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Man-Machine Simulation Models

Psychosocial and Performance Interaction

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PREFACE

The contemporary field of systems engineering has exhibited an increasing need for comparative evaluation of alternatives early in the research and evaluation phase. As the complexity and sophistication of systems increase, the rise in cost and time needed for their implementation makes more imperative the earliest possible prediction of their efficiency, thus enabling an early evaluation of modifications or alternative proposed systems.

A considerable body of applied techniques, useful in attacking these general alternative selection problems, has been developed in recent years by systems engineers. The large majority of the applications of these techniques, to date, have dealt only with equipment configuration and performance—with the underlying assumption that personnel were available or could readily be trained to control, operate, and maintain the equipment. Stated alternatively, the emphasis has been on selection of an optimum equipment system since man's capabilities seldom limited overall performance. This situation has begun to change in certain advanced equipment systems. "The missing or weak link in the planning of many expensive systems," admits de Sola Pool (1964) "is the prediction of human behavior." Fogel (1963) summarized the changing situation as follows:

"In the more recent past, however, increasing equipment complexity and environmental requirements have made it necessary for the designer to reach for the handbook to determine relevant data so that the human operator will "fit" the designed machine. We are presently faced with problems which require considerable understanding of the man and the machine so that both may be "married" in such a way that each one's attributes compensate for the other's deficiencies."

"Man-Machine Simulation Models" abstracts and presents the results of 10 years of research and digital experimentation conducted by Applied

Psychological Services, Inc. The work was directed toward the development of quantitative techniques for alternative system evaluation when personnel performance and interpersonnel relationships are conceded to be of importance to total system effectiveness—in fact, possibly the limiting aspect of system capabilities. It is a goal of the models described to predict system efficiency levels under various conditions that affect the performance of the man-machine system involved.

The initial impetus to the program was provided by the Office of Naval Research, Department of the Navy, in January 1958. This initial work yielded the two man-machine model described in the early chapters. Later, also under Office of Naval Research sponsorship, the techniques developed in the earlier work were amplified and applied to the development of a more sophisticated group-interactive simulation model which is described in later chapters.

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We acknowledge the substantial contributions of these persons and our indebtedness to them.

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MODELING AND SIMULATION

It is now becoming commonplace in scientific and business communities to predict gross outcomes of complex operations and event sequences in man-machine systems with the aid of the digital computer. The important features, characteristics, and outcomes of many systems, both real and planned, have been digitally reproduced by a process called "digital simulation." This method is proving to be a valuable aid to managers and analysts in such diverse disciplines as transportation, economics, international relations, population study, military operations, and logistics. The purpose of the technique is to provide quantitative estimates of the performance, efficiency, effectiveness, or "value" of systems or approaches so considered.

An example of the use of this technique is the simulation of a production plant to which a series of tasks is assigned. Here the computer is given data on the plant's resources—that is, the number of machines of each type, the number of men of each trade who can operate the machines, and the types of tasks to which they can be assigned. The computer is also given the workload that is to be processed through the plant during the time period to be simulated. This workload includes the work backlog at the beginning of the simulation and the tasks that are generated by a variety of means during the simulated period. Finally, the system operation rules are represented by a computer program of coded instructions. The program determines and controls such features as work-order priorities, overtime assignments, and methods for calculating how much, how fast, and how well the men and machines work when assigned to tasks in various combinations. Using all these data the computer processes the tasks sequentially in accordance with system operation rules by assigning them "on paper" (that is, in memory) to individual machines as if the tasks were actually routed from one machine to another. As part of the processing the computer maintains records of interest such as how often a task must be delayed because of a need to wait for each machine, how the workload is distributed among the men, and the size of the backlog as a function of time and trade. These are summarized into totals, averages, and distributions which provide numerical measures of labor and machine utilization efficiency for determining how well the system performs its functions.

It is clear from this brief example that a rather thorough analysis of the total man-machine system and its assigned job must be made in preparation for simulation. Stated in terms applicable to digital simulation in general the total job is reduced to a list of events that may be initiated, performed, and terminated with stated frequencies and in specified sequences by preselected events or conditions. The resources of men and equipments that are available to accomplish the job are itemized. Their capabilities, limitations, and behavior are described numerically. These data together with selected parameter values stating general limiting conditions (for example, total time allotted and working-hour limits) are placed on some computer input media such as punched cards or magnetic tape. A computer program is developed that dictates the logic as well as the storage, arithmetic, and recording operation sequence according to the simulation rules. Only after all of these tasks have been completed can the computer accomplish the simulation by operating on the data in accordance with the programmed logic and produce tabular, textual, and/or graphic results for study and analysis.

Once prepared for automatic processing, a mission simulation can be repeated a number of times with variations in the load to be processed, the resources available, the decision logic to be implemented, the manning complement, speeds of equipment, level of equipment automation, and the changes of work-processing rules. It should be noted that the simulation technique does not purport to find the "best" solution to any problem; rather, it demonstrates the consequences of a particular set of input conditions and decision rules applied to a process. The simulation of a variety of conditions may facilitate predevelopment evaluation of complex systems or the effects of changes in existing equipments. Consequently digital simulation can be used to select among alternative system proposals. It is also possible that such a tradeoff analysis would facilitate discovery of potential difficulties such as equipment or personnel overloading which analytic treatment alone would not disclose. The digital approach to simulation and predevelopment system test can produce a host of system planning information not provided by other techniques.

MODELS

Despite the variety of current uses to which the word is put, it may accurately be said that this general technique, which has been described briefly, may be termed computer "modeling." Today the much-bandied term "model" has been so broadly defined as to incorporate virtually any form of abstraction used to represent concrete phenomena. Thus English and English (1958) under definition 4 state that a model is

> ". . . a description of a set of data in terms of a symbol or symbols, and the manipulation of the symbols according to the rules of the system. The resulting transformations are translated back into the language of the data, and the relationships discovered by the manipulations are compared with the empirical facts."

From this definition a theory and a model would seem to be interchangeable to the extent that both are symbolic. Chapanis (1961), and the present authors, would prefer a more stringent definition such that a model, serving as it does as an analogy, would be a representation or likeness ". . . of certain aspects of complex events, structures, or systems made by using symbols or objects that in some way resemble the thing being modeled." The "theory of relativity," then, would not be a model; yet Freud's "hydraulic model" of psychic forces depicted as impinging on consciousness or Descartes' mechanistic analogy of blood flow would seem to answer this criterion. Chapanis' companion distinction between "replica models" (for example, a wind tunnel), which resemble in a physical way the thing being modeled, and "symbolic models," which abstractedly represent the modeled event, aids in classifying models.

Another classification of models that helps to place computer simulation in its proper perspective is the view presented by Sayre and Crosson (1963). They consider three distinct ways in which an "object" might be modeled: (a) replication, (b) formalization, and (c) simulation. The first class includes physical reproductions, facsimiles, test models, duplications, and dummies. In the second category of formal models both the components of the system modeled and the interconnections among them are represented by symbols that can be manipulated according to the provisions of a formal discipline such as logic or mathematics. The result in this case is an analytic solution to a set of general equations. Models which fall into the third category are those whose equations or rules do not admit analytic solution in general form but that nevertheless produce numerical values given sufficient computing capacity and time. This latter class has been made practical in the recent past by the widespread availability and decreasing cost of high-speed electronic calculating equipment. It is to this category that the attention of a wide variety of recent model development has been focused and to which the present work is directed. For a definition of computer simulation model, per se, Martin (1968) proposes, "A logical-mathematical representation of a concept, system, or operation programmed for solution on a high-speed electronic computer."

The primary goal of all three types of models is, of course, the same—to produce the essence of the object modeled faster, at lesser cost, or with greater convenience than could be achieved with the object or system itself. The selection of the simulation model, in particular, to represent systems involving human behavior is a natural one. It is acknowledged that the assignment of a specific type of model to human-performance description is difficult, especially when the definition must be mathematical in nature. Human behavior with its associated idiosyncrasies is complex. This complexity along with the interactions among behavioral elements makes for large computational requirements. For this reason computer modeling seems quite useful for the simulation of human performance.

ATTRIBUTES OF SIMULATION MODELS

There are two primary qualities that it is hoped any predictive model, including simulation models, would possess. First, it is desired that the model will be sufficiently general to enable simulation of a reasonably wide class of systems and missions. With this property a relatively few different models would be required, lowering the developmental, programming, documentation, and test costs involved in modeling. However, in the present state of model development it must be stated, in candor, that relatively little attention has been paid to this desiratum. Generally one finds a variety of models developed, each one to simulate some specific situation: for example, the population projection of a country or the medical conditions of postnuclear attack. Yet within any individual model early attempts are being made to generalize at least within a given subject matter.

In an attempt to achieve this first quality of generality the development of a simulation model has been an evolutionary process. Sometimes it is only after a model has been used that additional desirable features are recognized. Improvements in the statistical processes involved, representation of variables, presentation format, numerical techniques, and operational utilization have often become evident through use and study. It also frequently happens that new features must be added to incorporate an aspect that is important for selected tasks. Thus, with use and age, the simulation model grows in capacity, flexibility, and generality. This is accomplished, however, only at the expense of complexity and often of longer computer running time.

The second desired quality is validity; that is, that the model predict actual performance of the simulated man-machine system within an acceptable margin of error. The extent to which this objective is achievable is overwhelmingly dependent on both the validity of data presented to the computer and on the accuracy of the assumptions that are employed in developing the model's logic. Cremeans (1968) in discussing advantages of digital simulation has stated the case plainly by admitting that "simulation in the face of poor data and weak theoretical foundation is only an advantage if we recognize the weakness of the outputs as well as the inputs."

For the time being those engaged in model development have concentrated on achieving a model as an admittedly rough tool to help solve a problem or at least to give insights to a solution. Currently the model-using community is groping to determine the limits of applicability of the new-found technique. The immediate objective seems to be to find something that works reasonably well and only then to extend it in generality and to determine and improve its accuracy.

It may be said that the predictive validity of many of these models has been shown to be generally acceptable. Certainly the appetites of those who have been involved have been whetted. They are anxious to state their limiting assumptions and caution against misuse of results. But they are also enthusiastic about learning how best to use this new tool. Whatever else may be said about accuracy, however, it is virtually unanimous that the systematization which the technique requires yields a wealth of information about the tasks to which they are applied.

Subsequent chapters present more explicit information indicating the level of success that may be expected with current digital simulation models.

SCOPE

This volume presents the bases, structural logic, and results of applying two distinct computer-based simulation models. The first of these attempts to model the activity of a one- or a two-operator man-machine system. This first model has been employed for such diverse simulations as landing an aircraft, firing an air-to-air missile, searching out, detecting, and classifying a hostile submarine, and reentering the atmosphere in a spacecraft. The second of these models is directed at larger systems and possesses the capacity for simulating the actions of dozens of men who work at several independent stations. Both of the models are used to represent systems composed of equipments that are monitored, controlled, or used by operators. In addition to the general limitations of such models, as discussed above, both of the current models assume that the sequence of operator actions is known and that within limitations the operators will act in a "lawful" manner. The construct validity of these models is limited by the theoretical substrate (status of human behavioral knowledge) on which they are based as well as by the various representations of this theory within the models. We note, however, that models are probably best judged on utilitarian and predictive validity bases rather than on the bases of their assumptions alone.

The major distinctive feature of these models, when compared with other digital simulation models, is their emphasis on psychologically oriented or psychosocial variables. In addition to the necessary but general aspects of the system and its resources that are incorporated into most simulation models several psychological aspects have also been incorporated into the current models. Along with the data on equipments, missions, work stations, and the simulated rules of conduct there are also included calculations of such variables as time-induced stress, proficiency, morale of the individual operators, as well as team decisions, cohesiveness, and psychosocial efficiency and orientation of a group. In addition to results on reliability and availability of equipments these models generate data on personnel performance. The total system effectiveness measures reflect both man and machine performances.

Both models are designed in agreement with the thesis of Bekey and Gerlough (1965) that "one of the most important aspects of digital simulation is the ability to handle stochastic events, that is, events which occur randomly. Techniques for such problems are often known as Monte Carlo methods."

In defining the operating model to serve as representation of certain relevant aspects of the psychological processes for computer manipulation it was agreed not to attempt to duplicate every minute aspect of a real life situation. Rather the simulations attempt to predict practical criteria by operating on a relatively small number of factors. These factors are believed to capture the essence of those variables that current leaders in the field of psychology agree upon as affecting the performance of the human. These factors, believed salient by others, are set into a form which allows digital computer simulation and are manipulated to predict the criterion situation.

The extent of the detail to be simulated always plagues the model builder. Too detailed a simulation must be expected to cost more and