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KEYNOTE ADDRESS

***Alan Pritsker** is Chairman of Pritsker Corporation, a company that resulted from the merging of Pritsker & Associates, a software and services firm specializing in solving design problems with simulation, and FACTROL, a shop floor control software company. Pritsker was a founder of both companies and, initially, they operated separately to satisfy customer needs. However, in order to provide better service while coping with the burgeoning growth of simulation, they have been integrated into one larger company.*

Alan Pritsker was one of the first people to work on computer simulation. With Bachelor of Science and Masters degrees from Columbia and a Doctorate in operations research from Ohio State, he worked in industry, then taught at three universities prior to starting the companies.

Pritsker was researching simulation and moving it ahead as a technology while he taught the subject. His students were key to its development and his efforts resulted in establishing Purdue University as the hub of simulation activity. In addition to setting up and defining simulation studies at Purdue, Pritsker's work has impacted most other universities and his students have gone on to lead in the field around the country and the world.

WHY SIMULATION WORKS

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ABSTRACT

Simulation works because it deals with reality. We simulate models of real systems. We get closer to the system than any other type of modeler. We study the old system, collect data, understand first principles about the system, check out procedures in use before we start modeling, and we test proposed solutions against current operations or baseline designs. We do not force a system into a preconceived normative model. We strive to have our models used and our best alternatives implemented. We stay with a problem until a solution is implemented. We recognize that the model upon which we make our recommendations contains additional information and insights that are useful during implementation.

1. INTRODUCTION

In preparing this keynote speech, I had difficulty deciding whether to be specific or general. My reaction was that a keynote address should be general and considered the title: "Random Thoughts About Simulation." Since I am an "insider" to the WSC, I felt that a more specific topic would be of greater interest. I also knew I would be able to include my random thoughts under a specific talk title. Based on my combined modeling research, I should have reworked the title to "Why Simulation Works and Other Random Thoughts."

Simulation is the most used and useful technique of industrial engineers and operations researchers. It is used throughout the engineering and science communities. It has had a major impact on industrial and government operations. In the last decade, we have seen a fantastic increase in the number of individuals who are using simulation to solve problems and make decisions. This paper focuses on the reasons for this increase in the use of simulation and some of the research concepts that will help to continue the successful application of simulation.

2. WHY DOES SIMULATION WORK?

Simulation works because we abstract reality and because we, as problem solvers, are realistic modelers and analysts. We combine the engineering concepts of design and control with the experimental approach of the scientist. We use mathematics to solve problems and verify solutions. We see problems as opportunities. We are not hung up with optimization because we know our models are approximate. We don't worry about pitfalls until we are in sight of the solution. We have more and better tools to do the job. We know how to start a project and we are fast closers. We generate confidence in the decision maker about a correct course of action. We build models, use them, make a recommendation based on simulation results and implement the recommendation including the measurement of improvements obtained. We support on-going and continual improvement not just improvement.

It is ironic that simulation, a word that connotes a sense of unrealness, works because of the ability to include realism in the models that underlie a simulation analysis.

3. HOW DOES SIMULATION WORK?

Simulation is a young field. We've all heard comments regarding the growth of science and that 85% of all scientists that lived are alive today. My estimate is that 99.9% of all computer simulationists that lived are alive today. It is important to realize this. A young field needs direction. We must continue to be driven by our engineering heritage. We should not fall into the trap of defining problems because they are solvable. I repeat my premise - simulation works because of the realism that can be built into the models to be analyzed through simulation. One way we achieve realism is to model in stages, that is, evolutionary modeling. General purpose simulation languages make it easy to extend and modify a model to add characteristics which are deemed to be necessary for problem resolution.

To resolve problems requires the involvement of a decision maker. We have a difficult time modeling the decision maker, so we mimic the decision-making process and provide information similar to that used in actual operations, that is, in practice. This allows us to support many different types of decision makers either through model changes or by changing the user interface. Let's take a look at the type of decison makers we support.

Some decision makers only need an understanding of a system in order to move ahead. For such decision makers, the model is built for communication and explanation purposes. More emphasis is placed on descriptive or facility models and animations showing object flows so that the decision maker can perceive how the system or proposed system would operate. Simulation works for these decision makers by graphically describing their system's operations.

A second type of decision maker is involved in design and analysis situations and compares alternative solutions or scenarios. This entails the use of ranking and selection techniques during output analysis but requires that the model be capable of parameter changes and structural changes and to be able to provide information regarding how to improve designs. *Simulation models which have a one-to-one correspondence between model elements and system elements tend to be the best source for information on improvement possibilities.* Simulation works for these decision makers by illustrating alternative solutions and providing outputs that indicate where improvements are possible.

A third type of decision maker has the difficult problem of estimating absolute performance. This requires a model that includes all elements that can impact on the performance measure being estimated. For such situations, extensive data collection is typically required. Fortunately, simulation models allow for the use of many types of data including observed data, summarized data, and theoretical distributions. In some cases, the observed data may be obtained online from a collection device. Simulation works for these decision makers because a confidence is established in the model through the use of real data.

The fourth use of simulation by decision makers is in the control area. Both dispatchers and operational managers are involved in control decisions. At the dispatcher level, information is desired on performance measures given a schedule of orders released to the shop floor assuming a current status for the shop floor. This can be accomplished by a model of the shop floor and accessing production control or MRP II databases and shop floor status databases. Simulation models can include dispatching rules and heuristics or have scheduling algorithms embedded to perform the scheduling decisions. The individual performing the scheduling may be included in the simulation evaluation process. For operational management, the simulation model can be used to assess the current bottleneck points, the cost of expediting a particular job, the impact of contracting for additional work, and the desirability of adding resources to handle the current workload. The integration of operational management decisions with the scheduling decisions can be accomplished within a control environment. We are currently installing such capabilities. In some cases, models required for control may not have to be as detailed as those required for analysis and estimation. In control, the time between control actions may allow the use of a simpler model. Shortening the time between control points can compensate for a modeling inaccuracy, a bad decision, or a faulty implementation. Simulation is just starting to work for decision makers in the control area.

The above discussion relates to problem solving and the use of models within the problem solving process. How a decision maker perceives a model is not clear. What may be important to one decision maker may have little significance to another. The view of the model may be different and could depend on the decision maker's objective which relates to the functions of understanding, analysis, estimation, or control. Simulation models contain a large amount of information and do represent different things to different decision makers.

4. WHERE IS SIMULATION USED?

The systems of interest to the simulationist are extremely diverse. We perform design and analysis activities on the smallest of motions and on the largest of systems. The disciplines using modeling and simulation include engineering, business, mathematics and statistics, anthropology, sociology, psychology, medicine, physics and so on. There is hardly a field that doesn't make use of modeling and simulation. Not only is industry using modeling and simulation, but the government continues to be a strong supporter of the field. In 1989, the Department of Defense and the Department of Energy listed modeling and simulation as one of twenty-two critical technologies in the United States. It was the only technique-oriented field that was listed.

How can so many fields use the same technology? The answer is that we provide a perspective on modeling that is broad and flexible. Languages include the capability to model objects, events, processes, activities, differential, difference or algebraic equations, and a combination of the above. As mentioned previously, the models are easy to modify and extend. The languages allow and promote multiple levels of models. Hierarchical modeling capabilities allow one model to call another or to call a specialized program for solving a specific set of equations. For example, it is easy to imbed a linear programming solution procedure in a simulation model as an event to provide values of decision variables. In simulation models, no linearity assumptions are necessary nor are stationarity hypothesis presumed.

For the general purpose simulation languages, it is the user's responsibility to have a detailed knowledge of the system being modeled. For special purpose languages, it is the user's responsibility to make sure that the special features are appropriate for the elements of the system being modeled. *Because of the diversity of the systems that are studied from a simulation point of view, each simulation professional should learn a simulation language in detail.* In my experience, it is necessary to use a simulation language to model large complex systems, and it is from such models that an understanding and a detailed level of comprehension regarding modeling is obtained. After using one language, it is relatively easy to learn a second one. A course in which a simulation language is used to build and analyze models should be taught from a modeling concept perspective. The syntax and semantics and data structure of the language are important, but it is the modeling perspective and concepts of the language that should be emphasized. *To understand the perspective and concepts of a simulation language requires extensive application.*

5. THREE RESEARCH AREAS

5.1. Model Classification to Support Output Analysis

The analysis of simulation outputs is a perplexing topic. In practice, it appears that an analysis is either very easy or extremely difficult. Sometimes this dichotomy is hard to understand. Tremendous strides have been made in deriving theoretical results for output analysis and variance reduction. However, the results are not often used . The reasons for this are that the results are not easy to apply, thorough experimentation in the industrial and government sectors is not usually possible due to time contraints, the number of pitfalls associated with the applications of the results discourages their use and the number of variables and performance measures in a model make it difficult to apply the results. As an alternative, there has been a greater exploration of graphical means for viewing the outputs of a simulation. Through the use of animation, plots, histograms, pie charts, and range charts, the hope is that a complex problem can be converted to a simpler problem where the answer is perceived directly. This has not solved the problem. What is needed is robust statistical techniques that can be applied to diverse systems. Currently, the outputs of the simulation are viewed as a stochastic process for which we have sample records of observations from the process. In most cases, the knowledge of the model structure is not used as an input to an output analysis technique. One exception is the regenerative technique. *A classification of model types which supports a capability to use model information might help to improve statistical analysis techniques.*

5.2. Deterministic Models

An important question in building a model involving random variation concerns the source of the randomness. One source of randomness is activity times, that is, the time to perform a function. Two reasons for randomness for activity times is a lack of information on: 1) the types of operations being performed, and 2) the details of how a resource performs the function. If an activity is broken down into subactivities, the variability of the time to perform the subactivity tends to be less.

Research questions are being posed about the running and analysis of models that do not have random variation. If the parameters remain constant then one run can be used to evaluate a scenario. If it is hypothesized that model parameters take on distinct values at different times within a scenario, then the following research questions need to be answered:

- Is there a need for a different modeling language?
- What data collection and output analysis capabilities are required?
- Is it possible to analyze the periodicities in the model to estimate performance? Can a transform approach be used?
- Can the model be analyzed in two types of intervals: constant parameters and transitions to new parameter values? What procedures are available for detecting the beginning and ending of such intervals?

The research on deterministic models is being driven by practical considerations. Discussions with applications engineers indicate that approximately thirty percent of the simulation models being used in industry do not include random variations. These models are complex, multivariable, and employ complex algorithms. Basically, they are procedure evaluators. In a sense, they are similar to the models for evaluating scheduling, distribution and logistics methods. It is interesting to note that much of the current work in scheduling and routing by math programmers could be classified as deterministic simulation analysis.

5.3. Chaos

Recently I have been reading about Chaos. As a simulationist, many of the concepts of Chaos Theory give me a comfortable feeling. Others, however, strike a dissonant chord. Chaos Theory tends to deal with natural phenomena. It is a holistic approach to the study of turbulence, clouds and other nonlinear systems.

To chaos researchers, mathematics has become an experimental science, with the computer replacing laboratories full of test tubes and microscopes. Graphic images are the key. Kuhn states, "Under normal conditions, the research scientist is not an innovator but a solver of puzzles and the puzzles upon which he concentrates are those which he believes can be both stated and solved within the existing scientific tradition."[Kuhn, 1970] Gleick in Chaos continues this thought pattern, "A new science arises out of one that has reached a dead end. Often it requires an interdisciplinary character with its central discoveries coming from people straying outside the normal bounds of their specialities. The problems that obsess these theorists are not recognized as legitimate lines of inquiry."[Gleick, 1987]

The above quotes ring a familiar bell. As discussed in the introduction to this paper, simulation works because we are interested in real situations not theoretical puzzles that have esoteric solutions. Most of the time we are ignorant about the solution space and the characteristics of an answer. We deal in many fields and require an interdisciplinary team in order to understand the observed phenomena of the system with which we are dealing. We use many different modeling constructs to capture the essence of objects, events, processes, and activities. We intermingle these models with algebraic, differential, and difference equation models. Graphical outputs are used extensively for: understanding the models; verifying the outputs; validating that the models relate to the observed phenomena; and providing a means to improve operations.

Chaos researchers also deal with deterministic systems whose output have the appearance of random variation. The models developed for such situations include nonlinear effects and produce aperiodic dynamic behavior. Except for the aperiodic behavior, this aspect of Chaos Theory corresponds to our deterministic modeling analysis research.

Three aspects of Chaos Theory that are different are: 1) the lack of stationary behavior in the nonlinear models; 2) the butterfly effect which produces large impacts for seemingly small isolated changes; and 3) the concept that system behavior could not be built or estimated by piecing together models of subsystems. These deserve careful attention by the simulation community.

For the simulation researcher, it is normally assumed that stationary behavior does not exist in transient periods but does in steady-state periods. The transient period is considered as the time until steady-state is reached or the time over which an analysis is to be performed for a terminating system. The possibility that a model can continue to operate and never reach a regeneration point strikes at the heart of most statistical analysis of simulation output research. If stationarity is not assumed, what impact is there on modeling and analysis procedures? If nonstationary behavior exists in nature, should we expect it in man-made systems?

With regard to the butterfly effect, simulationists do observe large changes in behavior for small perturbations. This occurs when arrival rates approach service rates or more dramatically when a resource deadlock occurs. Fortunately, when dealing with a man-made system, we are able to change the system or its design. Thus, to some extent we deal with controlled chaos.

The third area of concern in Chaos Theory relates to predicting system performance from models describing system components. For simulation models, significant time is spent modeling the interfaces and information flow between components as well as the physical component interactions. Whether it is necessary to go beyond the modeling of interfaces to a holistic approach, as suggested by Chaos Theory, is another subject worth exploring.

6. CHALLENGES

The challenges we face are exciting. *We need* *to transfer the observed phenomena obtained from solving problems back to the academic institutions.* Case histories need to be written. Test problems need to be developed to promote the development of statistical tests that are easy to apply. A classification of systems needs to be developed in order to provide information on the need for higher level languages, knowledge-based statistical analysis, and standard subsystem models. Databases need to be populated with instances of observed behavior and with performance measures of system elements. A greater emphasis is required on total project performance including life-cycle costing.

7. CONCLUSION

As we approach the last decade of the 20th century, the simulation field has much to be thankful for. First, 99.9 % of us are still alive. We are a growing dynamic field with much diversity. Simulation is the most frequently used industrial engineering and operations research technique. We have established the need for simulation, shown that it works, and produced the tools to support problem solving using simulation. We have commercialized the field and demonstrated, without a doubt, the benefits obtainable from modeling, analysis, and problem solving using simulation.

In 1947, Winston Churchill in a speech before the House of Commons presented the following view of democracy.

> "Many forms of government have been tried, and will be tried in this world of sin and woe. No one pretends that democracy is perfect or all-wise. Indeed, it has been said that democracy is the worst form of Government except all those other forms that have been tried from time to time." [Churchill, 1947]

I close by paraphrasing Churchill's statement --

> *No one pretends that simulation is perfect. Indeed, it has been said that simulation is the worst form of analysis except all those other forms that have been tried from time to time.*

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