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GENERALIZING: IS IT POSSIBLE TO CREATE ALL-PURPOSE SIMULATIONS?

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ABSTRACT

The title poses the essential question addressed herein: Is it possible to construct simulations that permit use in application domains with widely ranging objectives? The question is raised in a tentative explanation of what is entailed in an answer. Beginning with a taxonomy based on simulation objectives, we identify differences among the categories with respect to what is attendant in realizing different objectives and in using associated methodologies and tools. The closing summary highlights the importance of producing an answer or eliminating the question.

1 INTRODUCTION

The question of model generalization arises most naturally in discussion with persons having second-hand knowledge of simulation. Why can a model of a cruise missile used in a training exercise not be employed, perhaps slightly modified, for examining the proposed improvements for a pending acquisition? The answer, usually given by someone immersed in simulation technology, appears simplistic and unacceptable to the questioner: the focus in a simulation study is to produce a model that represents real system behavior *to the extent necessary to meet study objectives.* The questioner's knowledge and experience with simulation, derived from a singular perspective, cannot fathom the differential meaning intended by the "objective qualification." On the other hand, just how fundamental are the differences that typically cause experienced simulationists to dismiss the concept of models that accommodate or adapt to different objectives?

Our intent is to initiate an examination (or reexamination) of the generalizability of model objectives as a potential factor for increasing the prospects for model reuse across application domains. As such we are excluding from our discussion modeling environments that provide the ability to reengineer or rework a model. We are necessarily limiting our discussion and further refining and clarifying our question to the more specific: "Is it possible to construct simulations that, in their own existence, can be modified by the end user to allow the use of those models in other application domains?"

We begin by considering how simulation studies are classified based on objectives. Education and Training, Analysis, and Acquisition and Acceptance describe three classes (Nance 1999). The same three classes are described by Cavitt, Overstreet, and Maly (1996, p. 629), but cast in slightly different forms as "research, acquisition, and training".

Following description of the classification scheme, we analyze each category with respect to objectives, methodologies and tools distinguishing similarities and contrasts. The discussion then focuses on major unresolved issues, relying heavily on the available literature to provide explanations and examples of the discussion points. The closing summary accentuates the need for further inquiry before reaching a conclusive answer to the generalizing question.

2 SIMULATION CLASSIFICATION

Note that our categorization of simulations does not agree with Balci (1997) who separates simulations into Problem Solving, Training, or Education categories. A more recent classification adds research (Nance and Balci 2001, p. 1565). The differences among classification systems do not invalidate any of them, rather they demonstrate the breadth and variability of simulation uses.

Another possibly more complete categorization of simulation goals and purposes is shown in Figure 1. In it, we attempt to place the major areas of simulation in some sort of relative position. Our discussion and analysis focuses on the three categories mentioned above. We feel that this tri-category division is the most effective and efficient demonstration of our ideas.

2.1 Education and Training

The Education and Training class of simulations, while fused by most goals, is divided by others significantly

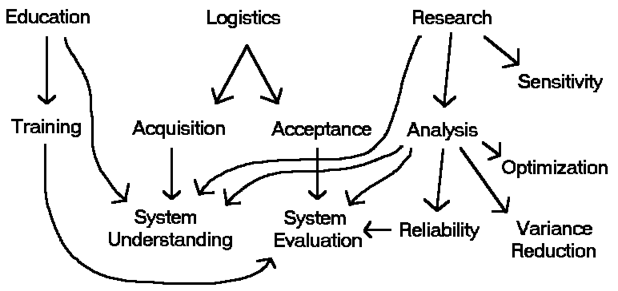

Figure 1: Possible Simulation "Taxonomy"

enough to distinguish between the two. Both Education and Training simulations share one major goal: to impart knowledge of a certain process, tool, or methodology to an individual (or group of individuals) with the end goal of improving the performance of the individual (or group).

Educational simulations are those used for the purpose of providing understanding of a system or process. An example of this would be a simulation model of an assembly line or some manufacturing process, perhaps with the objective of demonstrating to plant personnel how "just-in-time" inventory methods work. Another example would be a simulation model of a software or hardware device to demonstrate signal or information flow.

On the other hand, training simulations are those used for the purpose of developing specific skills or providing experience through practice. For example, let's suppose the assembly line simulation mentioned above might be subsequently modified so that an individual would need to respond to unexpected circumstances as part of the training of line supervisors. This change is indicative of a shift in the overall goal from education to training.

One can imagine the discussion in the planning meeting; "How about if we make the "sim" reflect symptoms of equipment failure so that we can train our technicians to diagnose the problems?" Now the focus appears to be on providing experience so that repair personnel can recognize symptoms to diagnose causes of failures and the corrective procedures that need to be applied. This simulation has gone beyond an educational role and has assumed a role geared more toward training.

Giussani (1991) provides an excellent example of a training simulation used within a manufacturing process in the second of three phases described in her paper. She describes the flow of coils of steel through a banding, weighing, and marking process. The phases of her study are identified in terms of the goals. The three phases of her study are to: 1) analyze the current hot mill banding process, 2) provide training for the process operators, and 3) to extend the model to simulate a new system to be integrated with the existing systems that are analyzed in the first phase.

Some of the best examples of this can be found in past Winter Simulation Conference Proceedings. An older, yet still relevant, example is the Childs and Lubaczewski (1987) report on distributed simulators for the upper command level of large army units. In the paper, we see the target audience - the "players" - placed in an actual or modeled decision-making environment. This environment can be at almost any level in the upper chain of command. The actions and commands of the players are monitored and evaluated on the effectiveness of the decisions that they make and the orders they give, although no empirical measure is mentioned.

An example from the Secretary of the Navy is a simulation to train members of an Integrated Project Team (IPT) in proper techniques of the purchasing process (Kenaston et al. 1998, p. 1). The first stated goal of the system is to "[understand] some of the complex and dynamic situations and make better decisions."

2.2 Analysis

Those simulations that are used to evaluate a process and/or improve some characteristic of that process are grouped into the Analysis class.

This appears to be the largest class of simulations, for the majority of the works in the prominent professional publications relate to analysis. As a result of this class being the largest, it is also the most diverse. The analysis class also includes simulations that can be assigned to more than a single category, Guissani (1991) being only one example among the many that exist.

Another example of a simulation designed with analysis objectives is that of Leilich (1998). His simulation compares alternatives for rail service in the Raleigh-Durham area. The model covers six key aspects of the problem situation for a rail simulation: 1) Defining simulation study objectives, 2) Obtaining accurate and complete data, 3) Calibrating base case operations with real world operations, 4) Achieving consensus on the base case (existing operations, if they exist), 5) Identifying alternatives to be evaluated, and 6) Converting performance findings to measures of service impact, capacity, and economics. In defining the problem in those terms, Leilich gives us a solid example of a simulation for analysis.

A third and final example of the simulations that fall in this class is the system described by Schulze (1993) for the public transportation system in Magdeburg, Germany. He describes the process followed to construct the simulation to analyze schedules of streetcars and busses, change time for passengers between different streetcar lines, change time between streetcars and busses depending on the time of day (morning, evening, and night) and consequences of new routes.

The common thread in these simulations is that they are all intended to analyze some situation so that proposed changes can be monitored for designated behavioral improvement.

2.3 Acquisition and Acceptance

As with our first class (Education and Training) we see a need to acknowledge the differences in the goals of Acquisition and Acceptance simulations, while recognizing that they are very similar. Simulations in this class are those used to evaluate a process or product to determine the suitability of that process/product in meeting a set of requirements or to validate that such requirements are met.

The U. S. Army's Simulation, Training, and Instrumentation Command (STRICOM) has noted the value of simulations to make acquisition decisions through Simulation Based Acquisition (SBA). STRICOM lists SBA as one of the tools to check for in a potential contractor's plan to provide a product. (USAMC 1996) The presence (or lack) of a SBA tool is an indicator of whether or not the agency responsible for acquiring that product should choose that company to develop it.

In a study for the U. S. Navy by the American Defense Preparedness Association (Clark, et al. 1996, p. ES-2), the authors have stated in a clear and concise manner the attitude that now prevails regarding SBA: "The issue is no longer whether extensive use of M&S tools has merit and benefits for acquisition, but rather how to develop and apply a new acquisition process in a deliberate and coordinated manner that uses these tools to maximum advantage and achieves even more dramatic cost and schedule reductions."

A good example of a simulation for the purposes of acceptance is given to us by Janowiak (1990). This describes the U. S. Navy's Integrated Combat Systems Test Facility (ICSTF). This test site provides the capability to simulate all external interfaces for a system. This provides a "wrap around" effect to facilitate testing.

3 OBJECTIVES

One goal that all proper simulations have in common is to provide accuracy in the modeling of the problem domain (Page and Nance 1994). This becomes readily evident in application domains such as multi-billion dollar contracts that may rely on the results of an acquisition or acceptance simulation. Another area where model accuracy is critical is in training for military operations or training for medical procedures where some decisions literally have life or death consequences. It seems logical that one would desire that a simulation model describe these situations as closely as possible.

Bell (1999, p. 74) touches on this 'precision of model' idea in his presentation of "The Effectiveness of Distributed Mission Training (DMT)" upon team interaction. He asks the question "Does the integration of DMT technologies into a training system materially improve the likelihood those who use DMT will successfully accomplish their missions?" While he does not answer this question with a definitive yes or no, he does report that the results are promising, thus enforcing the notion that model accuracy is worth the effort.

In contrast, we must also consider the cost associated with ensuring accuracy through validation. If an increased degree of accuracy is desired, the cost of validating the simulation increases, although not necessarily in proportion to the amount of gain in accuracy. This is described best by the cost-benefit relationship graph presented by Sargent (2000) and reproduced here as Figure 2. This graph depicts the non-linear relationship of cost vs. accuracy obtained through the Verification, Validation, and Accreditation (VV&A) process.

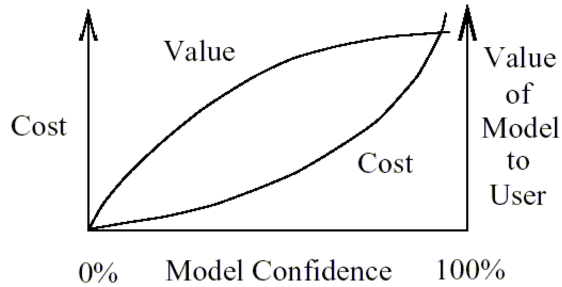

Figure 2: Cost-Benefit Relationship

Another common goal among the different classes of simulations is the ability to provide the capability to test decisions before they are actually implemented, which is one of the invaluable strengths of simulations. A hospital simulation to track changes in the procedures for patient processing presented by Drager (1992), displays this capability. Everything in conjunction with this task is considered a variable in the simulation, such as the distance someone would need to walk to retrieve paperwork or information pertaining to a certain case.

3.1 Education and Training

One goal specific to educational simulations is to provide understanding of a system, tool, or situation. Often these simulations provide practice and experience for the trainee to assist in this goal.

From a purely educational model, the next logical step is to use the simulation environment as a means to improve human performance and evaluate that improvement. If one can quantify an individual's or group's skills, both before and after interaction with a simulation, achievement of this goal is very practical. The key point is that the skill level must be measurable.

We see in Mertens (1993) how the accomplishment of this goal is achievable. The simulation presented in this paper models the battlefield command and control facilities to train upper level military leaders. This system appears to be the successor to Childs and Lubaczewski (1987).

An interesting note regarding simulation models in this classification is that they may reproduce the system to a lesser degree of accuracy than those used in other classifications without experiencing significant degradation in achieving the stated objectives. In general, the accuracy is sacrificed to produce a more cost effective model. To overcome this loss, participants must be cognizant of and compensate for these inaccuracies. In practice, this is a useful method to cut costs and sustain effective training.

3.2 Analysis

The main goal of simulations designed for Analysis is to evaluate process performance. Process in this context is a very broad term assuming the meaning of anything from the operation of a piece of software to financial transaction processing to fast food service and preparation procedures. This analysis may be used to change the process or to compare two different processes through statistical techniques.

Godward and Swart (1994, p. 1067) use process analysis in the determination of workforce requirements for Taco Bell. The simulation "determines the amount and deployment of labor required in a restaurant in order to meet a given level of sales while delivering quality, service, cleanliness and value to its customers." (Godward and Swart, 1994, p. 1067-1073). It analyzes sales data to determine business volume for a given time period, and allows planners to alter the location of preparation surfaces to analyze the traffic flow of the workers.

3.3 Acquisition and Acceptance

Simulations in this class are almost exclusively used to support a definitive decision from a limited set of alternatives. The simulation might be required, for example, to provide stimuli to a certain piece of equipment to emulate possible conditions. Measurements can then be taken in these varied situations without having to physically recreate the conditions. As such, the conditions can be precisely and repetitively applied to different pieces of equipment for evaluation or comparison purposes.

Processes are developed like those described in Horowitz (1990) in the examination of DoD policy. The recommended process is to use simulations to allow for faster and cheaper acquisitions than are possible from the traditional DoD acquisition process.

Cohen and Thompson (1999) present the argument that simulations can and should be used not only for acquisition, but for acceptance, evaluation, and upgrades as well. This well formed argument basically states that the same processes that have been used to procure a given system (in this example shipbuilding) should be used for maintenance functions to evaluate design changes prior to their implementation. Related to the evaluation use is the need to assess the contributions of a major subsystem to the performance improvement of the *total system* in the acquisition process.

3.3.1 Acquisition

One goal of simulations for acquisition is to evaluate process or product performance. This is a goal similar to that in the Analysis class with the exception of intent. The intent here is to make a purchasing decision, such as modeling a device to determine if the specifications can be attained within the projected budget constraints.

The goal of simulations used for Acquisition, and SBA in particular, can be best summed up by Strelich (1999) "The Simulation Based Acquisition (SBA) initiative is based on the integration and interoperation of simulations, models, tools, utilities, applications and databases supporting the construction of a virtual product that can be used to analyze and evaluate the full spectrum of lifecycle issues before, during, and after product development."

From this we can refine our definition of the objective of simulations used for Acquisition to be: "To analyze and evaluate lifecycle issues before, during, and after product development."

3.3.2 Acceptance

The difference between the goals of acquisition and acceptance is frankly a matter of timing. Most often, an acceptance simulation is using a pre-defined set of criteria, which may have been generated from an acquisition simulation. The main goal of the simulation is to verify the performance of the process or product being delivered. An acceptance decision needs to be based on the operation of the subsystem within a simulation of the total system in which it functions.

4 METHODOLOGIES AND TOOLS

In addition to the numerous simulation methodologies and tools, general assistance software is widely available to contemporary simulation model developers. Some of those that seem most promising include: Extensable Markup Language (XML) (Chatfield, Harrison, Hayya 2001), Unified Modeling Language (UML) (Richter and März 2000), and the Component-ORiented Simulation Architechture (CORSA) (Chen and Szymanski 2001). The difficulty in using such tools is their general lack of focus on the importance of temporal casualty in simulation modeling.

4.1 Education and Training

In general, training does not require great precision of calculations. It can, however, require special hardware and software depending on the level of detail and realism desired in the simulation. Some examples of items that may be required for a realistic simulation include: "display, tracker, audio, 3D/6D input, gesture, haptic, speech, computing hardware and software." (Schlager 1994, p. 317)

The High Level Architecture (HLA) has received much attention as the basis for federated simulation of models developed by the Department of Defense (DoD). The HLA is conceptualized as a successor to other DoD distributed simulation protocols, but the scope has been expanded to include other objectives.

4.2 Analysis

Simulations with analysis as their focus generally employ methodologies which do not require an exacting degree of precision. These models normally employ statistical analysis techniques to study trends in the model output. This is best described by Yücesan (1994, p. 99). "Since simulation is a statistical sampling experiment, appropriate statistical methods are essential to avoid erroneous conclusions, ultimately leading to poor decisions."

Statistical techniques may also be observed in models employing Rare Event Simulation. Haraszti and Townsend (1999, p. 402) describe a technique called splitting to "[achieve] increased occurrence of the rare target event." Rare Event Simulation is used in the effort to reproduce specific sets of stimuli, and techniques such as splitting that, based on the stratification of state space for simulation output, can achieve "computationally efficient analysis."

The general impression gleaned from reviewing the current literature is that development methodologies of simulations for the purpose of Analysis continue to transition from a procedural to an object-oriented paradigm. This shift is occurring due to an attempt to obtain the promises of object-oriented programming such as improvements in reliability and reusability.

4.3 Acquisition and Acceptance

This class of simulations normally requires a high degree of precision. As a result, the hardware performance requirement is very high. In addition, other systems such as servos or signal generation or measurement equipment are often required.

Mentioned earlier, Janowiak (1990) describes the U. S. Navy's Integrated Combat Systems Test Facility (ICFT). The Wrap Around Simulation Programs (WASPs) described within allow for sensor stimulation to emulate all inputs necessary for a system to be tested, thus eliminating the need for live testing until later stages of development.

5 MAJOR UNRESOLVED ISSUES

Creating models that can serve to accomplish multiple objectives is an ambitious undertaking. Unresolved issues confront computing professionals and the simulation community in particular. We present here the issues considered most challenging in realizing the goal of model generalization.

5.1 Granularity

Probably the most prominent issue is that of widely variant timing and granularity that appears within the same model or within interconnected models. Grain size, as defined by Choi and Chung (1995, p. 642), is "the amount of computations between communication points." The issue at hand is "how does one construct user-modifiable models that would support wide variations in granularity." We postulate that this question is not simple to answer in most if not all application domains.

Consider, for example, a model designed to support shipboard combat simulation. Ships move slowly when you compare a naval vessel to an aircraft. In the interest of expediency and efficiency, it would likely be necessary to build into the model some sort of time compression. If it were deemed appropriate to reuse this model in an aircraft combat situation, unforeseen consequences could emerge because of the drastic differences in granularity between two simulation situations and the impact of movement representation for surface ships and aircraft.

Granularity and its impact on modeling and representational requirements is addressed by Nance (1999), Pham and Bagrodia (1998), and Choi and Chung (1995).

5.2 Distribution of State Information

Another issue is presented by Tacic and Fujimoto, (1998) who approach the problem of the distribution of state information in a system. This problem is also presented within the restricted domain of military Command, Control, Communication, Computers, and Information (C^4I) simulations by Goldberg and Dworkin (1998, p. 2) "… most existing models, … having been built independently, have dissimilar model architectures and data structures; dissimilar languages and operating systems; and even dissimilar algorithms." This dissimilarity compounds the interoperability issues, thereby making state information distribution more problematic.

Further complications arise when a model becomes a federate in a distributed simulation. The necessity for maintaining a "system clock," observed by all components can be a difficult problem.

5.3 Universal Interoperability

The prior two issues combine nicely to highlight two facets of the issue of universal interoperability. Nance (1999, p. 1029) describes this issue in the discussion on the "Expanding Claims of HLA Suitability." Universal interoperability is not necessarily a desirable goal, regardless of its technical feasibility. Limited interoperability (especially among similar classes of simulations) seems to be a much more reasonable and attainable functionality.

5.4 Development Objectives

The next issue is that of differences in the importance of model development objectives. Much of the literature in the Parallel Discrete Event Simulation sub-community appears to have a narrow focus on the efficiency of a model, seemingly disregarding other important issues such as maintanability, portability, or extensibility (Page and Nance 1994).

Mertens (1993) describes the Corps Battle Simulator (CBS), a discrete-event simulation used by the military. At the original design time in the early 1980s, the main focus was on performance, but those objectives shifted significantly in the ensuing 10 years to stress interoperability as well. She also explains that portability was not an objective in the initial design stages, thus leading to complications in 1993 when the simulator is tied to a particular hardware/software platform.

5.5 Temporal Causality

The overriding objective of the majority of simulation models is to assist in the determination of a course of action based on the experimental results. Simply stated; models help make decisions. Temporal causality issues allow for the possibility of incorrect experimental results, thus opening the opportunity that the basis for a decision may be erroneous.

Temporal causality is an issue that affects distributed models, primarily with the objectives of Analysis and Acquisition or Acceptance and to a lesser extent Education and Training as well.

We downplay the effect of temporal causality issues in the Education and Training arena because the decision being made is generally based on the reaction of the subject to certain stimuli. If the stimuli are not those that the modeler expects, the subject can possibly still be evaluated based on the stimuli that are presented. The main impact of temporal causality in Education and Training is in model interoperability, an issue that the Time Management aspect of HLA attempts to address (Fujimoto and Weatherly 1996).

On the other hand, making an acquisition or analysis decision based on faulty simulation results can be very costly in monetary value and could possibly result in more far-reaching consequences, even the loss of human life.

5.6 Model Fidelity

Representational fidelity requirements for model components can vary, especially in distributed simulations, where more exacting requirements apply in one area but not in another. Varying fidelity is particularly relevant in training simulations. If the model does not demonstrate sufficient fidelity, the participant may not react to the exercise with the expected reality. This may affect the degree of success that the simulation produces in the improvement of skills.

The problem lies in the prohibitive cost in obtaining a suitably high degree of model fidelity. Because of the nature of most training simulations to attempt to immerse the trainee(s) in a realistic environment, expensive hardware components are oftentimes necessary. Most organizations are being required to operate with increasingly scarce resources, resulting in a tradeoff of cost effectiveness versus model fidelity.

Conversely, we also recognize that most models for Analysis or Acquisition and Acceptance should not be created with an exacting degree of fidelity. If a model is created that is extreme in it's fidelity then the other properties of the model such as maintainability and portability suffer. At the same time, the cost of the model is much higher than is necessary.

5.7 Standard Measures

Noticeably absent in the education and training class of simulations is a standard for the Measure of Effectiveness (MOE) or Measure of Performance (MOP). While there are individual goals and measures for different models, the determination of success or failure of a given exercise has historically tended to fail to include quantitative measures. The result is that most analyses of these exercises are subjective in nature, thus making it nearly impossible to compare the effectiveness of one simulation to that of another.

6 SUMMARY

This work is intended to raise the issue of all-purpose simulations by exploring the similarities and differences among simulation models and the methods used to achieve their objectives. Our attempt with this discussion is to:

(1) emphasize the importance of the title question for many in the simulation community,
(2) heighten sensitivity to the need for investigating alternative methods or paradigms and the ensuing consequences, and
(3) contemplate the intermediate- and long-term implications of accepting either an affirmative or negative answer to our original question.

Our effort to gain insights into fundamental differences in simulation studies based on objectives promotes only tentative conclusions. If generalization is achievable, with current technology the “cost” or “sacrifice” appears prohibitive. Perhaps we should view generalization as a higher dimension of reuse. And, just as with reuse, the challenge takes the forms of answers to questions of "When?" and "At what level of granularity?" Admittedly, the elimination of one question by replacing it with two is not a satisfactory resolution.

As an alternative consideration, is it possible that unchallenged assumptions can become the limiting factor in developing a solution that permits the development of more reusable simulations without excessive cost? That a radical change in perspective might provide the desired outcome is an evocative question.

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