CONTENTS

Section

I. INTRODUCTION 1

II. DETAILING THE ART FORMS AND THE STATE OF THE ART 6

III. ON VALUE AND PRICE 11

IV. PROSPECTS FOR GROWTH 15

V. TO RECAP 18

SYSTEMS SIMULATION AND GAMING AS AN APPROACH TO UNDERSTANDING ORGANIZATIONS

Martin Shubik*

The Rand Corporation, Santa Monica,
California

Garry Brewer*

The Rand Corporation, Santa Monica
California

1. INTRODUCTION

Complex problems often demand complex analytical techniques. So it is with attempts to understand organizations: reality, defying more prosaic aids to understanding, has forced us to develop increasingly sophisticated methods of observation, description, and analysis.

Gaming and systems simulation are two such methods. Generally characterized as having not only intuitive appeal -- based on nice descriptive properties -- but also a solid empirical basis, the methods have stimulated the development of a large and expanding professional community and literature. What the community does, what have been the trends and orders of magnitude of activity, and where it all seems to be headed are questions worthy of reflection.

It is amazing that after all these years there is still such difficulty in sorting out what we mean when discussing work in this area. Definitional "games" often degenerate into fruitless syntactic

---

*Any views expressed in this paper are those of the authors. They should not be interpreted as reflecting the views of The Rand Corporation or the official opinion or policy of its governmental or private research sponsors. Papers are reproduced by The Rand Corporation as a courtesy to members of its staff.

A version of this paper was originally presented at a Symposium on Computer Simulation as Related to Manpower and Personnel Planning at the U.S. Naval Academy, April 1971.

exercises; however, it is fairly important to distinguish four separate areas of work: *analytic models, machine simulation, man-machine games, and free-form games.*

Analytic Models. A good analytic model is usually quite abstract, poor in number of variables explicitly considered, but rich in terms of ease of manipulation and clarity of insight. Certain forms of warfare have been characterized quite well by game theoretic, analytic models in which two-sided or more than two-sided combat is considered explicitly.* For example, one might examine the optimal behavior of a red team versus a blue team when one side's strategy is not fixed.

In a situation such as a two-sided war, assuming pure opposition enables one to consider optimal tactics, deductions of an opposition's best strategy may lead to counter maximization strategies. Unfortunately, there are two primary reasons why it is generally not possible to do so. Representations of combat more complex than simple tactical encounters are usually not zero sum, i.e., it is usually *not* a situation of pure opposition. Elements omitted from the analysis in the interest of tractability and precision, e.g., "human factors," are often crucial to understand what is in fact going on.

Individuals most at home with analytic models are applied mathematicians, operations research analysts, and a breed of creature known as the "compterniks," although the computer is frequently used purely as an analytic aid.

In many situations the aim of an analytic model is to produce a single number as contrasted with multiple, interrelated indicators of system behavior. There may be more than a single number, a kill probability or a specific survival level for instance, that is of analytic interest. Frequently a single, end state condition for a system is calculated. This contrasts with the study of system behavior through time where end states may not be of interest or even relevant.

---

*Melvin Dresher, *Games of Strategy: Theory and Applications* (Englewood Cliffs: Prentice Hall, 1961), for example.

Machine Simulation. In contrast with analytic models, machine simulations very frequently involve many variables; the fetish of "realism" is often invoked sanctimoniously. Rationalizations made on behalf of the computer simulation are varied and nearly as numerous as the organizations in the business of "modeling anything, anywhere, anytime" -- for a consideration. A common (and frequently valid) argument is that mathematics is a relatively impoverished descriptive language, whereas the computer allows one to capture the richness or robustness of a real system. What is left unstated in this and other pleas is the enormous price one is likely to pay to approximate that reality. Simulations and the "simulators" responsible for their design, implementation, and operation are *much* harder to control than analytical models or modelers. Not only are there fewer discernible scientific standards available to aid in one's evaluation of a computer simulation versus a mathematical model, there is little or no general agreement among professionals in the trade as to what standards are pertinent and ought to be developed.

Certain low levels of misfeasance and abuse are tolerable for a profession; as the stakes increase, however, such laxity becomes too costly by any measure.

Salesmanship and "heap big science" may well be the undoing of this potentially highly useful aspect of the profession.

Large-scale computer simulations have heretofore been rather easy to sell. They appear reasonable; furthermore, they provide a wealth of material for a three-or four-star "Dog and Pony Show." Straight lines, curves that grow exponentially, curves that wiggle up and down, smooth curves, discontinuous curves -- whatever curve you want is the curve you get. Whatever system you want defended is defensible with a three-thousand variable black box. After all, who questions "science"?

The main types of people in the machine simulation business are analysts, mathematicians, systems engineers, "computerniks," and occasionally economists and defrocked physical scientists.

Sometimes machine simulations are called games. Frequently this is meaningful; often it is not. Man-machine simulations are normally referred to as games; terminological distinctions quickly tend to fuzz.

Man-machine Simulation. Man-machine simulation usually, but not always, involves a digital computer with some roles in the modeled system being played by people. Two distinctions are worth making. People may be used merely because they are cheaper than the software. Or, people may be used because human factors are important in the analysis of the situation. An example will serve to illustrate. Suppose one simulates a large, but relatively straightforward, logistics system. How minor, specific roles are carried out is of little or no interest. Given programming costs and this low-level interest, it may be literally cheaper to plug a captain or major into the role for a two- or three-week play of the game than it is to write the software to simulate him. In this case the man is made an integral part of the man-machine program.

In other situations, for other analytic purposes, one may wish to observe how the man behaves, what motivates the human component, and so forth. The "man" in man-machine is then clearly performing a quite different function.

In man-machine gaming and simulation, the personnel are usually analysts, systems engineers, experimental psychologists, social psychologists, and economists. Depending upon the nature and purpose of the enterprise, there may be a human factors emphasis where humans are studied and not merely used as inputs. With a systems engineering emphasis, humans are used because they are handy and relatively cheap. In the latter case, the orientation is more toward operations research analysis and systems engineering than it is to experimental psychology or social psychology.

Distinctions between man-machine and free-form games (simulations) are slight, but exist.

Free-form Gaming. In this type of gaming frequently no computer equipment is employed, or it may be used on the side to do some bookkeeping. Free-form gaming involves individuals operating in a scenario. It is the least amenable to technical control of the four types of work described.

Interesting to observe is that free-form gaming has the least technical control, the least money spent on it, yet it receives the most publicity and is done at the highest level. In the Studies, Analysis and Gaming Agency, individuals involved in some of the games may be at the Secretary level and at the three and four star Admiral or General level, yet the amount of money involved may be of the order of $10,000 per game.

Given these four different areas of study, it is fairly safe to say that in the Defense Department only two of them are characterized by "big money." Man-machine gaming is characterized by little money relative to what is being spent on simulation, and politico-military, free-form gaming, in spite of the way it appears, is characterized by miniscule money. Cost questions are important and shall momentarily be given attention.

II. DETAILING THE ART FORMS AND THE STATE OF THE ART

Besides providing the interested reader with several concrete examples of each of the simulation or game types, the purposes, use, and limitations of each may be summarized to help assess the current state of the art.

More on analytic models. Good analytic models help to spot a "chicken and egg problem" that once recognized can usually be solved. The point bears directly on the relationship among rigorous theoretical models, empiricism, and data gathering. An analytic model is usually too restricted to solve an actual operational problem directly. Because the model is normally clean and clear, however, it can provide insight about potential difficulties, indicate where additional measurements are most needed, and identify and order important omissions.

The optimal assignment problem, a pure analytic model created by John von Neumann, is a case in point.* The model has limited interest for purposes of direct, operational application. Assuming that one knows exactly what a man can (and will) do, constraining analytic possibilities with linearity assumptions and adopting a very restricted view of personnel assignment reduce direct operational utility. Nevertheless, von Neumann's work is clean, and abstractly captures the core of an important problem.

Analytic work on the Berlin Airlift provides an example where initial simple analysis yielded to more complex formulations as the problem began to be understood.** From the first linear program, the

---

*John von Neumann, "A Certain Two-person, Zero-sum Game Equivalent to the Optimal Assignment Problem," in H. W. Kohn and A. W. Tucker, eds., *Annals of Mathematical Study*, No. 28 (Princeton: Princeton University Press, 1953), pp. 12-15.

**A. S. Manne, "An Application of Linear Programming to Procurement of Transport Aircraft," *Management Science*, Vol. 2, No. 2 (January 1956).

analysis evolved to dynamic models and ended up as a combination dynamic model and simulation. The evolutionary process was probably, in a pragmatic sense, optimal. One might conjecture that until the problem was "learned" with simpler, more abstract analyses, realistic representation was just not possible.

To review the last thirty years, the growth in the use and power of analytic models has been absolutely astounding. In terms of techniques, new insights, and amount of personnel, growth in this period has probably been greater than in the 100 preceding years; quite possibly it even exceeds *all* previous work. In our opinion the prospects are still extremely good for more and more diversified applications of analytic models and for increased use of the computer as an analytical aid: *not* as a simulator, but for assistance to solve analytical problems. Furthermore, phenomenal advances in software and input/output aids have occurred in the last ten years. The outlook is bright indeed for serious scholarship, respectable problem solving, and careful application. The status and prospects for our three other types are less certain, although we tend to be optimistic.

And on to machine simulations. There are literally hundreds of machine simulations and models in the Department of Defense's current, active inventory. Force structure and weapons system evaluation models are representative of much of the activity, although a more precise description of the field is forthcoming.

We are certain, however, that machine simulation has been oversold in the last ten years, and the shakedown is now taking place. The process is healthy, albeit painful in certain quarters. Much has been learned that contributes to the beginnings of a serious professionalization of work in simulation. Problems have at least been delineated.

Three major problem areas that must still be viewed in considerable detail are (a) modeling and specification, (b) data gathering and validation, and (c) sensitivity analysis and question formulation. Each of these is a lengthy subject in itself. However, their importance may be summarized simply. *There is no such thing as a good general purpose simulation.*

Anyone who tells you that he has a good general purpose simulation falls into one of two categories: he is an unmitigated charlatan trying to sell a bill of goods; or, as is frequently the case, he is a rather good specialist who has been oversold by his own specialization to the point where he believes a good *special* purpose simulator to be a general purpose simulator. Examples of this can be seen in the construction of simulation languages. Three come to mind. There is Professor Jay Forrester's language Dynamo, best described before it was modernized as, "If the world were an RLC circuit, Forrester would be King." Languages like GPSS or Simscript are general-purpose languages only if the world happens to be a production inventory scheduling problem. Understandably, such is not the case.

The warning to beware of general-purpose simulations is not meant to depreciate the desire to have something that solves all problems. It deals instead with the difficulties of modeling, specification, data gathering, validation, sensitivity analysis, and question formulation. These are all nasty, boring, hard, dirty, tough subjects that make the difference between a viable, useful simulation and something that is only useful to supply nicely colored, wiggling graphs for stellar "Dog and Pony Shows."

The man in the machine (as subject and object). We could, if we wished, immediately apply an operation test by regarding how man-machine gaming is doing as an indication of how it should be doing. Waxing lyrical and biblical, the phrase that comes to mind is, "And they shall beat their gaming laboratories into lunch rooms." (Experience in the aerospace industry tells the tale, especially in the last five years.) Such was not always the state of affairs and one need only recall earlier, happier times and highly respectable activities to make the point.

The Logistics Simulation Laboratory at The Rand Corporation was one example of a man-machine simulation in which individuals were used more as an integral part of the machinery than as subjects for human factor analyses.* The team performance study initiated by Professor John Kennedy at Rand became the founding work for the System Development Corporation and is characterized predominantly as human factors studies.**

Man-machine gaming and simulation was, at its peak around 5-7 years ago, oversold. Currently, we suspect that it is being undersold. The key need in man-machine gaming is to build up a basic inventory that stresses substantive content in various areas of interest.

"Free-form" doesn't have to mean "loose and sloppy." A prime example of free-form gaming that should be most familiar is PME -- Political Military Exercises done at and for the Joint Chiefs of Staff by SAGA and others.*** These games are aimed at the strategic level and involve relatively high-priced personnel. They highlight some of the difficulties in costing. When we try to cost a game or a simulation, we have to decide not only how to cost the physical resources but what sort of value we wish to impute to the time of the people who play the game. If we only account for physical resources, all that a top level political military exercise needs are a couple of rooms, a few people who are already assigned to the Pentagon, some pencils, some pads of paper, and a bit of TV tape. The costs actually depend on how we evaluate the worth of the time of the top echelon teams.

There has been an extremely small amount of money spent on free-form gaming. With respect to the four types of gaming and simulation, it appears that publicity is inversely related to the amount expended in each area -- we suspect inversely as something like the fourth

---

*M. A. Geisler and A. S. Ginsberg, *Man-Machine Simulation Experience* (Santa Monica: The Rand Corporation, P-3214, August 1965).

**R. L. Chapman and J. L. Kennedy, *The Background and Implications of the Systems Research Laboratory Studies* (Santa Monica: The Rand Corporation, P-740, 1955). See also, N. Frederickson, "Factors in In-Basket Performance," *Psychological Monographs*, No. 22 (1962), for another good example of the genre.

***For a basic, clear introduction to this type of game, see Herbert Goldhamer and Hans Speier, "Some Observations on Political Gaming," *World Politics*, Vol. 12 (1959), pp. 71-83.

power. Free-form gaming has a few good practitioners; it attracts the most publicity; it is very hard to measure the product; and it is extremely difficult to describe whether the art form has improved in the last few years. We suspect that, as it cost a minimal amount initially, a little more money and some careful work in this area would probably be well worth the effort.

III. ON VALUE AND PRICE

There is an old rule in simulation worth indicating: *A simulation costs almost anything that the bookkeepers want to make it cost.* The reasons for this are complicated and merit lengthy treatment. Generally, the matter of cost depends heavily on whether one gets information from ongoing processes or whether special work to gather the data must be instituted. The joint costs of data gathering can be assigned in virtually any way. A standard operations research plea that forcing one to look at data saves untold millions for the "relatively" trifling costs of data acquisition ignores an important bureaucratic cost: people do not like to have their organizations and procedures deranged merely to collect data.

The question of value is intimately related first to how a simulation or game is used and then to what it costs. Three aspects are of particular interest: the level and type of use, the measure of worth of use, and the cost.

Levels of use. Four distinct levels of use may be noted.

Strategic, top decisionmaking usage is exemplified by the political-military exercise. Even though it is an open question as to how useful it has been, PME is explicitly labeled for use at the top strategic level, and it interfaces directly with the people who could be described as participants at that level. Weapons system procurement studies and simulations are implicitly designed for use at the top level. It appears that to some extent they are used for advocacy purposes to bolster one side of the budget process and not the other. After a large-scale weapons evaluation systems simulation has been performed, it appears that the information is used primarily, if not exclusively, by a given general or admiral rather than by other interested civilian participants. We do not assert that this is necessarily good, or bad. It is merely what appears to be the process.

The next level of interest is at the operational/bureaucratic and the scientific interface. Most studies, simulations, and much human factors work fall into this category. Here we see contractors and subcontractors working closely with their opposite numbers in the DoD bureaucracy. The problems are meant to be operational and relatively specific.

A third level is the scientific and advisory interface with operations. This describes a fair amount of the work sponsored by the Advanced Research Projects Agency. Investigations, such as some human factors studies, are typically of the sort where there is little interest in immediate application, but much in the building up of a basic supply of knowledge.

The fourth level is the more purely basic scientific and experimental work that utilizes top professionals in a scientific advisory capacity. When one uses a scientific advisor, expectations are that if not actively engaged in producing basic scientific knowledge, the advisor is at least actively aware of the developments in that body of knowledge. Included at this level is work in basic experimental psychology, programming, game theory, hardware and laboratory development, and human factors studies.

What is use worth? What are some appropriate measures for level and type of use? There is nothing approaching a consensus on these matters; worse, there is not even much discussion about them.

One standard applied in some areas is the market measure -- will it sell, does it get constantly funded? This is a relatively unsatisfactory criterion. It is a first-order measure, but the type that allows us to ask somewhat more profound questions.

Other possible measures might be: "How many top level briefings are given, based on this particular study?" Or one might use an index such as, "How many times is this particular study referred to in making operational decisions?" None of these are perfect in and of themselves, but it is at least useful to keep them all in mind.

Another way of constructing a measure would be to gather interview data on specific decisions. Was the decision to build a piece of hardware based upon the use of a certain study? And if it was, by whom, and what form of rationalization was given for the way in which the study was employed?

In some cases, the number of scientific publications might be a measure. And last, but by no means least, a key measure is: Who instigated the study? This question has to be viewed along two levels at least. Those who pay the bill are not necessarily those who requested the work. It is essential to ask fundamental questions about initiation if we are to begin understanding the capabilities of a model or simulation. Did Admiral "X", for example, really want a particular study, or did it happen that there were unused and forfeitable dollars remaining at the end of the fiscal year? To avoid the unpardonable, in the latter instances, the ever-present Ph.D. with a pet idea gets employed. He does "his" study; he has a good time; and the study is immediately shelved and quickly forgotten.

It is essential to know details of initiation so as to be able to trace any game or simulation through its "life," from initiation to promotion and implementation, and then on through evaluation and termination. Who wants it? Who sells it on what grounds, for what purposes? Who conceives and actually builds it? Who appraises it? Who decides to renew or retire it? This procession through the decisionmaking system is doubtless complex; nonetheless, it is important to be aware of the process, and understanding initiation is important.

Costs. Costs are enormously hard to determine. It is difficult to obtain a relevant, simple cost description. To some extent, random and somewhat irrelevant accounting figures are easy to obtain; but as the work we are discussing involves a quantity of invisible costs, overhead costs, jointly shared facilities and jointly used products, a meaningful costing procedure poses a deep scientific problem that is nowhere near being satisfactorily solved.

Though we are well aware of these and other difficulties, we can give basic, brief guesses about costs for each type of work.

Straight analysis and analytic models are doubtless relatively inexpensive. Realistically so, for the only overhead support required for much of a competent professional's enterprise is a pencil and pad of paper, or maybe chalk and a board. The IBM Executive typewriter, carbon ribbons, and high-grade bond paper most likely have *hindered* developments in this area by the imputation of God-given, immutable properties to tentative formulations. Frequently what one needs are quick and dirty analytical models that do not look nice but do contain good concepts. The medium is not the message; models are the message. To prevent defilement by infidels and to encourage thought, self-destruction of both model and medium is recommended.

Simulation, as presently done, is usually an extremely expensive pastime whose value may be inversely related to the cube of the fourth power of the output. The cost is also probably related as the cube of the fourth power of the number of parameters and variables dreamed up for use in the model. Simulation is generally expensive and the validity problems are difficult; therefore one does not like to risk making many general observations except to note that it helps to know one's business.

Man-machine simulation has more or less the same spotty record. It too is expensive, but both with simulation and man-machine simulation there *are* examples in which, although the work was expensive, it was distinctly worth the effort. One or two reasonably well-defined and understood questions, asked early, the answers to which were important, seemed to be a common property of successful examples. Not only was the answer important, the principals were intelligent enough to recognize the answer when confronted with it. Frequently in a large-scale simulation an answer may appear, but it passes unnoticed because no one recognizes it. After deciding what the question is, it pays to ask what a reasonable answer might look like. Neither step is often taken, as attested by the warehouses that are full of unanalyzed computer print-out, and boxes of punched cards.

Costs for free-form gaming are relatively low, although the publicity is disproportionately large. Given both absolute and relative low levels of present expenditures, a few additional pennies spent on this type of game would certainly do no harm -- it might even stimulate more serious scholarship.

How big are the sums involved? Our guess, and these are pure guesses informed by an exhaustive reading in the area but not by access to much inside information, is that free-form gaming accounts for less than $1 million per year. All other games, simulations, and studies account for anywhere between $150 and $300 million per year, depending upon how one defines his terms and totals his accounts.

IV. PROSPECTS FOR GROWTH

The profession and the field have grown like Topsy. Professionalization has finally begun. Coordination, standards, communication, independent appraisal, review, and accounting activities are all healthy indicators of a new awareness that can only be in the profession's own collective and individual self-interest. Let us stress, however, that the real work has only just begun.

Review boards. With respect to the use of professional review boards take this example.

Probably the most elaborate gaming facility in the world is at the Naval War College at Newport, Rhode Island. The Navy Electronic Warfare Simulator, NEWS, is perhaps the biggest electronic tube device machine ever constructed by man. It cost, in terms of 1950 dollars, around $12 million. This particular facility has long been run without, to the best of our knowledge, any continuous, professional, non-Navy review board. Such a board -- if it existed -- quite naturally would not only assess current operations and procedures, but would be expected to introject knowledge concerning advances in simulation, game theory, and analytical methods, and even general advances in war gaming. By definition, what we mean by continuous and professional excludes the practice of taking in one another's wash.

Communication, documentation and use. It is our opinion that it is a dangerous policy to keep the level of professional interconnection so low. The needs for better coordination, documentation, and studies of use specifically at the operational, experimental, and administrative interfaces are great. It is not enough that a study be finished according to contract specifications; what becomes of the study and how the study gets used are far more important considerations. Learning, kinds and amounts, must be evaluated so that a rational expenditure of resources can begin. Perhaps expenditures to ensure that evaluations are done on how previous studies were used are more important than running three or four extra studies. Weapons evaluation studies, for instance, that are either unused or misused may be worse than no studies at all. We strongly suspect that ill-conceived procedures of stewardship (e.g., military activities with high rates of turnover lack personnel continuity, producing short institutional memories), coupled with highly uneven documentation standards and procedures may account for low and/or ineffective model usage. If no one remembers why an existing model was built, for whom, and what its peculiar operating characteristics are, there may be a tendency to either use it incorrectly or build a new model from scratch. If there is little or no documentation, this potentially wasteful tendency becomes a practical certainty.

General purpose simulations. There is no such thing as a general purpose applied simulation; beware of anyone who promises it.

Either know or "get the business." There is no such thing as a simulation substitute for knowing one's business. If the business is assigning personnel, the individual who assumes that function ought to know his business thoroughly before he contracts to build a large simulator that will give all the answers. One of the real dangers is the poverty of the scientific interface between those who know their business and those who try to turn their models into a business.

Human factors and basic knowledge. A fifth and final point is that there is a desperate need for large-scale basic knowledge of human factors. There is an extreme danger, given funding patterns at the present moment, that no one has estimated the shortage of supply of basic knowledge. There is great and legitimate need for basic work on topics such as studies on panic behavior, studies in threat and confrontation, and even basic studies on human motivation. The list is large. Desperately needed, also, is a review of the kinds of basic knowledge that need expanding, how these tasks should be interfaced with the operational establishment, and what form of funding might be brought to bear.

Render unto the National Science Foundation that which is NSF's. However, let us begin to make very sure that the interface, the connection between NSF and other sources of research funds, is what it needs to be.

V. TO RECAP

The future for gaming and simulation is quite good. There is a steady building up of demand. There has been an enormous improvement in technology and analysis. Far more personnel are now available than ten years ago. Control in determining how effective the growth of this area is going to be is in each of our hands. If we fail to exercise that control, it is going to be easy to butcher another couple of hundred million dollars. If we fail to build up a basic knowledge store, we are going to retard drastically needed improvements in the system for another five to ten years or more. If we fail to integrate top decisionmaking systems and the bureaucratic interface with research work by failing to provide decent scientific advice for the operators, we may produce work that superficially can be judged as good, but in actuality will by no means be cost effective.

Finally, the future is good; the demand is growing; knowledge and technology are improving; but the growth has to be controlled and the control is primarily up to us.