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# THE INSTITUTE OF MANAGEMENT SCIENCES REPORT OF THE FIFTH ANNUAL INTERNATIONAL MEETING

*October 16–18, 1958, Philadelphia*

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## A. Recent Developments in Decision and Network Models. *Chairman:* FRED RIGBY, *Office of Naval Research.*

1. "RECENT DEVELOPMENTS IN STOCHASTIC DECISION THEORY," JACOB MARSCHAK, *Graduate School of Industrial Administration, Carnegie Institute of Technology.*

Most of the paper's results are due to collaboration or discussion with H. D. Block, D. Davidson, and G. Debreu; and references to the work of N. Georgescu-Roegen, D. Luce, and A. Papandreou are made.

Let $A$ be the set of all alternatives. Suppose that if a given individual is offered a fixed ("feasible") subset $F$ of $A$ he will choose the element $a$ of $F$ with fixed probability $a(F)$. Such probabilities, if they exist at all, may or may not satisfy certain constraints that constitute various forms of "stochastic consistency," all more realistic than the assumption of man's "absolute consistency." The logical relations between these constraints are studied. Some constraints state the existence of varying "current utilities" only: these are jointly distributed random variables. Other constraints are more restrictive. They state the existence of "weak," (merely rankable) or of "strong" (measurable) "permanent utilities:" these are constants analogous to "sensations" of psychologists Fechner and Thurstone. Possible statistical tests of the empirical validity of the various constraints, especially when based on scant repetitions of observations, are discussed.

When the alternatives offered to the subject are wagers, ("investments") additional propositions arise; the "absolute" theory of expected utility (as used, for example, in the theory of games) is replaced by its "stochastic" counterpart, with some implications amenable to statistical tests.

2. "GRAPH THEORETIC METHODS IN THE MANAGEMENT SCIENCES," FRANK HARARY, *Princeton University* and *Institute for Advanced Study.*

The purpose of this paper is to illustrate the potential utility of graph theoretical methods for the management sciences. In a series of joint papers with I. C. Ross, we have combined a graph theoretical approach with matrix theory and set theory to handle problems concerning redundancies, liaison persons, cliques, and strengthening and weaken-

ing members of a group. The correspondence between these organizational concepts and ideas from graph theory is as follows. A redundancy is analogous to a directed path which passes through the same point more than once. A liaison person in an organization has the role of a cut point of a connected graph. A clique is taken as a maximal complete subgraph. A strengthening member of a group is one whose presence causes the graph of a group to be more highly connected than the graph obtained when he is absent.

We also include brief mention of graphical treatments of status and contrastatus, the attainment of unanimity in a power structure, tournaments and production schedules, and structural balance. The ideas developed in our paper on status and contrastatus were inspired by "Parkinson's Law"; contrastatus is defined in terms of the amount of status weighing down on a person in an organization. The development of a criterion for unanimity in a theory of social power involves the concept of "power subgroup" which is of independent interest. Tournaments and production schedules pertain to situations in which there is a collection of tasks and a preferred ordering between every pair of tasks. "Structural balance" (written jointly with D. Cartwright) has to do with groups in which both positive and negative relationships may occur.

**B. Accounting and Value Theory.** *Chairman:* WASSILY W. LEONTIEF, *Department of Economics, Harvard University.*

1. "PROBLEMS OF MEASUREMENT OF VALUES," C. WEST CHURCHMAN, *School of Business Administration, University of California.*

The paper begins with a classification of the sciences in the terms of descriptive, predictive, and prescriptive. Descriptive science describes what has occurred. Predictive describes what will occur. Prescriptive describes what ought to occur. The paper then considers which of these categories is most appropriate with respect to management science and concludes that management science is a prescriptive discipline, eventually will have to face the problems of the verification of ethical judgments.

2. "ACCOUNTING, MANAGEMENT SCIENCE AND BUSINESS DECISION MAKING," DAVID B. HERTZ, *Arthur Andersen and Company, New York.*

As businesses have grown more complex the need for information which provides maximum utility to decision makers becomes more and more imperative. The accounting function has always provided considerable information for the decision maker but very often the accountant has looked upon it as an historical operation. As the decision making process comes more and more under scrutiny by management accountants and others, improvement in the utility of such information has become a genuine objective. Progress is being made in developing means of accounting to provide information giving the relevant decision maker a means for achieving decisions which have greater probabilities of obtaining some objective. Research in decision making processes is providing new approaches to developing such information. Reference is made to linear programming and its implications for cost accounting and decision making, multiple regression, inventory anticipation through the use of probability accounting, statistical cost determination, computers and data processing theory and other recent developments.

In summary, the point is made that there is little or no work being done in decision process studies of the management sciences which is not important and material to accounting methodology.

**Annual Presidential Address:** "THE INSTITUTE OF MANAGEMENT SCIENCES," GEORGE KOZMETSKY, *President.* Paper not received.

**C. Simulation Methods.** *Chairman:* ROGER CRANE, *Touche, Niven, Bailey and Smart.*

1. "A SYSTEM STUDY FOR THE AUTOMATIC SORTING OF LETTER MAIL," ISRAEL ROTKIN AND MARTIN C. STARK, *National Bureau of Standards.*

An automatic system for sorting letter mail is being developed for the Post Office Department at the National Bureau of Standards. It is called a CODESORT system because the initial step is the conversion of the address on the mail into an abbreviated, standardized signal on a magnetic film-strip sprayed along the bottom of the address. This conversion is done by human operators. Thereafter the process is entirely automatic. An electronic directory controls the flow of the mail and an electromechanical distributor carries out the sorting function under the control of the directory. This system will sort both outgoing and incoming mail and it will also arrange the mail in the normal order of a carrier's walk.

A first prototype installation is expected to be ready for test by the end of 1959.

The second part of the joint paper (by Mr. Stark) describes the development of a method for reducing addresses on envelopes to abbreviated form following standardized coding rules. The presentation discusses the complete code format, with all the items needed to represent fully both the outgoing and incoming portions of the address. The paper describes the use of a digital computer to test code plans by applying the code rules to the 38,000 post office names in the United States and checking the resulting codes for duplications.

Human engineering tests have been conducted to compare simple longer codes with sophisticated shorter codes and to determine suitable working conditions, training techniques, output rates and other performance criteria for coding personnel.

2. "LARGE SCALE ECONOMIC DECISION MAKING MODELS," MARTIN GREENBERGER, *School of Industrial Management, Massachusetts Institute of Technology.*

The last decade has seen a large number of attempts to characterize aspects of the American economy in model form. Mathematicians, physicists, and engineers have participated side by side with behavioral scientists in constructing these models. Their limited success has not dampened their enthusiasm nor reduced interest and activity in the field. In fact, a steadily increasing number of research projects and empirical studies are being devoted to mathematical formulations of the economy.

Attention is focused on the objectives, uses, and characteristics of several of the large-scale formulations. Among the examples considered are the linear programming models; the Leontief-type input-output models; the statistical models of Tinbergen, Klein, and Goldberger; the Industrial Dynamics models of Forrester; and the decision-unit models of Orcutt. The Forrester and Orcutt models are the most recent of those discussed. Both are dynamic characterizations of certain aspects of the economy, and both use computer simulation for testing and implementation. Nevertheless, the two have important differences in emphasis, basic structure, and treatment of stochastic elements. Since the author has been personally associated with both of these models during developmental stages, they are discussed in somewhat greater detail than the others. For the most part, however, the survey is cursory and non-evaluative in nature.

3. "A HEURISTIC PROGRAM FOR ASSEMBLY LINE BALANCING," FRED M. TONGE, *The RAND Corporation.*

The assembly line balancing problem considered here is:

Given an assembly process composed of elemental tasks, each task characterized by an operation time per unit of product and a set of partial ordering relationships with other tasks, what is the minimum number of workmen needed to attain a stated production rate?

Several rigorous formulations of this problem are examined and contrasted with the human use of heuristics in dealing with such complex situations.

The heuristic program for assembly line balancing makes use of three major components:

1.) A routine for constructing related but simpler problems of the class mentioned above from the initial one. This routine proceeds by grouping together adjacent elemental tasks into compound elements, using a small number of simple heuristics suggested by the topology of the problem.

2.) A general assignment routine for solving problems of this class by a straightforward allocation of workmen to jobs. (These jobs may be aggregates of several elemental tasks, requiring an allocation of more than one workman.)

3.) Some heuristics for regrouping elemental tasks among the compound elements of a problem; thus creating a closely related problem of the same class.

After making an estimate of the total number of men required to meet a known production rate for the given product, the executive program constructs a hierarchy of related but successively simpler problems. The general assignment routine is then applied to the simplest problem. After successful allocation of the available workmen to jobs (here represented by compound elements), each compound element is taken as a separate problem of this class and the general assignment routine applied recursively to it, and so on down to the level of tasks (either compound elements or elemental tasks) requiring a single workman. The regrouping heuristics are called upon to shift elemental tasks from one compound element to another whenever the general assignment routine fails. If the general assignment should completely fail on any problem, another successful allocation is sought for the simpler problem from which the failing one was derived, and the recursive cycle is then restarted. If the simplest problem should fail, the estimate of workmen required is increased and the entire process started again.

Flowcharts of each phase of the program are presented, and the heuristics used in each are considered in detail. The means chosen to mechanize this program are discussed, and operating results to date on actual problems are reviewed.

## D. Queueing Theory and Systems Engineering. *Chairman:* MAX A. WOODBURY, *Research Professor of Mathematics, New York University.*

1. "BASIC QUEUEING THEORY APPLIED TO PRODUCTION, INVENTORY, DISTRIBUTION," GLEN CAMP, *Case Institute of Technology.*

The practical application of queueing thory to complex production-inventory-distribution systems is discussed. The single server is first considered, in terms of (a) the statistics of arrival and service times, including feedback control on the parameters of the distributions arising from intrinsic factors, managerial actions, etc.; (b) various priority rules; (c), discrete-fluid and fluid-discrete transformations; etc. Understanding of single servers has advanced greatly in recent years, with the result that most cases arising in practice can be handled satisfactorily.

Complex production-inventory-distribution systems are then considered as approximately representable, in many cases, as series-parallel networks of single servers through which streams of several different items (orders, products, etc.) flow, and in which feedback signals from various parts of the system control the statistical parameters of arrivals and service times in other parts. Optimality criteria are discussed, and some analytic methods for approximating and bounding the optimal system are presented.

2. "THEORY IN SYSTEM ANALYSIS AND SYSTEM SYNTHESIS," HARRY H. GOODE, *Technical Director, Bendix Systems Division, Bendix Aviation Corporation and Electronics Defense Group, Engineering Research Institute, University of Michigan;* AND WILLIAM P. TANNER, JR., *Electronics Defense Group, Engineering Research Institute, University of Michigan.*

After distinquishing between the systems engineer and the operations researcher this paper outlines bounds on the subject matter of systems engineering by giving characteristics of systems and going into some detail on the character of the practice of systems engineering. Systems engineering is stated to be both an analytic and synthetic process and the phases through which the systems engineer passes in designing the system are outlined.

Using this outline of the systems engineering process, the literature of the last two or three years is reviewed to underline progress in the areas of the choice of a measure of effectiveness, in single-thread design, in simulation, etc. It is concluded that comparatively little gain in knowledge of a general theory of systems engineering has occurred.

Toward such a theory, the paper proceeds to outline a hierarchy of systems due to Boulding and to generalize on a system element by means of a model taken from mathematical statistics. With this basis, various aspects of the performance and design of

adaptive large-scale systems are considered such as centralization versus decentralization, standardization of information, the optimum size of a sub-unit, etc. The paper closes with a note concerning the desirability of contributions to the general theory of systems engineering.

3. "DYNAMIC MODELS AND ANALOGIES IN THE STUDY OF LARGE SCALE SYSTEMS," JAY W. FORRESTER, *School of Industrial Management, Massachusetts Institute of Technology.*

The foundation now exists for developing a quantitative method of analysis for the fundamental interactions that determine industrial growth and fluctuation. An understanding of the dynamic forces can grow out of the background of information-feedback theory, sampled-data servomechanisms, the effect of noise on system behavior, the use of digital computers as simulators of complex systems, and the experience of the last decade in automatic making of tactical military decisions.

At MIT we call this research field "Industrial Dynamics" with four phases: basic underlying theory, plausible but hypothetical systems studies to demonstrate important phenomena, case studies jointly with cooperating companies on urgent problems of corporate top management, and an educational program aimed at providing a framework for tying together other management school subjects. As our precedent, we should aspire to provide for management the foundation which physics provides for engineering. Such analysis must treat the firm as a whole, often including the dynamics of its market. In a single model we must be prepared to represent money flow, capital investment, employment, movement of goods, and the psychological factors of habit, speculation, resistance to change, and hope. All these must be tied together with the information flow network and the decision-making processes. Such an approach shows an orderly underlying structure which provides a sufficient cause for and explanation of the seemingly erratic and volatile behavior we observe in industrial activity. Such models must realistically represent our descriptive and intuitive knowledge of the systems with which we are dealing.

As we are now formulating these systems, a mathematical model contains no simultaneous equations. It contains reservoirs interconnected by flow rates. Reservoirs contain goods, orders, in-process decisions, employees, cash, and all other countable items which would exist if the system were brought to rest. The interconnecting rates of flow are controlled by decisions in the system. These may be either the overt decisions open to free choice of people or the implicit decisions which are controlled by the existing state of the system.

The models will be highly non-linear and contain a few hundred to several thousand variables. Even so, they are entirely practical to handle on present day computers. The limitation on realistic representation arises from one's perception of the important factors in the system, not from restrictions on how many of these factors can be incorporated. In nonlinear systems of this complexity, optimizing has no meaning. The goal is, instead, to improve performance but not to demand proven perfection. Industrial Dynamics will be an empirical, experimental aid to the practicing manager coping with the full complexities he now faces, but will not be a road to concise, generalized, mathematical theory or optimum solutions.

## E. Resource Allocation Models. *Chairman:* MELVIN E. SALVESON, *President, Center for Advanced Management.*

1. "LOGISTIC SYSTEMS," HARLAN D. MILLS, *Market Research Corporation of America,* and *Princeton University.*

Many logistic problems are those of "organized complexity"—involving moderately large but heterogeneous systems too complex to handle with classical concepts of mathematical analysis. Our current shortcomings usually have to do with too much detail and too little perspective—the problem is to trade one for another in an effective way.

We mathematize logistics in order to organize and summarize common logical features of

a variety of problems, approaches, and techniques concerned with the location and flow of materiel in physical operations. Our point of view is statistical, seeking to replace discrete and exact microscopic measurements and relations of logistic operations by macroscopic statistical measurements and relations which summarize larger aspects of overall performance. The underlying rationale considers logistic operations as partially controlled stochastic processes, in which decision makers acquire information (sample statistics) and act upon it (through decision policies) over time. In this framework, problems of logistic decision and policy become those of statistical measurement and stochastic control of moderately large heterogeneous systems.

2. "STOCHASTIC APPROXIMATIONS TO OPTIMUM DECISION RULES," ABRAHAM CHARNES, *The Technological Institute, Northwestern University,* AND W. W. COOPER, *Graduate School of Industrial Administration, Carnegie Institute of Technology.*

A new conceptual and analytical vehicle for problems of temporal planning under uncertainty, involving determination of optimal (sequential) stochastic decision rules is defined and illustrated by means of a typical industrial example. The paper presents a method of attack which splits the problem into two non-linear (or linear) programming parts, (i) determining optimal probability distributions, (ii) approximating the optimal distributions as closely as possible by decision rules of prescribed form.

## F. Programming, Games, Decisions and Strategies. *Chairman:* GIFFORD SYMONDS, *Esso Standard Oil Company.*

1. "GAMES, DECISIONS AND INDUSTRIAL ORGANIZATION," MARTIN SHUBIK, *Management Consulting Service, General Electric Company, New York.*

In the fifteen years since the publication of the Theory of Games and Economic Behavior, several hundreds of papers and articles have appeared under the general classification of the theory of games.

With the proliferation of the literature, many subdivisions of game theory have appeared. Before we are in a position to understand fully the possibilities for application of game theory, we need to distinguish among five very different developments. They are, respectively:

1. The theory of solution for two-person constant-sum games.
2. The description of the extensive form of a game.
3. The theories of solution for n-person games (where $n \geqslant 2$ for non-constant-sum games; $n \geqslant 3$ for constant-sum games).
4. The theories of solution for games against nature (games in which rules are not completely specified).
5. The theories of solution for dynamic games.

There are only a few industrial uses of two-person constant-sum games. They have been applied to advertising problems and oil company competition. Many military uses have been made of these games in problems involving "duels" or in search problems.

The description of the extensive form of a game has provided a new and precise language for the study of certain aspects of decision making. The precise definitions of strategy, payoff, information and so forth serve as the building blocks for decision theory and organization theory.

There is no uniquely believed theory of solution for n-person games. Shapley, Nash, Luce, Raiffa, Vickrey, Harsanyi, Shubik among others have offered alternative solutions to that of von Neuman and Morgenstern. Empirical work has been done by Flood and others to check the types of solution which are encountered in plays by small groups. The different theories have been applied to problems involving: voting, bargaining, decentralization, political and economic power, competition and collusion.

Many different conventions have been suggested as solutions for games against nature. Savage, Milnor and Hurwicz are among those who have offered conventions for handling un-

certainty. The work in this area is closely related to statistical decision theory. Bennion has given a simple and effective example of an application of games against nature to a capital budgeting problem.

Dynamic games provide models for situations with indeterminate endings. They are related closely to learning theory models. Games of survival and games of economic survival provide models of the firm which can be used to investigate long-range strategies and which mirror the different motives for optimization in which both survival and maximization of expected income (or some other function of income) may play roles.

2. "IMPACT OF THE NEW FORMAL TECHNIQUES ON ECONOMIC THEORY," WILLIAM BAUMOL, *Princeton University.*

The new mathematical techniques such as mathematical programming and Game theory have enriched rather than revolutionized economic theory as they were originally expected to do. They have contributed very few new theorems but they have provided us with new interpretations of much of our existing theory and have permitted us to extend the domain of significance of some of the existing theorems.

For example mathematical programming has permitted us to generalize the basic theorem on the competitive allocation of resources to cover the production of free goods and goods which are not sold because they are too expensive, and has permitted us to simplify the McKenzie theorem on the existence of an equilibrium in a competitive economy. In addition, the duality theorems have given us a very useful interpretation of the Lagrange multiplier in the analysis of output determination in the theory of the firm.

Game theory also has provided us with all sorts of suggestive concepts—coalitions, domination, mixed strategies, etc. However, here again, the theory rather than revolutionizing oligopoly theory has taken its place alongside other economic oligopoly models. The zero sum two person game—is the most highly developed portion of game theory but its assumptions are so restrictive that it is difficult to find any close approximations in the economy. Even the non zero sum game assumes that the players form a coalition and maximize against the dummy player (they obtain their joint maximum gain and hence act like a monopoly) and that then they only fight over the division of the spoils. In this way the theory sidesteps one of the most important problems of oligopoly theory which asks just how the total "take" of an oligopolistic industry will differ from that of a monopoly.

The new tools have thus been very helpful to economists but they have had less radical effects than might have been expected, largely because they are almost pure mathematics. Hence their empirical content is (as it should be) nil or almost nil. Real revolutions in economic theory must, I believe, wait until these tools can be combined with empirical observation which can for example permit us to choose among the fantastic number of possible oligopoly models. Only then can we hope to come up with a rich body of concrete new conclusions.

## G. Recent Developments in Programming. *Chairman:* A. W. TUCKER, *Department of Mathematics, Princeton University.*

1. "MULTI-STAGE PROGRAMMING MODELS," GEORGE DANTZIG, *The RAND Corporation.* Abstract not received.

2. "NEW GENERALIZATIONS IN THE THEORY OF GAMES & LINEAR PROGRAMMING," KENNETH KRETSCHMER, *University of Pittsburgh.* Abstract not received.

3. "DYNAMIC PROGRAMMING MODELS AND ALGORITHMS," STUART DREYFUS, *The RAND Corporation.*

This paper considers four algorithms for the solution of dynamic programming processes. The areas of applicability of each are indicated, and the solution of a particular problem by the use of each algorithm is discussed.

## H. Simulation and Automata. *Chairman:* HERMAN H. GOLDSTINE, *International Business Machines Corporation.*

1. "SIMULATION OF LARGE SCALE INDUSTRIAL AND LOGISTIC SYSTEMS," MURRAY GEISLER, *The RAND Corporation.*

Simulation in the Logistics Systems Laboratory is directed towards transferring research results to a very large and complex real world organization like the U. S. Air Force. This requires that the simulation contain organizational detail, information flow systems, and inputs that produce situations and conditions in the same order of detail as are encountered in real world organizations.

The paper describes the first experiment of the Logistics Systems Laboratory in which a proposed and an existing system were both simulated. The purpose of the experiment was to determine whether the proposed system would function better in terms of both effectiveness and cost when compared with the existing system. The experiment indicated that such was the case, and a detailed description of the proposed system was thereby available, which included not only the policies, but also the detailed procedures represented through manuals, reporting systems, and computer programs. This material is being used by the Air Force in its continuing implementation of the policies contained in the proposed logistics system.

2. "THEORETICAL AND EXPERIMENTAL DEVELOPMENTS IN AUTOMATA," ALLEN NEWELL, *The RAND Corporation* and HERBERT A. SIMON, *Carnegie Institute of Technology, Pittsburgh, Pennsylvania.*

The study of automata is the study of artifacts that exhibit behavior like humans'. It is concerned with whether a machine can recognize a human face, play master chess, compose a symphony, discover a new scientific law, reproduce itself, and so on. The study of automata is not one of the management sciences, although it is relevant to them in several ways: in foreshadowing future automation; in extending the types of numerical and symbolic manipulation computers can do; and in studying human behavior in organizational and problem solving contexts.

This non-technical paper assesses recent advances in the study of automata, emphasizing four broad points:

1. The study of automata has now advanced from speculation to construction.

2. This transformation is almost entirely due to the coming of age of the digital computer—in size and speed—and to its use for general symbol manipulation rather than numerical calculation.

3. Present efforts focus on two main problems—intelligent behavior and pattern recognition, each following a quite separate course and using different concepts.

4. There are close and reciprocal relations with the sciences that study the corresponding human processes: with the study of human higher mental processes, and nerve physiology, respectively.

Intelligent behavior consists in handling difficult tasks without prepared procedures—solving problems when you don't know in advance how to solve them. The difficult tasks that currently are being programmed for computers include checkers, chess, and theorem proving in logic and plane geometry. For none of them do practical systematic solution procedures exist. The basic approach is to search for possible solutions and to test if one is acceptable. But since the number of possibilities is very large, the real problem is to find cues, guides, and hints—heuristics—that reduce the amount of search and the cost of testing. To illustrate, a program, the Logic Theorist, is considered in detail (constructed by J. C. Shaw and the authors). This program discovers proofs for theorems in elementary symbolic logic, and since 1956 has been tested with about 300 theorems under various conditions. The program is truly symbolic—it could run without a single arithmetic addition. It is recursive, proceeding by generating problems, subproblems, sub-subproblems and so on. It uses heuristics to determine which subproblems to generate, to keep, to work on.

Pattern recognition consists in extracting information from unprepared environments that are very rich in information. It is not simply a subspecies of intelligent behavior, since it appears to be so immediate and effective in higher organisms as to involve mechanisms not employed in the other. Work on this problem has generally started from models of the central nervous system, following fairly closely the current state of physiological knowledge. The nerve net is a parallel system of simple components and low logical depth, which contrasts sharply with the programs used to produce intelligent behavior. The latter are serial systems with complex components and great logical depth. The study of pattern recognition is well illustrated by the recent work of F. Rosenblatt on a system called the Perceptron. A Perceptron is a nerve net consisting of only three levels: a retina, an association area, and response units, with the cells connected together essentially at random. It accepts any stimulation that can be put on its two-dimensional retina. It is capable of learning to distinguish patterns, like $E$'s and $X$'s, if it is simply presented with a sequence of examples in various positions and orientations.

In summary, some of the factors are noted that make the study of automata an exceedingly fast-moving field, and one that management scientists would do well to watch.

3. "MATHEMATICAL METHODS IN SIMULATION," FRANZ ALT, *National Bureau of Standards*.

Several cases are discussed in which operational problems have been attacked by simulation. Studies of mechanized post office systems lead to experiments, carried out on electronic computing machines, in which the destinations of letters are represented by random numbers generated according to appropriate probability distributions, and the characteristics of various proposed mail-sorting machines are simulated by instructions to the computer. In this way one can obtain information on the sorting rate, the average length of time a letter remains in the machine, and the frequency with which batches of mail for a particular destination leave the machine. Automobile traffic at road intersections has been studied by simulation in order to determine the effects of traffic lights, reserved lanes or access ramps, etc. Similarly, queueing line problems can be solved by simulation. Large-scale studies have been made of military tactics by simulating naval engagements, tank battles, antiaircraft defense systems and other military operations on electronic computers. In such problems, information on the characteristics of weapons and the tactics used by commanders are fed into the computer, and the actual course of battle is determined by means of random numbers which indicate the outcome of accidental elements, such as the hits or misses from artillery fire. Certain problems in physics, for instance the penetration of nuclear particles into a shield, lend themselves to study by simulation in a very similar way.

From these examples, certain general observations are abstracted concerning different classes of problems, the use of random numbers in simulation (Monte Carlo method) and the effectiveness of simulation compared to other methods of approach.

**Dinner Speaker:** THE HONORABLE ROBERT DECHERT, *General Counsel, Department of Defense.* "A LAWYER-EXECUTIVE'S FAITH IN THE FUTURE OF MANAGEMENT SCIENCE". Summary was published in the BULLETIN, December 1, 1958.

**I. Contributed Papers.** *Chairman:* ANDREW VAZSONYI, *Alderson Associates;* EZRA GLASER, *National Analysts, Inc.*

SESSION I. THE USE OF SIMULATION IN MANAGEMENT

1. "MONTE CARLO SIMULATION OF CLAIM DISTRIBUTION IN A LIFE-INSURANCE COMPANY—A CASE HISTORY," NATHAN F. JONES, P. B. HEIT, AND D. G. LIVINGSTON, *The Prudential Insurance Company of America.*

It was desired to obtain distributions, by number and amount, of claims to be expected

in the future from a special sub-population of the insurer's possible claimants. The distributions of lives over the various basic claim probability classes and of amounts of insurance over lives were substantially skewed and not independent, necessitating, because of a time consideration, use of Monte Carlo methods simulating "years of experience". In order to reduce computer costs, "reduction factors", which substantially increased model efficiency without significant distortion of the characteristics of the basic distributions, were devised and applied to certain sub-groups. The determination and use of the reduction factors in Monte Carlo procedure are illustrated in a hypothetical life insurance premium and contingency reserve problem.

2. "A TECHNICAL LANGUAGE FOR THE GENERAL SIMULATION OF TIME DEPENDENT SYSTEMS," PATRICK HARRIS AND KENNETH R. BLAKE, *Operations Research Group, United Aircraft Corporation, East Hartford, Connecticut.*

The complexities arising for the necessity to take the "systems as a whole" approach to systems problems have created the need for new analytic tools and techniques. Numeric simulation is one such technique growing in importance. Using the philosophy embodied in the dynamic programming approach to systems, a basis of a language of simulation is suggested which considers the following general characteristics in the description of any discrete dynamic system.

Let $S$ be a discrete physical system whose state at any time is given by a vector $X = (x_1, x_2, \cdots, x_n)$ of state variables. $X_t$ is the state of $S$ at time $t$. For every initial state $X_0$ there follows a sequence of states; $X_0, X_1, X_2 \cdots$. The state of the system may change with the passage of time; i.e., for any state of $S$ there exists a transformation of that state which yields the next state. If at any time there is a choice of transformations on $X$, then a process which makes the choice or decision is called a decision process where a decision is equivalent to a transformation. Let $F = F_r$ denote the set of all possible transformations of $X$. Denote by $Z$ the decision process which selects the transformation to be used. If $F_{r_t}$, the transformation selected at time $t$, depends only on the last state $X_{t-1}$, then the decision process $Z$ is a function of $X$ whose range is $F$; i.e., $Z(X)$ $F$ or more specifically $F_{r_t} = Z(X_{t-1})$. Hence, we see that the decision process provides us with a means of obtaining any state of the system from the previous state since, given $X_{t-1}$, $F_{r_t} = Z(X_{t-1})$ and $X_t = F_{r_t}(X_{t-1})$.

From this formulation a specific formalism using the propositional calculus is derived. An application to a simple inventory system is made.

It is suggested that this representation will lead to the development of an automatic programming routine so that one could state the system to be simulated in the "language" constructed and have a computer program for it compiled automatically.

3. "COMPETITIVE COEFFICIENTS," LAWRENCE FRIEDMAN, *Mgr. Operations Research, M and M Candies.*

In any true competitive situation there is always a value relationship among the competitors. By means of competitive coefficients it is possible to quantify an indirect loss or gain as a result of a gain or loss by other competitors. These coefficients are useful in determining the true or ultimate payoff to each competitor as a result of the various alternatives in a competitive situation. In certain situations the use of the competitive coefficients leads to a rational solution of the non zero sum game.

4. "BUSINESS DECISION GAMES FOR MANAGEMENT TRAINING PURPOSES," J. L. DILLINGER, *School of Business, Northwestern University.*

The purpose of this paper is to compare and analyze two different "plays" by two different management groups of the same business decision game. The "game" used was the UCLA Executive Game No. 2. The different groups of similar background were two sets of top and middle management executives attending Northwestern University's Institute for Management. The same problem situation was given both groups. The resulting simi-

larities and divergences in the "play" will be analyzed and compared. Any possibly significant generalizations will be advanced and discussed.

5. "A NOTE ON EVALUATING OPERATIONAL GAMING," DIAN R. HITCHCOCK,* *Member of the Technical Staff, Ramo Wooldridge Division, Thompson Ramo Wooldridge Inc.*

Operational gaming is a simulation activity with potential application as an evaluation tool, a demonstration device, or a training aid. Any evaluation of operational gaming with respect to these applications requires a prelusive analysis of the functions of simulation in evaluation, demonstration, and training. The differences between these functions are investigated by means of an example which emphasizes that the three types of simulators—the discovery model, the demonstration model, and the training model—are "realistic" in different respects and that the circumstances in which they are used presuppose different amounts of knowledge about the thing simulated.

6. "SOME PROBLEMS IN DIGITAL SYSTEMS SIMULATION," R. W. CONWAY, B. M. JOHNSON, AND W. L. MAXWELL, *Department of Industrial and Engineering Administration, Cornell University.*

This is a paper *on* simulation rather than the description of a specific problem treated *by* simulation. It describes some of the work done on an ONR sponsored project to develop a general purpose queue-network simulator for a medium-scale computer. One of the primary objectives of this work was to study simulation per se.

Two types of problems are discussed. The first are those involved in the actual construction of a simulator in the form of a program for an automatic computer—questions of timing and synchronizing the operations of the elements of the system, maintaining files of unknown and variable length, and designing the system for flexible operation. The second are those involved in the use of such a simulator—questions of experimental design, initial conditions, steady-state measurements, and efficient sampling of output data.

7. "'HAND' VERSUS 'MACHINE' BUSINESS DECISION GAMES." J. L. DILLINGER, *School of Business, Northwestern University, Evanston, Ill.*

Some controversy has developed over the efficacy of using an electronic computing machine in a "business decision game." Two "hand" games and two "machine" games will be described, analyzed, and compared. Experience with each will be cited. Some possible generalizations will be cited and discussed.

## SESSION II. THEORETICAL METHODS

1. "THE DUAL SIMPLEX ALGORITHM FOR BOUNDED VARIABLES (WITH APPLICATION TO A REGRESSION PROBLEM)," HARVEY M. WAGNER, *Stanford University.*

Applications of linear programming models in which the variables are bounded from above are becoming more frequent. Charnes, Lemke, and Dantzig have offered a variant of the simplex method for solving $m$ equation linear programming problems, where the $n$ variables are bounded from above; their method has the advantage of utilizing a tableau with only $m$ rows, but presents certain computational complexities. In the present paper we demonstrate how Lemke's dual simplex algorithm may also be extended in a manner which requires a tableau with only $m$ rows. This extension appears to avoid some of the complexities of the previous method; further it provides another simplex-type algorithm which may be used to solve general linear programming problems.

The technique is illustrated by means of a statistical regression analysis example. Given $n$ observations on $p$ "independent" variables and one "dependent" variable, a regression line of best fit is sought; "best fit" is here defined as that line which minimizes the sum of the absolute deviations. By employing the fundamental dual theorem in linear pro-

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* This paper was written and presented while the author was a member of the Operations Research Group of System Development Corporation.

gramming, the problem may be formulated as a $p$ equation linear programming model with bounded variables. The regression coefficients may then be found by utilizing the suggested dual simplex algorithm for bounded variables.

2. "ON THE SOLUTION OF TWO-PERSON ZERO-SUM GAMES BY THE SIMPLEX METHOD," VALDEMARS PUNGA, *Rensselaer Polytechnic Institute.*

Studying methods of solutions of two-person zero-sum games, say, in a pleasant way according to Williams "The Compleat Strategist" or in a more serious way using adjoint submatrices, say, according to McKinsey's book, one gets the impression that the solution of a large game is a very messy job, reminiscent of "cut and try" method. It is a known fact that any rectangular game can be solved in a straightforward manner (i.e. without any "cut and try" element) by the simplex method of linear programming.

Although many excellent papers clearly indicate the process of reduction of a game for the simplex procedure, the whole process is usually somewhat obscured by the game theoretical considerations. The objective of this paper is to present in a simple way the successive steps necessary for the solution of the game by the simplex method, followed by the short explanation of the steps and an illustrative example.

3. "THE DEMONSTRATION OF STATISTICAL CONTROL PROBLEMS BY AN ELECTRONIC DEVICE," JOHN P. HYLAND, *The Standard Oil Company.*

Problems arise in the control of complex systems which are subject to operational fluctuations of a random character or in which measurements are subject to error of appreciable magnitude. These random fluctuations are superimposed on the fundamental physical relationships inherent in the system and sometimes lead to great difficulty in the interpretation of measurements and effects and in attempting to deduce how the fundamental physical variables are related in systems where this is not already known. An electronic device has been set up which permits the duplication of systems of various types with known or hypothetical physical relationships in the important variables so that the effect of random variations of certain kinds can be studied and methods developed for the control of the systems.

4. "QUEUEING THEORY AS A TOOL IN ECONOMIC PLANNING," JAY B. HEYNE AND LEWIS BROTMAN, *Systems Analysis Laboratory, Hughes Aircraft Company, Culver City, California.*

The costs of defense, measurable in dollars per attacking wave, rise sharply when probabilities of electronic failure are introduced. For this reason it becomes imperative to develop techniques leading to the prediction and control of the life characteristics of electronic weapon systems. These same techniques are useful to the industrial consumer in the anticipation of cost factors which bear on his use of electronic systems. These costs may be measured in dollars per operating hour and are determined in a manner which makes them sensitive to probabilities of system failure. Knowledge of electronic part behavior is not, and will not for some time be, complete enough to enable the assignment of specific cause and effect relationships to part failures. Thus, recourse to statistical analysis of electronic failure patterns must be taken. A review of suggested modifications in design practice is made. These modifications are deemed necessary to the prolongation of electronic system life. These same techniques can be used in the analysis of the logistic environment and in the determination of cost factors related to this environment. These techniques are discussed in terms of their use, their inherent limitations and their possibilities for continued profitable investigation.

5. "A MEASURE OF THE POWER OF A CLASSIFICATION SCHEME," MICHAEL H. HALBERT, *Case Institute of Technology.*

This paper presents a method for measuring the worth, value, or power of a classification scheme. The categories of classification need not be mutually exclusive; they can be

made exhaustive always by the addition of a miscellaneous category. The values are developed from the decision rules and the pay-off matrix, which can be given or an optimum set of decision rules can be developed, given the pay-off matrix.

The fundamental notion behind this approach is the explicit requirement for a set of primitive properties of the elements to be classified. These properties (or predicates) serve as defining variables for all possible classification schemes, as well as to provide the value measure. Thus, a classification sub-set derives its value from the absolute difference between the marginal probability of an element of the total set possessing some particular attribute and the conditional probability, given that the element belongs to the subset. In the simple case, the value is merely summed over all of the predicates. Later extensions consider non additive values, misinformation, and cost of the classification procedure itself.

The final section of the paper deals with the difference between natural, linguistic classification systems, and special "scientific" ones. Scientific classification schemes can be optimized relevant to a specific set of decision rules and pay-offs. Mention is made of a method of ranking various scientific disciplines by the general power of the classification schemes they use. Work is still in progress on complete formalization and generalization over possible decision rules and multiple value systems.

6. "INCREASING THE CAPACITY OF A NETWORK: THE PARAMETRIC BUDGET PROBLEM," D. R. Fulkerson, *The RAND Corporation, Santa Monica, Calif.*

Suppose that a fixed budget can be allocated among the links of a network for the purpose of increasing its flow capacity relative to a given source and sink. How should the money be spent in order to maximize the resulting total flow? Assuming the cost of increasing link capacity is linear and homogeneous, an algorithm is developed that produces solutions not only for a fixed budget but for all budgets. Although the budget problem does not formally fall within the class of transportation-type programming problems, it is interesting to note that a variant of the labeling procedure for maximum flow problems can also be used here.

7. "SOME CONCEPTS AND PROBLEM AREAS IN THE FLIGHT MANAGEMENT OF VEHICULAR SYSTEMS," David Ellis, Leon Steinman, Fred Ludwig: *Litton Industries, Computer and Control Systems Division, Research and Analysis Department, West Los Angeles, California.*

Typical constraints influencing the quality of mission performance are imposed by geometry, time, the tactical environment and inherent systems limitations. Direct and indirect operational consequences of such constraints as well as their successive interactions and ordering in time define the flight management problem.

The overt processes of greatest management interest are those associated with decision making and action formulation. Complex stimuli, more or less representative of the display/control state of the art, depict flight origin, in-flight reference, and terminus against a background of display assemblages simultaneously cascading information concerning fuel/energy utilization and the tactical situation.

The type and amounts of information available are importantly related to the propriety of decision and subsequent action. Selection criteria must therefore be applied to information stimuli. Following selection of types and amounts of information to be presented, consideration is given the means for sensory acquisition, accessible storage and unambiguous presentation of the data.

The inadequacy of conventional approaches to refractory display/control problems engendered by high performance conveyances has stimulated conceptual elaboration in the direction of displays which accomplish at least a partial integration of *a priori* and transiently sensed information. The degree of success achieved to date in the physical expression of such concepts permits some speculation concerning future developments and applications of more refined sensory-computer-display linkages.

## SESSION III. MANAGEMENT DECISION MAKING

1. "A CLOSER LOOK AT THE LEASING OF CAPITAL ASSETS," LEON QUINTO, *International Business Machines Corporation.*

This paper is a progress report of the authors' researches into the problems involved in the leasing of capital assets subject to obsolescence. In Part I, the decision to purchase rather than lease is analyzed from the viewpoint of the user. A formula is presented which enables the user to compute the rate of return obtained from purchase based on an assumed useful life for the machine. The rate of return when compared with the customer's capital-cut off rate makes a clear-cut decision possible. The problems involved in estimating useful life are analyzed in detail although some of the problems do not as yet admit of a precise solution.

In Part II, the decision to lease rather than sell is analyzed from the viewpoint of the manufacturer who, in fact, is in two quite different types of business: production and banking. A financial subsidiary is presented as the solution to the capital shortage problem which results from the fact that so much of the producer's capital remains locked up in inventory. We develop criteria for deciding when such a subsidiary will enhance the overall profits of the producer.

2. "A NEW APPROACH TO DYNAMIC EQUIPMENT POLICY," FRANÇOIS OLMER, *Senior Scientist, Armour Research Foundation, Technology Center, Chicago 16, Illinois.*

An expression giving the economic life of industrial equipment is derived from the logarithmic time decrement of salvage values.

This expression offers management a basis for computing alternative costs in a less arbitrary fashion than the present MAPI techniques.

3. "THE MEASUREMENT OF PRODUCTIVITY IN A RETAIL SALES ORGANIZATION," HAROLD W. MARTIN, *Rensselaer Polytechnic Institute, Troy, New York* AND R. H. COBB, *Operations Research Section, Standard Oil Co., Cleveland, Ohio.*

The problems entailed in measuring productivity are examined and a common means of productivity measurement for use in industry and commerce is suggested. Application of the suggested method to the special case of measuring the productivity of retail selling functions is discussed and two specific applications, each encompassing a major part of the selling functions in a retail department store, are described. Comparative data emanating from these case studies is discussed and models showing the effects of the product assortments offered for sale on the productivity of the selling functions involved are presented. The relationship between productivity and profits in such cases is analyzed and is presented in the form of a representative model.

4. "MANAGEMENT INSIGHT," M. LAWRENCE FURST, *American Bosch Arma Corporation.*

The mounting efforts in the field of management have been taken to mean that progress is being made proportionately. The fact is that the accelerated expenditures of time and money are desperate measures in the face of pressing management problems such as exist in the missile and satellite programs. Of particular interest is the exorbitant commitment to "scientific" management tools, especially those sanctified by Operations Research.

This paper presents the proper direction that management investigation should take based on results obtained from a novel analytic technique. The proposed method provides the breakthrough by which the complete management picture is obtained and thereby, the insights for optimizing the "solution" path.

5. "THE QUEUE- AND DOLLAR-COST OF SCHEDULED SERVICE-SHUTOFFS," HENRY CLAY PRICE.

The present study has been done relative to such shutoffs of refreshment service for

employee work-breaks. An analytical determination has been made of the relative and absolute costs, principally in paid employee time consumed, of a free time-choice refreshment break system versus a partially controlled system which resulted in long queues. It is shown that the former can save many thousands of dollars per year in avoiding wasted employee queue-time, e.g., in the 2000-employee 3-queue establishment studied, about $100,000 per year. Alternate approaches toward improvement are mentioned, and generalized equations are presented.

6. "A SYSTEM OF PRODUCT DEVELOPMENT," E. CURETON HARRIS, *Rider College, Trenton, N. J.*

Millions of dollars are wasted each year on products that fail. An important cause of these failures is management's lack of knowledge of the operation of product development. This paper presents a system of product development. It is based on procedures used by leading manufacturers and research organizations to develop new products and improve old ones (or to determine when development is not worth while); the philosophy, methods and procedures of operations research; statistical methods which may be used by product development managers working with statisticians to increase the probability of making sound decisions about alternative actions. To overcome widespread confusion in current usage of the term, a workable definition of PRODUCT DEVELOPMENT is proposed and explained. A graphic model, showing the flow of basic activities and the points at which management decisions must be made is presented. Each of the steps in product development and their inter-relationships is described. Since many product decisions depend upon consumer research, and consumer research is often misused, basic aspects of this tool and the product development manager's vital role in its reliable usage is presented in some detail.

7. "DECISION MAKING IN TIME," JOHN DEWITT NORTON, *National Planning Association.*

The conceptual scheme of triangular programming is used to describe elements of the decision process. Programming is shown to be a process of requisitioning in advance. The characteristics of the triangular form are illustrated by a simplified manufacturing operation. The approach is then generalized and applied schematically (1) to any sequence of supply activities characterized by a flow of availabilities which when committed in turn mature as availabilities in later periods; (2) the set of demands derived as requisitions from stipulated future targets. The two formulations are dual with respect to direction in time, stipulated and derived quantities, and process represented (causal vs. prescriptive). These formulations are first represented separately in two-way arrays, by time period, then combined in a single grid. The commitments formulation leads to a unique prediction. The requisitioning formulation allows for alternative future programs. Past commitments projected as future availabilities limit the discretion of decision makers. Conditions for feasible programs are stated. In the absence of an explicit optimization criterion, a procedure for the selection of a preferred program by systematic comparative analysis is described. While this approach is advanced primarily to elucidate the decision making process, it furnishes prototype programming models for economy-wide, industry within economy, firm within industry, and plant projections.

## SESSION IV. PLANNING AND SCHEDULING STUDIES

1. "OPERATIONS RESEARCH IN PLANNING STUDY-TYPE CONTRACTS," D. R. J. WHITE, *American Machine & Foundry Company.*

Many study-type, cost-plus-fixed-fee contracts are annually awarded by the Department of Defense and other government agencies. Of these programs, a large percentage are very broadly defined in the original statement of work. Often the first few month's effort, therefore, is earmarked for establishing a detailed recommended program to be followed during the remainder of the contract and the methods to be used to achieve the general objectives. Since there frequently exists a large number of variables that could be

studied, a decision regarding the depth and breadth of proposed effort is often a formidable task. The consequences of inadequately supportable judgments can commit monies to marginal returns.

By applying the techniques and mathematical models developed in this paper, confident decisions can be made to suitably embrace user's needs. These decisions represent a weighting of the relative difficulty of eliciting all supporting input information, of the relative magnitude of effort required to gainfully employ each facet of this information (physical realizability), and of the contract duration and number of dollars available. An illustrative example is presented on a study of equipment standardization.

2. "ON THE PERFORMANCE OF WEAPONS SYSTEMS USING SIMULATION TECHNIQUES," D. R. J. WHITE, *American Machine & Foundry Company.*

Under the present weapons-system concept, an increasing pressure is being exerted upon management to assure that a system in development will fulfill the user's needs. This paper presents a technique, entitled the "Evaluation Concept," which has been successfully applied in ascertaining the performances of electromagnetic receiving systems in the presence of vast radiating populations. Applicable to many other problems, this concept instrumented with digital computer simulation techniques is a versatile tool available to management for helping fulfill the responsibilities entrusted to it.

The Evaluation Concept consists of methods for eliciting and defining user's needs, translating these needs into the languages of technical requirements, simulating weapons systems and applying them to their environments, comparing the results with the original needs by scoring techniques, and producing recommendations based on the scores. Most of these operations are defined by elements of an overall mathematical model. By programming this model in a high-speed, general-purpose digital computer, a meaningful evaluation of either operational or proposed systems can be ascertained with a flexibility and confidence believed to be otherwise impossible.

To implement the Evaluation Concept an illustrative example is presented on the electromagnetic interference problem. The radiating characteristics of several transmitters* are discretely simulated on an IBM-704 computer including their scan properties (where applicable) and the solid-space antenna patterns. Propagation phenomena, terrain effects, and the characteristics of a real or proposed receiver* system design are also simulated. The resultant interference effects upon different receivers are readily ascertained as a function of receiver location with respect to the transmitters, of the numbers and types of transmitters, and of the variation of the propagation phenomena and terrain effects. Optimizing the design parameters, frequency assignment, and tactical use is one major output.

3. "OPTIMUM PROGRAMMING OF MARKETING MIX," ANDREW VAZSONYI, *Alderson Associates, Inc.*

A certain merchandising concern wanted to improve the budgeting policy for advertising, promotional and selling effort. The concern has a national distribution coverage and a variety of product lines. The advertising media are both national and local, the promotional and selling effort is conducted from regional offices, but budgets are set from the home office.

All attempts to relate national sales to the advertising, promotional and selling effort have failed. However a multiple regression analysis showed high correlation between regional sales and the marketing effort. The regression equations resulted in significantly different coefficients for the different components of the marketing effort. Not only the sales productivity of advertising, promotion and sales effort was found to be different, but variations within each of these components were discovered. The data also showed, that when the advertising effort is below a "threshold," no sales response was obtained.

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* For security reasons, hypothetical characteristics are used.

The study resulted in a reorientation of the marketing effort of the firm and in a substantial benefit in marketing efficiency.

4. "A MODEL FOR AUTOMATION OF THE SCHEDULING OF ENGINEERS' WORK ACTIVITIES," HENRY BEERS, *Eastern Consulting Associates.*

The extension of this model to an operating system should permit significant improvements in both the schedule and its method of preparation. The model has been designed primarily for organizations faced with the problems of allocating to many and diverse projects the time of its engineers and the associated activities of recording and accounting for this time, particularly with respect to project progress. The model is relatively unsophisticated and its design is such that extension to an operating system could be accomplished through use of standard punched card accounting equipment.

The presentation will include: a) description of the model, b) operating procedure for a system based upon the model, and, c) discussion of advantages and disadvantages of such a system.

5. "APPROXIMATE SOLUTION OF INVENTORY PROBLEMS WITH FIXED DELIVERY TIME," MARTIN J. BECKMANN, *Yale University.*

Suppose that replenishment of inventory requires long, but fixed delivery times. The simplest situation that can be studied is that in which demand is for one unit at a time and perfectly random, i.e. as described by a Poisson process. If the spacing of demands is not random, or if the number of units demanded at a time is itself variable, an exact solution meets with greater difficulties. Now our confidence in the demand distribution may not be such as to justify elaborate calculations. This paper develops an approximate solution from a rigorous expression for the expected value of discounted future costs. First, expected discounted cost is shown to be nearly proportional to average cost averaged over a net stock cycle extending from the maximal stock level $S$ to the reordering point $s$ or slightly beyond. Net stock is defined as stock on hand plus outstanding orders minus shortages. The average cost over net stock cycle is easily calculated as a function of the policy parameters $s$ and $S$. When certain approximations are made in this formula, the optimal order size turns out to be that of Wilson's lot size formula. For the reordering point we obtain a condition which requires that the average conditional probability of a stock-out during the reordering time (averaged over a net stock cycle) be equalized to the ratio of storage costs to shortage penalty.

6. "ON THE SENSITIVITY OF ELEMENTARY INVENTORY MODELS," JOSEPH L. BALINTFY, *The Johns Hopkins University.*

Models of numerous inventory systems can be expressed as a function of the form, $y = f(x)$, where x is a control variable (lot size, inventory level, etc.), and y is the total cost of keeping inventory. For each system there exists an optimal value $x_0$ of variable x and a corresponding minimum cost, $y_0$.

In the literature of elementary inventory models, E. Naddor has defined the sensitivity of an inventory system as the ratio, $y/y_0$ which is a function of the deviation from $x_0$. The present paper explores a more general definition of sensitivity.

One generalization is to define sensitivity as

$$\frac{y - y_0}{x - x_0} \cdot \frac{x_0 \%}{y_0 \%}.$$

This term is the ratio of average percentage changes from the optimum values and allows comparison among different models. Further generalization is to define sensitivity in an analogous way to elasticity,

$$\frac{dy}{dx} \cdot \frac{x \%}{y \%},$$

a familiar concept used in economics and system engineering.

Analysis of the sensitivity of elementary inventory models is presented, and some general conclusions are given. In particular it is shown that the sensitivity of models with lot size control is significantly different from that of models in which surplus and shortage costs are balanced.

7. "THE COMBINED USE OF ANALYTIC, DYNAMIC PROGRAM, AND SIMULATION MODELS IN AN INVENTORY MANAGEMENT PROBLEM," HERBERT W. KARR, *Planning Research Corporation, 10966 Le Comte Avenue, Los Angeles 24, California.*

The paper describes an inventory management project requiring the development of a set of easy to compute stocking policy rules in the face of such complexities as a dynamic, finite length operating program and multiple inventory locations which prevented the solution by straightforward analytical procedures. The approach taken was: (1) to develop a dynamic programming model that assumed a single inventory location; (2) to develop a Monte Carlo simulation of a multiple inventory location system to obtain an approximate correction function for use in the single location dynamic programming model; and (3) to conduct a parameter study of the modified dynamic programming model in order to generate simplified analytical operating decision rules.

8. "THE TRUCK DISPATCHING PROBLEM," G. B. DANTZIG, *The RAND Corporation, Santa Monica, Calif.* AND J. H. RAMSER, *The Atlantic Refining Co., Philadelphia, Pennsylvania.*

The paper is concerned with the optimum routing of a fleet of gasoline delivery trucks between a bulk terminal and a large number of service stations supplied by the terminal. The shortest routes between any two points in the system are given and a demand for one or several products is specified for a number of stations within the distribution system. It is desired to find a way to assign stations to trucks in such a manner that station demands are satisfied and total mileage covered by the fleet is a minimum. A procedure based on a linear programming formulation is given for obtaining a near optimal solution. The calculations may be readily performed by hand or by an automatic digital computing machine. No practical applications of the method have been made as yet. A number of trial problems have been calculated, however.

9. "DESIGNING A BUSINESS MANAGEMENT SIMULATION," D. H. MCGALLIARD, *Remington Rand UNIVAC.*

In the past year much has been written about business management simulation and management "games". Many writers have dealt with particular games and the advantages which can be realized through their use. Games can be developed either to illustrate classical relationships in business elements or to illustrate a specific operating system. Some use electronic computers, some do not.

In the design of a simulation (or game) the objectives must be established. Possible objectives are: training, testing applied management sciences techniques, and measuring certain management skills. Then the scope must be determined. In an effort to achieve realism, you must guard against overcomplicating the game. After the objectives and the scope of the game have been established, the exact relationship of the various factors must be fixed. These relationships expressed mathematically are called the model.

The layout of input and output forms used in playing the game is of great importance. Factors to consider are readability, conformance with general accounting and reporting conventions, and simplicity. In addition, the effect of possible later changes to the game model should be kept in mind.

The final test is the playing of the game. Results should be compared with the original objectives, the reaction of the players and their evaluation of the model for realism and acceptability should be secured. The value of the "post-mortem" session after the game play is highly important. It is here that players reveal their reactions and point up ways in which the models can be improved.