SDC

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Some Approaches to Simulation, Modeling, and Gaming at SDC

Michael J. Redgrave

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SYSTEM DEVELOPMENT CORPORATION, SANTA MONICA, CALIFORNIA

1.0 INTRODUCTION

Much of the activity with which the System Development Corporation has been associated has utilized some elements of modeling, simulation, and gaming. These elements have run the gamut from complex automated models of major systems to simple pencil-and-paper games. As the corporation has expanded its operations, the diversification of its simulation efforts has resulted in many applications of modeling, simulation, and gaming. With this diversification has come a need to have an occasional restatement of concepts and to exchange information on new simulation techniques and their application. As with any rapidly expanding field of endeavor, there is little time for the practitioners to spend on philosophical reflection and semantic clarification. The Washington Division Seminars on Modeling, Simulation, and Gaming provided this time, and also the opportunity for individuals to cross-examine methodology and obtain information through the interplay of ideas.

The topics discussed ranged from the establishment of some general working definitions to an examination of the effort being spent on the development of general methodologies for simulation construction. Instances from SDC's diverse activities were cited and briefly described whenever possible. It is hoped that this report, which presents the results of the seminar discussions, will give the reader an understanding of the kind of work being done by SDC in the field of simulation. And that it will provoke thought and additional discussion which will lead to further clarification and expansion of this field.

The following individuals were members of the seminar panel and participated in the discussion.

Milton Ash	Research Directorate
Robert Davis	Development Division
Michael Lackner	Research Directorate
Paul Peach	Command Control Division
Theodor Polk	Air Defense Division
Robert Rogers	Washington Division
William Smith	Command Control Division
Robert Totschek	Air Defense Division
Benham Morriss, Moderator	Manager, Washington Division

2.0 GENERAL ASPECTS OF SIMULATION

2.1 ESTABLISHMENT OF WORKING DEFINITIONS

The initial phase of this seminar was devoted to a discussion of the general aspects of simulation, modeling, and gaming. The areas considered were:

1. An establishment of working definitions of terms that are associated with this field;

2. The problem of seeking validation of constructed simulations;

3. Possible taxonomies of simulation models.

It must be pointed out that any attempts at definition invariably lead to semantic difficulties. Many of the terms used in the field of simulation have broad meanings and occur in many other contexts. Further, the definitions offered here are not to be construed as representing dogmatic statements on the part of the seminar participants but rather as the laying of a foundation upon which further discussion may build. The following definitions, then, are to serve as the establishment of a common language of discourse.

1. Simulation. Simulation, in its broadest sense, may be thought of as being any type of representation of reality with varying degrees of realism or different degrees of effort to include the details of the environment within which the subject of the simulation resides. However, it must be pointed out that efforts to include richness do not necessarily imply that the details of the environment or, for that matter, the object being simulated, be incorporated exactly as they appear in the real world. The details may be simulated as functions rather than physical entities. For example, a World War II Link Trainer is usually called a simulator, yet it does not appear to possess all the features of the airplane which it simulates. It does not possess an engine, a landing gear, or propeller. Yet these real-world components are incorporated in the simulator, not as physical copies, but as functional ones. (The function of an engine is to supply power: power is present in the simulator as electricity.)

Thus we can see that a simulation need not be iconic (a physical copy) but may well be an abstract representation of the real world. Elements of reality may reside in the simulation, if at all, in a form far removed from their actual appearance.

The omission of real-world parameters from the construction process, either deliberately or accidentally, constitutes the Achilles' heel of any simulation. An analyst is not required to transform all of the parameters into his simulation. He may pick and choose those which he feels are more meaningful to him and his purpose. Indeed, there may also exist parameters of which he is unaware. This incomplete transformation, of course, results in the simulation being only an approximation of the real world.[1] Many parameters are left behind when the transformation is effected and, what may be more

[1]The phrase "real world" is used in this report as a generality to refer to that which is being simulated.

important, interactions between those parameters incorporated and those omitted are lost. Caution therefore must be used in the application and interpretation of the results of a simulation.

The initial definition of "simulation" has now become modified by such words as "abstract," "transformation," and "purpose of the user." These modifications should not be too surprising since simulation is fundamentally not a precise concept. Everybody has an intrinsic feel for what the word means, but a verbal or written expression of definition becomes difficult and fraught with semantic pitfalls. Perhaps the best that can be said in the way of definition is that simulation is a representation, or technique, which transforms, either iconically or by abstraction, selected aspects of the real world out of their resident framework into a form more convenient for the purposes of the analyst.

2. Model. As evidenced by some of the literature on the subject, the word "model" is often used as a synonym for "simulation." The feeling here is that the two words are not equivalent but are complementary. Many of the statements made about "simulation" apply equally well to "model"; for example, a model is a transformation of real-world parameters and possesses properties characteristic of the designer's personality. However, a model differs from a simulation in that a model lacks dynamism. Equations of state, for example, may be considered models, as may a rod-and-ball representation of a molecule; however, until these models are moved through time by some means or other, they cannot be construed as simulations. A model, then, is the vehicle for simulation. As such, models may run the gamut from iconics (physical replicas) through symbolic or mathematical constructs. But models are, at best, only approximations of the real world. Upon application they may be discarded if they yield unreasonable or incorrect results, or improved as changes in the transformation of the real-world parameters are made.

3. Gaming. Gaming may be considered as a type of simulation which describes a conflict situation. This conflict may be in several forms, two of which are: between participating players manipulating available resources, subject to some previously stated rules of action; and between the simulation designer and the uncertainty that exists in those aspects of the real world he wishes to transform.

4. Algorithm. An algorithm is a stated rule or procedure that may be followed to arrive at some specified goal. It is a rule that always works. Examples of algorithms are replete in the literature concerning linear programming, numerical analysis, and queueing theory.

5. Heuristic. A heuristic is an attempt to arrive at a solution. The concept of search, or goal-seeking, is incorporated in this procedure.

6. Aggregation. Aggregation refers to the lumping together of many variables or events into a few well-chosen parameters in order to: achieve a condensation of computer time; or circumvent an area of ignorance concerning interaction of parameters.

7. Stochastic. A stochastic event is one whose occurrence or non-occurrence depends on a random process. An example of a stochastic event is the winning of a game of Bingo--the winning card is determined by a random selection of numbers from a container.

The following schematic indicates how some of the terms could be related.

Modeling
|
Simulation
|
Gaming
|
Player Participation

(Competitive game)

2.2 THE MATTER OF SIMULATION VALIDITY

The definition of simulation proposed earlier stated that simulation is a transformation of selected aspects of the real world into a form more convenient for the purposes of the analyst. As such, a simulation describes only those parts of the system that are visible to, and understood by, the analyst, and are of interest to him. The question naturally arises, "How confident can the analyst be when he extrapolates the output of a simulation to the real world?"

The answer to this question involves the problem of how well the transformation has been performed and how faithful a representation has been obtained. The matter of simulation validity is not easy to resolve, because among the reasons for simulation are the many times the real world is denied to the analyst for direct experimentation. With this avenue of experimental validation blocked, in what other manner(s) may some sort of simulation validity be obtained?

It was suggested that there are two alternatives (and possibly more). The first may be termed face validity. Face validity involves a "seat-of-the-pants" feel for the acceptability or rationality of the simulation. The simulation may be examined for internal logic and reasonableness of outputs by people versed in the system being modeled. It is hardly a satisfactory method of validation, but nevertheless it does provide some reassurance to the analyst.

The second alternative is one called interim validity. This procedure involves the comparison of simulations which are concerned with the same real-world constructs but which were assembled using different techniques. If agreement is obtained between the outputs from the different simulations, this agreement constitutes some measure of model validity. If there is poor agreement, or none, then there is no interim validity and the analyst has to rely on some sort of face validity. This last point often creates a dilemma for the simulation designers. If the different simulations possess good face validity yet poor interim validity, how is this impasse to be bridged? There would seem to be only two recourses: an appeal to some high authority, or a test of the simulations in the real world.

Perhaps the most comfortable recourse is that validity which results from experimental verification from the real world. Although ultimate validation is impossible because of the inability to repeat a given experiment exactly in the real world, the use of good experimental design and analysis of variance provides acceptable means for experimental validity.

2.3 POSSIBLE TAXONOMIES FOR SIMULATIONS

With the wide variety and number of simulations being developed and in use, any discussion of simulation invariably involves the mentioning of a taxonomic structure by which all these simulations could be classified. While there were some thoughts expressed that this was neither the time in the history of simulation to establish a taxonomy, nor would it be useful, some taxonomic schemes were suggested.

Generally speaking, the task of the taxonomist is to structure the field of discourse into a system of categories. These categories may be regarded as pigeonholes which are labeled by one or more properties. This system serves as a bookkeeping device; objects in the field which has been so structured may be filed away in the correct pigeon hole by comparing the properties possessed by the objects against those set forth on the pigeonhole labels.

Definition of the categories is not, of course, entirely arbitrary. In the first place, certain general principles obviously should apply. Categories should not be generated promiscuously in excess of real need and, other things being equal, the definitions should be such as to maximize the distinction between the categories; perhaps the reverse side of the coin is to define the categories in such a way that cases of ambiguous assignment of object to pigeon hole is reduced to a minimum. However, the Aristotelian dream of taxonomic systems to which objects can be assigned unambiguously has been discarded; the real world simply does not bear the requisite resemblance to the Aristotelian Heaven.

In addition to these general factors, a major consideration determining the nature of a taxonomic system is the purpose in the mind of the builder. Hence, the same field may be given a different taxonomic structuring by persons having different objectives in mind. For example, in classifying flowers, a botanist will prefer the Linnaeic system which reflects differences in underlying structures due to biological evolution; on the other hand, a floral arranger may prefer to classify flowers according to the more superficial qualities of color, shape, and flowering time because these properties are more relevant to his purpose.

Similarly with the field of simulation. Several taxonomic schemes were suggested, each with its own merits and each reflecting a different purpose in the mind of the taxonomist. For example, in SDC's System Simulation Research Laboratory, simulations are classified according to the relative degree of participation of people and equipment. The taxonomy covers a spectrum of situations, one pole of which may be a training exercise or pencil-and-paper game, both involving only people, whereas at the other pole of the spectrum, there is the fully automated system. Unfortunately, there are not yet any well-formulated decision rules whereby a given simulation may be placed along this spectrum. Indeed, these decision rules may never be formulated, since it is perhaps impossible to attach metric interpretations to these simulations.

Another taxonomic scheme proposed was to classify simulations by their purpose. Earlier, it was stated that the purposes of simulation are to train, to predict, and to demonstrate. It is possible to fractionate the simulation population on this basis, though inevitably there will be multiplicity of category assignment. This is not too surprising since these categories are not mutually exclusive.

A third proposal is to categorize on the basis of the degree of abstraction involved in the transformation. This categorization would range from an iconic (physical copy) to a completely symbolic model.

This listing could continue indefinitely because there are as many taxonomic schemes as there are designer purposes.

This section has discussed definitions, simulation validity, and taxonomic schemes suitable for categorizing simulations. Throughout, a singular lack of dogmatism was manifested. It is realized that simulation still involves a degree of creativity on the part of the designer. Definitions are difficult and subject to much argumentation, for simulation is still very much an art and, as such, possesses many qualities which defy delineation. What this phase of the seminar attempted was to sort out those qualities which could be codified, and establish a firm foundation for the remainder of the seminar.

3.0 EXAMPLES OF SIMULATIONS DESIGNED BY SYSTEM DEVELOPMENT CORPORATION

As pointed out in the definition, simulations are attempts to copy systems which are understood in principle, and are created for the convenience of the experimenter in order to discover quantitative relationships. Many times the scientist desires to examine natural or man-made phenomena in situs. However, the examination is not always possible due to one or more of the following reasons:

1. That aspect of the real world in which there is interest does not presently exist.

2. It is forbidden, on ethical or political grounds, to "tinker" with the real world.

3. The cost, such as for mock war maneuvers, is far too expensive.

4. Events in the real world are uncontrollable for experimental purposes.

As a result of these objections to direct experimentation, the phenomena of interest are re-created in the laboratory as intact as is possible or necessary for the purposes of the experiment. As many of the observables are transformed as are amenable to (this may include environmental factors) and capable of description by the model builder. The sequencing of events as they occur in the real world is hopefully preserved, and interacting elements are allowed full play.

The uses of simulation are as follows:

1. Training of personnel.

2. Manipulation of the resources of the real world in order to make predictions concerning future events. Subsumed under prediction are such functions as design, evaluation, and experimental validation of the logical consistency of outputs and internal flow.

3. Demonstration.

Each of these goals is important within its own right, yet may be combined with either or both of the other purposes.

3.1 SIMULATION AND TRAINING: THE SYSTEM TRAINING PROGRAM

An example of simulation as used in a training program may be taken from the System Training Program (STP) at SDC.[2] The central purpose of the STP is to train air defense personnel in the system skills relevant to the accomplishment of their primary mission, defense against enemy air attack. Such training is accomplished on a variety of system levels ranging from single aircraft control and warning sites to the entire North American air defense complex through the presentation of a carefully constructed and meticulously controlled artificial situation (called an STP problem), and the subsequent analysis of the system's reactions. The vehicle for presenting such a situation to an air defense system is a set of materials called training aids.

STP training aids govern the course of a problem by establishing the initial conditions, providing simulated counterparts of the dynamic inputs reviewed by the system in real life from sensing devices, information processing equipment, or external agencies, and specifying the results of some classes of problem contingencies. They assist in the analysis of results by providing organized descriptions of the problem's controlled aspects. The problem itself may serve a variety of purposes: exercising of standard operating procedures, trying out new methods of operation, testing of novel concepts, and evaluation of extant procedures.

A variety of simulation technologies contribute not only to the running of an STP problem, but also the production of the associated training aids. Within the scope of the first realm fall the techniques associated with specialized simulation equipments, the methods for inserting other types of externally originated data into the system and the general ground rules for running an STP problem. The computer-based system for producing training aids, on the other hand, requires its own simulation models: aircraft and their motion through space and time are rigorously modeled, as are the characteristics of the equipment which detects, emits, or processes electromagnetic echoes and emanations. Models of the air defense system, of its sensory ties to its environment, and some of its standard operating procedures are also required.

The level of fidelity required in STP simulation to permit adequate transfer of training has never been determined to the universal satisfaction of the specialists who have opinions on that subject. One result of the divergence of views in this area has been the preference to err in the direction of providing more realism than is required rather than risk not furnishing enough,

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[2]Extracted from a paper presented by Robert Polk at the Washington Division Seminars, July 19, 1961.

thus tending to make the various STP models fairly general in terms of the real situations which they simulate. A fortuitous byproduct of that generality has been flexibility in the application of old models to novel contexts, facilitating the incorporation of new features into STP; the application of STP vehicles to special studies; and the adaptation of extant models to non-STP tasks.

3.2 SIMULATION AND PREDICTION

Three examples of simulation as used for prediction and system examination were presented and are discussed below. These are the Terminal Air Traffic Control Model, Communications Vulnerability Model, and Department of Defense Damage Assessment System.

3.2.1 The Terminal Air Traffic Control Model. The first model examines the question of Terminal Air Traffic Control as it might appear in the post-1970 era.[3] The terminal area consists roughly of a circle 50 miles in diameter which is placed 15,000 feet above a multi-airport complex. All aircraft are under positive control (instrument flight rules) and will be streaming into and out of the terminal area. These aircraft will be simulated by pilot simulators interacting with a computer, as well as ground controller simulators. The diversity of aircraft characteristics in the 1970 period and beyond, between small private aircraft up to Mach-3 transports, will pose new and interesting control problems. Under the complex of airports will be a superordinate agency with simultaneous and positive control of the over-all terminal area. The tracks of the aircraft will be simulated by tracking schemes similar to those used in the SAGE System (Semi-Automatic Ground Environment). Briefly, the interaction of the aircraft and the terminal control areas will be studied to determine better methods of coping with the anticipated terminal traffic of 1970 loads. The initial configuration will be a two-airport control system consisting of elementary tactical control functions. Here there will be no superordinate agency. As we begin to understand the functions of this simple system, we will build from it to the more complete system described earlier. The time scale to reach the multiple-airport common-control simulation seems to be about one to two years beyond the date of the opening of the System Simulation Research Laboratory.

3.2.2 The Communications Vulnerability Model. The Communications Vulnerability Model[4] is a general purpose model and operates on four categories of input

[3]Extracted from a paper presented by Milton Ash at the Washington Division Seminars, July 19, 1961.

[4]Extracted from a paper presented by Robert Totschek at the Washington Division Seminars, July 19, 1961.

data: critical points, circuits, targets, and bombs. Critical points consist of microwave towers, communication terminals, repeater stations, key central offices, and any other defined point of interest. These points are specified by name, number, location, hardness, connecting points, and a switching-time delay number. Circuits are defined as specific paths or routes from one customer location or terminal to another terminal. The circuits are described by the names of the terminals, the time delays in minutes, and the points en route. Targets take into account United States retaliatory bases, high-density population areas, and industry. Missile warheads are listed by assigned target name, ordered by time of detonation, and categorized by their reliability, Circular Error Probable (CEP), height of burst, and yield. These categories of information form the input data for the vulnerability model. The program uses two Monte Carlo routines to determine the vulnerability of a selected list of targets, critical points, and functions to nuclear blast effects from a prescribed set of enemy missiles. The first Monte Carlo determines whether or not a missile fires; a second Monte Carlo determines the impact point, based on the CEP of the weapon. The yield of the weapon and the hardness of nearby points are then used to assess the resulting damage. Presently, the model handles the United States, but it may be enlarged to cover greater areas.

3.2.3 Department of Defense Damage Assessment System.[5] The task of the Damage Assessment Department is to assist the Defense Atomic Support Agency in the design and implementation of the Department of Defense Damage Assessment Center. The present design of the system contains two separable subsystems.

1. The first subsystem, the Rapid Damage Assessment System, has as one of its major functions the task of estimating nuclear weapons effects upon a selected target list in real time. These estimates of blast damage and fallout are computed by simulations that incorporate models of the weapons and the target points.

Target points are modeled by describing their essential characteristics. These characteristics fall into two general classes: parameters used in damage computations; and parameters that define the target in terms of its importance to the DOD. The first category includes:

a. Latitude, longitude;

b. Vulnerability indices for blast damage;

c. Vulnerability indices for fallout.

[5] Extracted from a paper presented by Robert Rogers at the Washington Division Seminars, July 19, 1961.

In the second category are:

a. Category code;

b. Capacity;

c. Geographical descriptors;

d. Political descriptors;

e. Command descriptors.

Weapons are modeled in the system by describing their:

a. Yield;

b. Height of burst;

c. Designated ground zero;

d. Aiming error;

e. Abort/Attrition probability;

f. Fission/Fusion factor;

g. Time of detonation.

The real world is simulated by inputting lists of these weapon parameters. The primary outputs of the simulation include:

a. Target probabilities of survival (blast damage);

b. Fallout intensities at the target points;

c. Effective biological doses at the target points;

d. Times of arrival for fallout at the target points.

These, in turn, are used to estimate:

a. Capacity degradation;

b. Blast casualties and fatalities;

c. Fallout casualties and fatalities.

2. The second subsystem, the Hazard and Vulnerability (H&V) System, is designed to simulate hypothetical attacks on either real or hypothetical target points. Again, the weapons and the target points are modeled as described above.

One model of this subsystem simulates up to five weapon attacks at one time and computes the same outputs as described above for each attack pattern. In addition, by incorporating probability weights for each attack pattern, weighted mean probabilities of survival are computed for each target point.

Another model of this subsystem is concerned with the effects of weapon attacks upon network systems such as railroad networks and communication networks. For this problem, a network is modeled as a linear graph connecting two terminal nodes. After assessing damage against each facility within the network, the individual probabilities of survival are used to compute path probabilities of survival and probability of survival of at least one path through the network, given a set of 10 paths defining the network.

The third model of H & V is used to estimate joint probabilities of occurrence of different values of:

a. Overpressure experienced versus radiation dose intensity experienced;

b. Overpressure experienced versus maximum biological dose experienced;

c. Overpressure experienced versus time of arrival of fallout;

d. Radiation dose intensity experienced versus maximum biological dose experienced;

e. Radiation dose intensity experienced versus time of arrival of fallout;

f. Maximum biological dose experienced versus time of arrival of fallout.

An interesting part of this latter model is the Monte Carlo technique of setting wind patterns for the fallout computations. This Monte Carlo technique incorporates in its sampling from the distribution of wind vectors at a particular point the correlation of the wind vectors at the geographical points described for any particular problem.

3.3 SIMULATION AND PLAYER-PARTICIPATION

3.3.1 Arms Control Simulation. In addition to the incorporation of participants in the simulation for training purposes, there is another large area of human participation and that is in the area of games. Although the word "game" sometimes possesses a frivolous connotation, there is really no better word available to describe such activities as mock war maneuvers and competitive manipulation of symbolic resources. Game theory has done much to remove the popular conception of the word "game" by stressing the concept of strategy and establishing a set of axioms (utility theory) to govern decision making. Although game theory as such is not in wide use as a technique for resolving real-world problems, certain aspects of it are incorporated in the many player-participation games now in use, both in industry and military organizations.

An example of such a game is the Arms Control Simulation, now under development at SDC.[6] This simulation focuses specifically on arms inspection. It takes as a point of departure the notion that arms inspection is a system problem and not one of sensor technology alone. This has led to the formulation of a simulation approach to explore the system aspects of the problem and to an experimental structure which is quite similar, in many respects, to traditional "war games," in which two teams--nominally "Red" and "Blue"--staffed with qualified experts, represent a conflict of interests within some form of simulated "world."

In an Arms Control Simulation study, the experimental structure consists of the following elements: two teams (Red and Blue); a control or "referee" element for resolving conflicts; a simulation "vehicle" consisting of a data base, and defining "reality" for game purposes, experimental models for manipulating this data base, and sensor models forming the restricted perceptive filter by which assessment is made.

Imposed on a particular experiment is a specific Arms Inspection Agreement for study. The scope of this agreement can vary widely and deals, for example, with such restricted topics as nuclear testing, or more broadly with constraints on the use, testing, or production of certain weapons, or mobilization for a surprise attack.

The major role of the Blue Team is to evaluate and correlate the significant information collected and to generate the required reports on the Red Team's activities. This is done with the aid of a processing system which processes the raw sensor data into fact files. The management of such a system includes the specification of decision criteria and the establishment and maintenance

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[6] Paper presented by Robert H. Davis at the Washington Division Seminars, July 19, 1961.

of a working fact file--a "derived data base"--against which discriminations and evaluations can be made, trends forecasted, and intentions inferred.

These are some examples of the uses of simulatior at System Development Corporation. There are others, but these give a good cross section. As a tool in the hands of a careful analyst, simulation can be extremely helpful. There are pitfalls in that it must be kept constantly in mind that a simulation is only an approximation and is only as good as the analyst's understanding of that which he is simulating. Many real-world parameters are invisible or unknown, interactions are poorly understood, and environmental influences greatly affect the motivation and reaction of player-participants who are required to make decisions and manipulate resources.

The above comments cannot be repeated enough, for simulation is not a panacea of problem solution, nor is it some magic blackbox which automatically spouts out answers just by pushing a button. It is a man-made device and, as such, should be used with restraint and intelligence.

4.0 TECHNIQUES OF SIMULATION

This section is concerned with a discussion of some of the techniques that are used in the construction of simulations. It is difficult to say that a specific technique is unique to simulation, but there are many instances of procedures that are currently popular in this field. Such methods as the Monte Carlo technique for resolving uncertainty, algorithms such as those of linear programming and dynamic programming, and the incorporation of people into the simulation for purposes other than training are all widely used in simulation. Further, there is a growing awareness of the need to establish general methodologies of simulation, especially in the design phase of model construction. Examples of these will be cited from the System Development Corporation's activity in this area.

4.1 MATHEMATICAL

In talking about the techniques of modeling, there are several dimensions that should be considered. One of these dimensions is the normal phase of analysis and design through which the designer might proceed. The subject matter of this phase varies, of course, for it covers such items as the question of economy: will a pencil-and-paper solution be sufficient or is an expensive computerized model required? Questions like these are important and have to be asked of the customer concerning his problem area. Decisions regarding the choice of mathematical techniques to be employed and the advisability of constructing a man-machine simulation have to be made. Naturally, the choices made in this phase of the construction process are going to be tempered by the biases and background of the design group. For example, the designer may be inclined toward the Monte Carlo method for determining the occurrence of probabilistic events, whereas another designer would seek a different analytic resolution of uncertainty.

The choice of a mathematical vehicle is quite open. There are some problems which are tailor made for solution by such specific techniques as linear programming or Monte Carlo sampling from known distributions. Others may be solved by any number of the procedures available from both classical and modern analysis.

4.2 INCORPORATION OF PLAYER PARTICIPANTS

The incorporation of people into the simulations creates certain problems such as providing the participants with motivation and maintaining a meaningful degree of correspondence between the simulation and the real world. For example, when simulating a command and control center, is it necessary that the simulated center be painted the same color as the actual center? Is it necessary that there be exactly the same amount of equipment in both centers? To meet these problems, the designer needs to exercise a certain amount of personal judgment, for as pointed out earlier, there are virtually no guidelines to use in determining critical parameters. It might be possible to undertake an experimental program to determine this, but so often a simulation is constructed because the real world is denied for experimentation. Good judgment on the part of the designer is therefore the only possible alternative.

The problem of motivation is a critical one. Participants are performing in an artificial environment where the normal penalties for failure do not obtain. For example, a war-gaming exercise does not involve the same dangers as an actual war. How is motivation to be created and maintained?

There is no easy answer to this question. In the initial stages of a simulation, the participant's motivation is high because of the novelty of the situation. However, this tends to decrease as familiarity with the equipment and procedures increases. This is especially true of training exercises, though to a far lesser extent in war-gaming activities where new situations are occurring and new decision-making environments being created. Face validity of the simulation also has an effect. If, from a face validity point of view, the simulation does not seem to represent real world experience, the participants will soon become bored.

With these attendant problems accompanying the incorporation of people into the simulation, why is it necessary to have participants? There are several reasons for this. The first is, of course, for training purposes. The second is that many times a simulation has built into it a set of decision-making algorithms and the designer would like to perform some kind of validity test of these algorithms to see if the participants, given the same items of information, arrive at similar decisions. Moreover, they may request more information be given or indicate how the decision-making algorithm may be improved. This process might well be reversed, with the participants being used as experimental subjects from whom decision-making rules are to be extracted. For example, management of a business firm makes many decisions daily. In the design of a simulation of this business, the designer may wish to computerize many of the daily decisions so as to reduce the number of stochastic nodes in the simulation. He will then be faced with the task of discovering the basis for these daily decisions. An iterative process will then be involved whereby the participant will make decisions based on different items of information. As patterns in decision making evolve, they can be algorithmized and no longer be the participant's responsibility.

A third reason for using participants is to simulate situations in which there is a lack of understanding. For example, no one really understands why wars take place. Because of this lack of understanding, scenarios are being developed at RAND Corporation in order to determine the cause of limited wars. Three different types of people are used in developing these scenarios; military strategists, political experts, and economic specialists. These scenarios are developed under several restraints: they have to be feasible militarily, politically, and economically; and they have to be coherent.

By virtue of this lack of understanding of decision processes and event causations, it is essential to incorporate participants into the simulation. The attendant disadvantages still remain, and the designer must be very cautious about the application of the results obtained from such simulations.

4.3 GENERAL METHODOLOGIES OF SIMULATION

The discussion to this point was concerned with specific techniques used in simulation. The discussion then turned to the problem of defining or discovering meaningful procedures which may be used in any simulation construction.

Since simulation is still an art and as such requires a large amount of creativity on the part of the builder, the initial stages of design may well defy generalization. However, once the creative hurdle has been passed several procedures are possible. The following examples will serve as illustrations of general procedures which might be followed in the design phase of various categories of models.

4.3.1 Simulation in the Design Phase of a Command and Control System. In keeping with the corporation's efforts to establish general simulation methodologies, the Command Control Division at Lexington, Massachusetts has proposed a procedure which will hopefully be useful in the design phase of a complex command and control system.[7] This system is to provide the Commander in Chief of NORAD with a semiautomatic command and control system designed to aid him in meeting his responsibilities for the detection of, and defense against, aerospace attack on the North American Continent. Some of the decisions that the system will have to assist in making are related to the preattack phase, battle phase, and the postbattle phase of any enemy action against the

[7] Extracted from a paper presented by William R. Smith at the Washington Division Seminars, July 19, 1961.

continent. CINCNORAD and his staff will be required to conduct aerospace surveillance for attack detection, threat evaluation, and control of defense forces.

It is obvious that a complete understanding of the decision-making processes in this environment is not available at the present time because the anticipated environment does not exist. Speculation is abundant about these processes and the information required for them, but final definition will necessarily await the outcome of the human factors and other types of research on the system.

The proposed technique to be used in the design phase of such a command and control system is an iterative human factors simulation which will provide timely insight into the informational requirements for decision making in the NORAD context. This technique will provide early guidance for data processing and reduction requirements, display needs, and manning requirements.

The first step of the procedure would be to design scenarios which would present the different kinds of situations now envisioned. These scenarios will be presented to NORAD personnel for their responses to the problems posed. In the process of completing the problems, it is anticipated that the information will not always be adequate for making many of the required decisions. Iterated new problems can then be prepared which will contain the new information requested by a sufficiently large sample of the NORAD personnel. On the basis of subsequent decision-making responses to the gradually changing scenarios, inferences will be made about the usefulness of the new information and the desirability of insuring that the system provide it in the way proposed.

In this way, the experimenters can identify weaknesses in the prepared informational contents of their scenarios and directly iterate the requirements for function decision making. This evolutionary process begins with modest kinds of information and grows into a very complex set of experimental results which in time will describe extensively and intensively the information requirements for all positions in the system.

4.3.2 Simulation Facility (SIMFAC). Another illustration of the establishment of general procedures may be found in the Command Control Division, at the System Development Corporation installation in Paramus, New Jersey, where the main center of simulation is the Simulation Facility (SIMFAC).[8] The physical facility is a partial model of the SAC Control Center at Omaha. A glassed-in gallery overlooks a work area and a set of screens. Automatic projection equipment makes it possible to display pictures on these screens, to change slides quickly, and to call for the display of any one of a large number of

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[8]Extracted from a paper presented by Paul Peach at the Washington Division Seminars, July 19, 1961.

slides. Desks in the work area and gallery can be equipped with telephones, slide control boxes, and any optional equipment that may be desired. Several tape recorders are provided for monitoring. Although the facility is a physical representation of the SAC Control Center, it can be made to represent a wide variety of communication systems.

SIMFAC equipment was installed in the spring of 1961, and the completion of final checkout was scheduled for later in the same year. There is no dearth of proposals for the use of this facility, some of which are closer to standard experimental psychology than to modeling and gaming in the more special sense. An experiment is already under way to study the responses of subjects required to make decisions in a limited time, when their information includes a great deal that is irrelevant, or when their attention is refocused in the course of the experiment. A proposal has been made to match human decision makers against decision-making computer programs in situations subject to random variation and heavy penalties for late decisions.

4.3.3 Simulation Package (SIMPAC). Another area in which the corporation has been expending effort is in the development of general simulation construction. An example of this effort is to be found in the Research Directorate where SIMPAC (Simulation Package) is being built.[9] The general requirements of a digital simulation are:

1. A model in a form which can at once be related to the phenomena under study and compatible with the requirements and restrictions of a digital computer.

2. A means of expressing the model in a form translatable to computer code.

3. A means of moving the model through time.

4. A means of recording the performance of the model.

SIMPAC is the result of an attempt to provide means of realizing these four objectives in an economical fashion by designing a "simulation package" incorporating coherent techniques of modeling and implementation. Further, SIMPAC is a language coupled program. It provides a macrolanguage for building a model, and a computer program for moving the model through time and recording its performance. The computer program provides over 90 separate services called out by macroinstructions used in the construction of the model. These are compatible with symbolic machine language, and additional macroinstructions may be defined by the user.

[9] Extracted from a paper presented by Michael Lackner at the Washington Division Seminars, July 19, 1961.

The class of systems susceptible to simulation by SIMPAC is one which can be adequately modeled as a queue-server network. The network may be complex; the queues may be subject to dynamic queue disciplines; the servers may have dynamic capacities; and the individual members of queues may be identifiable.

The servers in this network are activities in the pure sense; that is, not X doing Y to Z, but just Y. The queue may be formed of transactions representing discrete interactions between activities. The transactions may represent physical entities or bearers of information such as messages. Servers in the network become operative when operational resources, such as people or machines, are assigned to them by other activities.

The components of a SIMPAC-constructed model are activities, operational resources, queues, and transactions. The system analysis leading to construction of a model consists of the identification of these components in the system under study. This is so, whether the subject system is in the original design stage or is operating. This analysis yields the following results:

1. Potential queues are identified. Since it is assumed that a queue may occur between any interacting activities which occur at different times or at different rates, potential queues exist at all such points of interaction. Buffers which can contain these queues are measured for capacity.

2. The various subject matter of the system is identified. Interactions between activities are reflected in the makeup of transactions, wherein each transaction is described by the characteristics which serve to identify it in the context of the system.

3. Activities stand apart from the people or machines who perform them.

4. Control activity is separate from other activity. Operations which control other operations are identified and their mode of control established.

5. Operational resources are measured in terms of their ability to perform the activities to which they may be allocated.

Following this system analysis, or perhaps in conjunction with it, aggregation must take place to yield a reasonable number of system components. These are then assembled as the model.

The model consists of one module per component. Conventions and procedures for constructing these modules have been developed which assume their mutual coherence while emphasizing the benefits of modularity.

This ended the discussion on techniques of simulation. From this brief survey, it may be observed that there is still a great deal of subjectivity involved in simulation construction. Much depends on the background and inclinations of the designer. A few general metodologies are being developed and hopefully more will come. Simulation, however, is still an art and relies heavily on creativity, an ill-defined quality. In all probability, there will never be a Golden Rule established to produce this phase of simulation construction.

5.0 CONCLUDING REMARKS

This report has presented the results of the Washington Division Seminars held 19 July - 21 July at Falls Church, Virginia.

The general feeling of the participants was that modeling and simulation should not be considered as separate disciplines because they rely so heavily on contributions not only from the sciences but from the liberal arts. For if one were to expose a cross section of almost all the recognized disciplines, there would be seen a subset of activities called "modeling and simulation," whether it be physics, economics or experimental psychology. The construction of a model forces upon the practitioner of these disciplines logical thought and a coherent description of his area of interest.

Modeling and simulation, then, are useful tools for scientific inquiry. This last statement, however, should not be construed as implying that these tools should always be used to solve a problem or that they will always find a solution. They should be used judiciously and their predictive qualities applied with knowledgeable caution.

Many times a problem can be solved without resort to a computerized simulation. It was suggested at the seminars that a policy be established to encourage the customer to buy a feasibility study prior to deciding to have such a simulation. This is a good point since this kind of simulation can be extremely expensive, both in time and money. Further, the problem may be ill-defined and to rush blindly into a computer simulation may well prove unfortunate.

It would seem advisable to restate here three pitfalls of modeling and simulation:

1. In the real world there are characteristics that are either invisible or unknown to the analyst; consequently, the simulation or transformation runs the serious risk of being incomplete for the desired purpose.

2. The analyst may have difficulty in deciding which observables to simulate for the most desirable results; the decision, when made, is a subjective one and bias enters the simulation.

3. Relationships between the observables are difficult to define properly.

The main point to be kept in mind is that modeling and simulation, although not necessarily a solution to all problems, are extremely useful techniques. Benefits gained from completed simulation studies are invaluable and would not have been obtained in any other feasible way.