding Times, JOHN L EVERETT, *E. H Smith and Co*

Pollaczek* and Crommelin† have derived the system state probabilities when a random load is imposed on a cooperative set of parallel channels in which the holding times are constant This paper presents an alternative method of obtaining these same probabilities which, although less sophisticated, involves considerably less algebraic and numerical manipulations The case discussed is the general one in which an empty channel will accept a request for service immediately upon arrival The relationship of this case to the one in which the channels are open momentarily at time intervals equal to the holding time will also be shown. Finally, the results

* F. Pollaczek, *Math. Zeitz.* **38,** 492–537, 1934.

† C. D. Crommelin, *P.O.E E.J.* **25** (1), April 1932.

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obtained under the constant holding time assumption will be compared with those obtained with random holding times.

The Use of Time Series Methods in Sales Forecasting and Inventory Control, GEORGE P. WADSWORTH, *Massachusetts Institute of Technology.*

Systematic Requirements, RONALD O. BADERTSCHER, *North American Aviation, Inc.*

A systematic method of obtaining the requirements of a system is presented. It is shown that different types of systems have many features and requirements in common.

By referring to a systematic listing, it is considered possible to establish requirements more quickly and with a greater degree of thoroughness, safety, and confidence.

Some of the general listings covered are purpose, fail safety, cost, time, operating conditions, physical and human components, and noise.

Emphasis is placed upon the problem of fail safety which has become so important with the advent of widespread automatic controls. Particular distinction is made between reliability and the different levels of fail safety required. Applications of the method are made for the establishing of specifications for aircraft components and for establishing a United Nations organization effective in keeping world peace. In the latter case it is shown what functions and powers are required in such a system in order to accomplish its purpose safely.

The Effect of Reliability of 'Supervisory' Equipment on the Accuracy of a 'Supervised' System, ALEXANDER W. BOLDYREFF, *1038 N. Richman Avenue, Fullerton, California.*

This study deals with a basic system, the performance of which degenerates through random errors increasing with the square root of operating time

The probable circular error of this system can be made independent of the time by the addition to the system of supervisory equipment capable of periodic correction of the errors of the basic system.

Assuming the supervisory equipment 'fail safe' and subject to constant hazard type of failure, the performance of the supervised system is determined for various values of reliability of the supervisory equipment.

It is shown that a great improvement in performance is possible even with unreliable supervision.

Testing for Very High Reliability, J. V. BREAKWELL, *21 Temple Avenue, Long Beach 3, California*

This paper is a sequel to one presented at the Cleveland Meeting (See p. 59) on May 16, 1953 A balance is sought between the cost of testing and the expectation of loss due to accepting an insufficiently reliable product or rejecting a sufficiently reliable one. This economical balance is achieved in two different contexts In the first, the articles are classifiable into just two groups, satisfactory and defective. Using the Poisson approximation to the distribution of the number of defectives in a sample, 'optimum' test parameters have been obtained and are presented in a chart. In the second, the articles are classifiable according to some physical test measurement whose underlying distribution is supposed to be normal. The reliability, which is the fraction of the normal population lying within known critical limits, will be estimated from sample information, and 'optimum' test parameters are obtainable from formulas similar to some discussed in the Cleveland paper The

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theory is extended to sequential tests, and to tests of successive batches in which the assumption of some continuity in quality permits some reduction in testing

Conference on Inventory Control and Production Planning, four invited papers under the chairmanship of JOHN F. MAGEE, *Arthur D. Little, Inc.*

Mr R C. DOWELL, *Johnson and Johnson*, presented the production planning problem as it is seen by business management, using a one-man company example to indicate the impact on sales, financial, and labor policies He noted how the complexity of modern business operations has increased the difficulty of reaching sound decisions in the production planning area, and pointed forcefully to the need for research groups to compromise between ideal solutions, available information, and existing skills in the business, and to learn to present their findings and proposals in the customary terminology of business

Dr H A SIMON, *Carnegie Institute of Technology*, reviewed theoretical developments by Whitin and others in the area of setting order quantities, and by Simon and others in the area of setting operating levels in the face of costs and forecasts Dr Simon referred to the linear programming work of Charnes, Cooper, and others in scheduling operations He emphasized the need for theory which can be used, and the desirability of methods which are relatively insensitive to inaccuracies in costs and forecasts

Dr GEORGE E KIMBALL, *Columbia University*, presented a simple card method for arriving at "good" (close to optimum) schedules in a variety of situations, once certain general criteria were established, as an illustration of practical methods yielding approximately optimal solutions

Dr. ARTHUR A. BROWN, *General Electric Company*, summarized and reviewed the comments of preceding speakers

The general discussion which followed centered about the reliability of cost information, the effects of alternative formulations of unfilled order costs, the interpretation and use of servo theory methods, and the potential need for redesigning business information systems for better operational control A highlight of the discussion was the presentation of physical models by Professor DONALD CAMPBELL, *M I T*, to illustrate the difference between physical layout and information flow, and to emphasize the need for thorough study and careful design of control information flow before planning and control systems can be effective.

Optimal Strategies for Coping with a Business Recession, GLEN D. CAMP, *Melpar, Inc*

Some applications of OR to business retrenchment and withdrawal are presented These introduce no new concepts of methodologies, but involve situations which are new in the brief history of OR (See p. 92.)

An Analysis of the Operation of a Railroad Classification Yard, FRANK B. BROWN, ROBERT O BLANCHARD, and ROGER R. CRANE, *Melpar, Inc.*

The results of an analysis of the process of classifying freight cars in a yard are presented Yard operations are of particular interest to the railroads since, according to available figures, the per cent of freight train time in yards is excessive The yard from whose operations the data for this study were obtained is a relatively efficient one; hence, although it provided a satisfactory basis for developing a tech-

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nique for analyzing classification yards, the opportunities for improvement were not great. However certain areas where some improvement appears possible were uncovered.

Also included are the description of an elementary model of classification yard operations, a comparison of computations based on this model with actual data (the Monte Carlo method was used to reproduce the statistical characteristics of the yard), and the results of the application of the model to evaluate certain possible improvements in yard operations.

A Problem in Production Scheduling, STANLEY ROTHMAN, *General Electric Company.*

The problem is one of scheduling a mixed piece-work, day-work job shop that has production, and research and development operations. Taken as constant are the sequence of operations of the articles being produced, the time-study estimates of the requirements of each operation, the number of machine tools of each type available, the labor rate at each station, and a management-established cost of in-process inventory Considered as parameters are the rejection rate at each station, the inspection system (progressive versus final), machine breakdown, dispatching, incentive for piece-work, lap-phasing or gap-phasing, and the number of workers of a given labor classification The approach is one of using a computer to minimize a production cost figure as a function of the order in which jobs are put into shop and to further vary the parameters so as to achieve over-all improvement in the operation of the shop

Operation Sampling and Analysis for the Determination of Production Time Standards, HAROLD W MARTIN, *Rensselaer Polytechnic Institute*

Preliminary industrial experiments in operation sampling and analysis demonstrate the adaptability thereof to the determination of production time standards of known degrees of accuracy.

The degree of occurrence of the work and nonwork elements comprising any reasonable number of related or unrelated industrial jobs performed in the same general location can be concurrently and economically determined to a known or any desired degree of accuracy through planned random sampling of the occurrence of the elements

From production statistics compiled during the sampling period, elapsed times per piece produced are determined Statistical analysis of these time intervals and their constituent elements, combined with adjustment thereof, based on the relationship between prescribed worker utilization levels and the actual utilization levels revealed by the elemental random sampling, enables economic determination of production time standards.

Since the inherent degree of accuracy of such time standards is calculable, they are, to this extent, superior to time standards determined by stop watch time study.

Data concerning a number of industrial case histories involving the application of operation sampling and analysis will be concisely presented and briefly reviewed

Simulation by Computation as an Operations Research Tool, CUTHBERT C HURD, *International Business Machines Corp.*

Computers are of great value as simulators in the field of industrial design Examples are· design of distillation columns, missile trajectories, heat transfer. Hence, since industrial design is a component of operations research, simulation by computation is already being used as an operations research tool. This paper

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describes how simulation by computation can possibly be extended to other components of operations research and an example is given in the field of machine shop scheduling. Finally, speculative remarks are made concerning possible uses of computer simulation in the 'automatic factory.'

Optimum Dispatching Program for a Steam-Electric Generation and Transmission System, E. L HARDER, *Westinghouse Electric Corp*

Determination of the most economic dispatch, considering both production and transmission costs, is an objective of every electric utility. The method described involves determination of a transmission loss formula based on simplifying assumptions For maximum economy, at any load the incremental delivered power cost, including the cost of losses, must be the same for each generating station The resulting simultaneous equations are solved by an iterative procedure to obtain the most economic dispatch. The problems of bringing a complex interconnected utility system within the scope of this simple outline are described Other methods of solving the problem are indicated.

School Planning in Manchester, Massachusetts, EDWARD S. GILFILLAN, JR., *Lincoln Avenue, Manchester, Mass.*

Although Manchester has just completed a new school plant there is already a shortage of classrooms. A School Planning Committee has been set up to make studies to assist the decision as to when, where, and what kind of new facilities should be built.

The Committee has conducted a detailed census of the town and made a number of studies based on this and other data. Curves are presented showing the distribution of ages of mothers and children to be expected with in- and out-migrant families, the birth rate to be expected from the spectrum of mother ages, and the rate at which new housing may be expected to become available by death of the present occupants. The effect and trends of enrollment in private and parochial schools is discussed.

A forecast of the school population to 1965 is presented and compared with an empirical forecast based only on the past history of the school population

A Verification of Lanchester's Law, J. H. ENGEL, *Operations Evaluation Group.*

An example of an operations research technique for verifying the validity of certain Lanchester equations is an actual combat situation is demonstrated In the situation tested our own forces surrounded and captured an island.

The equations tested are

$$\frac{dM}{dt}=P_t-AN, \qquad \frac{dN}{dt}=-BM,$$

with· $M(N)$ the number of effective, friendly (enemy) troops,
$A(B)$ the friendly (enemy) combat loss rate per opposing combatant,
P_t the rate friendly troops enter combat,

Information required for the verification is P_t, M for each day of the engagement, knowledge that enemy troops are not reinforced or withdrawn, and the day when the enemy is destroyed (or, alternatively, N_T/N_o at the end of the engagement) If N_o, the number of enemy troops at the beginning of the engagement, is known, A and B may be evaluated.

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In an analysis of such a situation, the equations were found to be applicable

The value of such analyses increases when repeated often enough to permit general conclusions to be drawn.

Application of the Theory of Value to a Study of Intrinsic Values and Cost Allocation in the Cost Analysis of a Weapons System, NICHOLAS M. SMITH, JR., FRANKLIN C. BROOKS and W. SCOTT PAYNE, *Operations Research Office.*

In the cost analysis of a weapons system, two classes of problems may arise depending upon the area or scope of the analysis. One of these has to do with the treatment of commodities which, because of their scarcity, are called *strategic*, and a second one with the allocation of charges which are common to the mission under consideration and other missions of the weapons system It will be shown through the concepts of the theory of value that if one adopts three postulates for the methodology of his analysis, that one can uniquely assign intrinsic values to the strategic materials, and that one and only one method of allocation of common charges is permitted These postulates are (1) that the sub-optimization within the framework of the analysis be required to give the same preference as if the problem of next larger scope were considered; (2) the intrinsic values of the strategic materials must go to zero when there is no longer a scarcity; and (3) that all arbitrary divisions of common charges or total cost be done consistently (i.e , in the same ratio). It results that the intrinsic value to be assigned to the strategic material is the cost of substituting a nonstrategic material weighted by the fractional inadequacy of the strategic stockpile; and that the common charges should be allocated in proportion to the military worth of the respective missions.

The assertion that a unique solution exists to these problems often leads to emotional disturbances and these disturbances are deemed to be well founded, inasmuch as the fundamental values are seldom explicitly known The ability to negotiate the manner of allocation of common charges is essentially a market place transaction wherein fundamental social values are revealed.

Cost Criteria in Typical Combat Operations, A. J. KARCHERE, *Operations Research Office.*

The standard tools of economic analysis are useful in an evaluation of weapons systems. Decisions regarding weapons systems are always made within the context of a combat problem or operation There are three kinds of decisions which must be made First, given the combat situation, which of several alternative weapons systems should be used? Second, given the weapons systems, in what proportions should they be used? Third, given the proportions of the weapons systems, how many of them should be used?

To assist in the analysis of practical problems, possible cost and effect characteristics of weapons systems are examined. Marginal costs may be constant, increasing, or decreasing With the total amount of resources available for the weapons system being given, it is likely that the marginal effect of a weapons system will be either constant or decreasing. In an optimum weapons system the marginal cost-effect ratios of all weapons systems would be equal. This is not the sole criterion, but it is a useful first approximation.

Although the theoretical principles for determining optimum allocation are clear, the practical problem presents great difficulties. The technique of sub-optimization provides a method for dealing with this problem. Two criteria that may be useful in sub-optimization analyses are suggested.

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Cost Considerations in Weapon System Programs, F. P. HOEBER, *Operations Research Office.*

The most serious omission of the first-approximation weapons systems evaluation discussed in Mr Karchere's paper is an explicit treatment of problems associated with time. These are the problems of programming, the decisions on scheduling research and development, procurement, recruitment, and training Some of the special aspects of cost analysis for such decisions are discussed in this paper

It is necessary for the Armed Forces to allocate resources between investment and current operating expenditure This raises the problem of how to take account of the risk of war, expectations of budget appropriations, and ordinary business risk This would require an explicit evaluation of the temporal sequence in which the costs are incurred, i.e., the costs of a program. Although it is theoretically possible to establish a discount factor that can be used to find the present value of resources expected to be used in alternative programs, it is not likely that the operations analyst will be competent to make the judgments required The presentation of both year-by-year and average-annual costs is recommended as the most practical way of assisting the decision maker

The effectiveness of weapons systems will vary through time as the enemy develops counter-measures and as technical knowledge changes This makes it necessary to examine the dynamics of weapons system succession

There is also another problem closely associated with time which is important in weapons systems evaluation. In some cases it may not be possible to produce the quantity of the weapons system required by the optimum solution given by the static equilibrium analysis in the time specified by the program The problem of allocating the resources available in the specified period of time remains A method for dealing with this 'feasibility' problem is suggested

Organization and Information in Task Groups, LEE S CHRISTIE, *Tufts College*

Recent studies of organizational factors in human information handling have provided results important for operations research.

Laboratory groups were given simple information collection tasks under controlled conditions. Decisions were restricted to choices of message destination, and the effects of various imposed communication nets analyzed A technique of group action quantization was used which made possible a well-defined measure of group efficiencies and group goal

Various communication nets were used which differ in the maximum of efficiency they permit, and in the distribution of group acts per task, assuming equiprobable random choices

Experimental results show that an equiprobable random model is poor even for initial behavior. In centralized nets personnel are found to learn fairly rapidly to do as well as the nets permit, but such nets have a high value for the minimum action required A net designed to give the lowest average action for task completion with random message-destination choices fails to achieve its limiting minimum. A similar net with higher random average and a favorable minimum is shown to learn its minimum readily

Differences among the results for different nets are found to be explained in terms of a concept of 'locally rational behavior' and the combinatorial characteristics of the nets

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The Usefulness of Crash-Rescue Vehicles in Aircraft Accidents, ROBERT A. PORTER, *Eglin Air Force Base, Florida* (Read by title only).

The uses of Crash-Rescue vehicles are two: to save lives and to save property. In the design of such vehicles two desirable attributes—speed in reaching the scene of the crash, and amount of fire fighting and other rescue equipment carried—are largely antithetical. The purpose of this study is to determine what problems actual aircraft crashes pose to the rescue equipment, and the implications of these actual situations for efficient design of the equipment. The data available were records of crashes at air force bases for a year's time, and the 'state of the art' of crash vehicle design obtained from a series of tests on such vehicles carried out at the Air Proving Ground Command. It is shown that the Crash-Rescue Service pays for itself in terms of property damage prevented, and that the two uses for which the vehicles are designed, saving of life and saving of property, do not impose mutually incompatible requirements on the design of the vehicles.

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