Simulation in Information Systems Research

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INTRODUCTION

Simulation is a standard research technique of the natural sciences, social sciences, and engineering disciplines. The paradigm of simulation provides an accepted mode of development, validation, and verification by which complex, highly dynamic interactions can be probed and analyzed. The approach enables researchers to phrase experiments in a controlled environment where the concepts, variables, and relationships of the domain can be manipulated. Then, employing standard experimental design techniques, the simulation represents the behavior of the underlying system. The behavior can be analyzed statistically for its regularity and critical values where the dynamics may become unstable. Further, once the simulation model is developed, sensitivity analysis can be done to probe the interdependencies of the elements of the underlying system upon one another.

Without the use of computers, the concept of simulation uses physical models to provide the experimental framework examining complex systems. These physical models incorporate dimensions of a real system, abstracted into the model. If one wants to explore a pilot's ability to manage a cockpit's physical controls under different degrees of information loading, one constructs a mock cockpit and offers the pilot different amounts of information to handle. The experiment of the physical simulation relies on the modeler validly abstracting relevant aspects of the real cockpit into the mock cockpit.

Computer-realizable simulation has become an option with the development of computers and the representation of models within a computing environment. Programming known mathematical representations of physical behaviors became a standard use of computers with programming languages such as FORTRAN, designed to numerically analyze mathematical functions within acceptable tolerances. In fact, the disciplines of management science and operations research are defined by their various modeling approaches to represent the behavior of physical systems into mathematical and computational frameworks - simulation being one of the frameworks. In fact, the initiation of these fields are usually traced to their successes in the 1940s with military-related research of dynamic systems using computers and simulation.

Today, simulation continues to be a tool for understanding complex, dynamic systems—but not for proposing optimal solutions to their interactions. Optimization cannot be a mathematical analysis goal of simulation; other mathematical approaches exist for this analysis goal. Typically, the dynamics and interactions of a simulated system are too complex to be captured into a mathematical structure, lending itself to optimization algorithms. Simulation provides a methodical way to describe and to examine the dynamic space of the system's behavior.

The usage of simulation to understand complex systems is not done solely in the natural and physical sciences. Social sciences such as economics and psychology have relied on the concept as a technique to test theories of behavior. Even performing well-defined, "what-if?" analysis in spreadsheet applications to assess supply-and-demand interactions constitutes simulation. Social psychologists might use a simulation framework by developing a research model based on probabilistic structures. The probabilities describe the tendency of elements in a social system such as a crowd to react and change into a mob. In the vernacular of the field, simulation examines the modeled elements, tendencies, and interactions, by manipulating the "stat rats" in order to probe the behavior.

Numerous computational approaches have been developed to handle simulations. General-purpose programming languages such as FORTRAN or C++ can represent the model and realize its execution. General-purpose simulation packages such as SIMAN (Pegden, Shannon & Sadowski, 1990), ARENA (Kelton, Sadowski & Sturrock, 2004), GPSS (Schriber, 1974), or MATLAB (Palm, 2001) have been classically used to represent the model and to facilitate the representation of time for the execution of the model. In addition, special-purpose simulation environments have been developed for specific domains ranging from inventory logistics, chemical manufacturing, to air-traffic control.

Modeling and statistical processes are foundations to simulation. Hannon and Ruth (2001) emphasize dynamic modeling perspectives; Shanbhag and Rao (2003) target stochastic processes as an aspect to simulation; Severance (2001) focuses on the systems-thinking perspective guiding simulation development; Powell and Baker (2004) show how simulation can be realized in easily accessible spreadsheet software; and Chung (2004) captures the general manner of the basics and techniques in a handbook for simulation modeling.

Simulation's advantage stems from the safe, abstract environment invented by the model. Often the underlying system to be understood may be (1) dangerous to manipulate, (2) unavailable for controlled manipulations, or (3) non-existent at the current period of time. The simulation of a proposed new rail-transport system based on a current city's environment captures all three of these conditions.

Simulation also has its down side. A good simulation depends upon a good model of the underlying system. Creating a good model requires analytical, mathematical, and logic skills. Executing the simulation requires computational skills. Understanding the results of the simulation requires knowledge about the underlying system and about the mapping of it into the model. These skills require training and development which are not readily available in the average technical professional.

BACKGROUND

Simulation incorporates experimental design as its underlying paradigm for understanding complex, dynamic systems. By manipulating the input variables and system parameters within acceptable and legal value ranges, the behavior of the system can be mapped as a function of the changes defined by the experimental design. More than one experimental design¾more than one set of experiments, more than set of variable perturbations¾may exist for any modeled system. The modeler determines what aspects of the system need to be captured in the model in order to be probed by the experiments. The process begins with a conceptual model of the system.

A prerequisite to constructing a simulation is to understand the behavior of the system and to represent it sufficiently in a valid model, which can be realized (executed) in a computational format. If the behavior is not well understood, the abstraction into the model may not accurately represent the relationship between the input variables and the output variables. The process of validation examines the correspondence between the modeled input and output pairings, and the actual input and output pairings. This correspondence should show statistical goodness-of-fit. If it does not, the conceptual model needs to be revised. Until this correspondence is valid, proceeding with the experimental design would not be rational.

Models, long a standard of research and engineering, are an abstraction of the significant features and relationships of a system. This abstraction enables the system to be studied for the purpose of prediction or comparison. The experimenter knows the system intimately and defines a level of analysis appropriate in order to enable the prediction of a system's behavior or to compare the effects of change upon the system's behavior.

Generally, models may be represented as linguistic, iconic, or physical representations. The choice depends upon how the modeler expresses the fundamental relationships of the target behavior. Examples of each of these are as follows:

1. A mathematical model of a business's order fulfillment interactions requires equations¾a model based on the language of mathematics.
2. A process model of an organization's enterprise-wide data distribution plan requires diagrams of nodes and connections - a model capturing behavior possibilities by the use of icons.
3. A construction, 3D model of a company's proposed new production plant requires an architectural layout of objects of buildings and land¾a model showing components' interactions based on physical scale.

Although a variety of texts present simulation, classic coverage of the simulation development process from model conceptualization to simulation execution can be found in Banks and Carson (1984), Law and Kelton (2000), Winston (1987), and Zeigler (1984, 1976). Coverage of a variety of classic implementation platforms for simulation can be found in Watson and Blackstone (1989). Aburdene (1988) presents both discrete-event simulation and continuous simulation, and provides examples across a variety of disciplines and applications from information diffusion to modeling the arms race. Pegden et al. (1990, pp. 12-13) identify the simulation process as a set of 12 steps. These steps cover the project management aspects of the simulation study as well as the conceptual management of the experiment.

1. Problem definition: Identifying the goal and purpose to the simulation
2. Project planning: Identifying and coordinating the hardware, software, staff, and management resources required
3. System definition: Identifying the system to be studied—in classical general systems analysis terms
4. Conceptual model formulation: Extending the system definition to incorporate formal variables, relationships, and interaction logic
5. Preliminary experimental design: Identifying an experimental framework by which to assess the study,

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