VSI - MODELS AND SIMULATIONS

HISTORIC NOTES

The principals of VSI have been building models and simulations for over forty years. VSI's former parent company, PSI, has been in the modeling and simulation business since its inception in 1974. The company has teamed with various clients on many projects in both the Government and Commercial sectors, providing high quality modeling and simulation solutions for a wide range of complex system needs. Solutions have spanned detailed communication protocols; tools for network design, analysis, and management; information assurance and information warfare; and integrated air defense systems. These are a sampling of the types of M&S application areas of expertise. This environment created and evolved a cutting edge simulation tool, the General Simulation System (GSS), with run-time graphics that allows dynamic, real-time interactions and modifications of models as well as scenarios *while they are running*.

VSI has developed a modeling and simulation environment to build operational planning tools as well as facilitate experimentation, design, and analysis using appropriate effectiveness metrics. These tools are aimed at meeting the challenge to design and build complex real time planning and control systems. Using VSI's General Simulation System (GSS), simulations can be run multiple times automatically for parametric or sensitivity analysis, or automatically using the GSS optimization facility.

BUILDING MODELS AND SIMULATIONS

Simulations are generally used to determine the probability that a particular outcome - or Measures Of Merit (MOM) - will occur in the future. This requires running a simulation multiple times to generate distributions based upon selected parameter variations. As indicated in Figure 1 below, the *models* contained in a simulation determine the accuracy of the MOM.

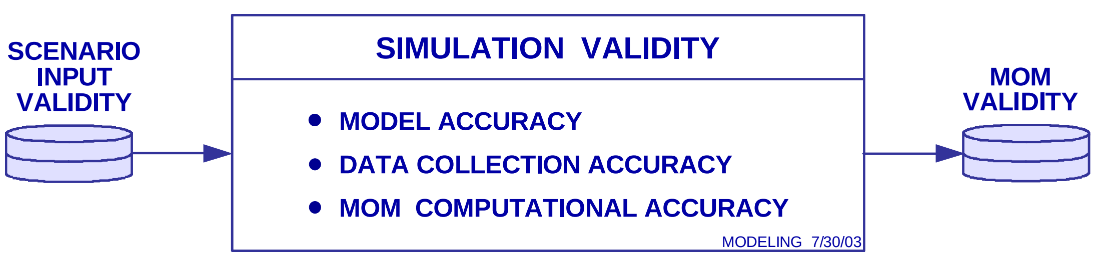

Figure 1. Determining Model Validity

Models are built to represent entities that are incorporated into a simulation. Models must contain sufficient detail so that, when a simulation is run, the measures of performance or effectiveness produced are sufficiently accurate to meet validity requirements on the results, or sufficiently accurate predictions.

ACHIEVING HIGH PRODUCTIVITY

At VSI, we are concerned with the time and cost of building, validating, and running very large scale simulations. Unfortunately, of the vast numbers of people involved in the field of simulation, very few have been through the life-cycle of enough simulations to understand what it takes to achieve sufficient productivity to have happy outcomes. Many simulation efforts have been terminated based upon one of the following show stoppers It (the simulation):

- Took much too long to run;
- did not run reliably;
- had too much variation in output with small changes in input;
- did not get validated;
- did not get completed within time and cost constraints;
- could not get agreement on the design.

To avoid the many pitfalls associated with an unsuccessful simulation effort, VSI has concentrated on achieving high productivity by providing a CAD environment in which to design, build, and test very large scale simulations. Productivity of simulations depends upon model *reusability* and *speed*. Both topics are covered below.

REUSABLE MODEL PROPERTIES

The ease with which models can be built, validated, and shared among organizations is the key to minimizing the time and cost to obtain valid results from simulations. Size, complexity, and number of instances of a particular model operating in a simulation dictate that such models must be easily isolated and understood in order to be reused by other than the original modeler. The concepts presented here provide an approach to building models that can be easily reused in very large scale simulations.

There are three critical properties of models that relate to meeting these goals. These are described below.

Range of Model Validity

This determines the range of analysis applications over which a model of a particular entity can be used to obtain valid results. Clearly, the model that provides more accurate responses, over wider ranges of inputs, also provides a wider range of validity. The wider the range of model validity, the wider the range of reusability.

Models that have wider ranges of accuracy (validity), generally have more detail, and are more complex. Very simple models are attractive, but usually have more narrow ranges of validity. Clearly, there are trade-offs between model complexity and range of validity.

From a technical standpoint, if a model does not contain enough detail to produce sufficiently accurate results, it might be deemed worthless. If it is more accurate than necessary, one is assured of the validity of the results. There is no doubt that, when using simulation to support difficult analyses, people like to have margins of safety with respect to validity, a far better situation. In terms of economics, the more detail required to widen the validity range, the more investment required to build the model. Hence, the wider the range of validity, the more valuable the model.

Model Understandability

This property determines the ability of an analyst or modeler, other than the original author, to understand the model to the extent that it is easily validated and reused. From an economic standpoint, models that are more easily understood are more valuable because they are more easily validated, modified, and reused.

Model Independence

Model independence can be defined in many ways. The context of concern here is the ease with which we can replace one model with another. Specifically, we are concerned with the economics of achieving this, assuming that the resulting simulation remains valid.

Large scale simulations generally contain a large number of interconnected models. This includes many different types of models, as well as many instances of a given type. The property of model independence determines the ease with which one can pull a model or submodel out of a set of interconnected models, and replace it with another model. Model independence is related directly to the amount of interconnectivity one model has with the other models in a simulation.

Modeling along physical equipment module lines is the opposite to abstraction. So it is not surprising that, when comparing approaches, abstraction leads to lack of independence.

In an engineering development, the designer decides where to draw boundaries around the primitive devices that make up components, and the sets of components that make up higher level modules. The lines are usually drawn to accommodate the economics of maintenance as well as fabrication. In GSS, the modeler decides what processes and resources are within a model's boundaries to support validity and reusability. As we will see, independence of a GSS model is then defined by the interconnection of these resources and processes.

The three properties defined above represent productivity multipliers on scarce modeling manpower. Models built with these properties can provide:

- Leverage to tackle simulation problems that are otherwise unaffordable due to the inability to control model complexity.
- Ability to share the burden of investments in complex models across multiple organizations.

DEVELOPING LARGE SCALE SIMULATIONS

Figure 2 provides a more in-depth view of what it takes to achieve high productivity when building and running large scale simulations. The individual issues are addressed below.

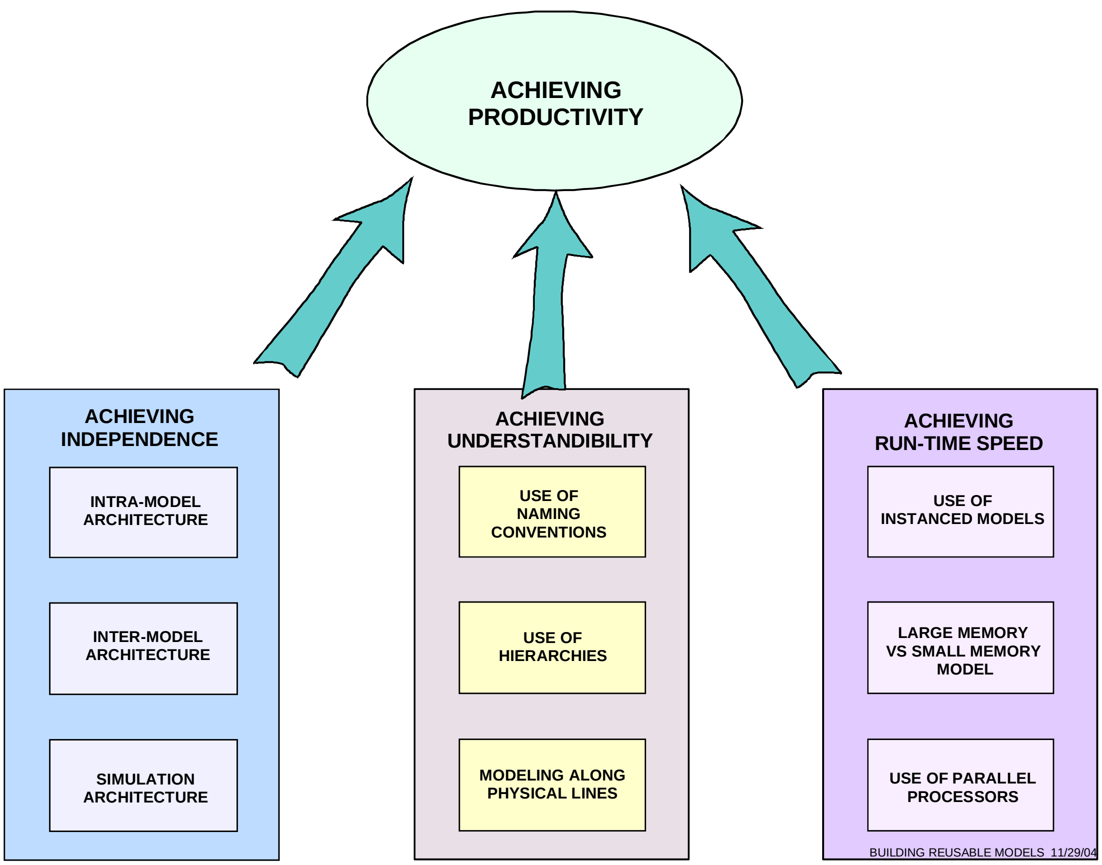

Figure 2. Achieving Productivity

Achieving Independence

Simulation Architecture - The overall simulation architecture must be designed to allow easy reuse of existing models or new models to be built. This must also serve to make the architecture easy to understand.

Inter-Model Architecture - How models share resources, files, utility and library modules is critical to achieving good inter-model architecture at all levels of models.

Intra-Model Architecture - The decomposition of models into submodels, resources and processes is critical to reuse and understandability.

Achieving Understandability

Modeling Along Physical Lines - Following the architecture of physical systems is key to ensuring understandability and independence of models. This is addressed further below.

Use Of Hierarchies - Hierarchical organizations are used to organize large complex structures to improve understandability and independence.

Use Of Naming Conventions - Using names - everywhere - that relate directly to the physical systems being modeled are critical to understandability.

Achieving Run-Time Speed

Use Of Parallel Processors - The only way to get order-of-magnitude increases in speed is through the use of parallel processing.

Large Versus Small Memory Model - Saving memory is no longer a constraint when designing software. Always trade memory for improved speed.

Use of Instanced Models - Use of the GSS instanced model facility provides automatic features when using a parallel processor environment.

THE GSS PARADIGMS THAT SUPPORT INCREASED PRODUCTIVITY

The critical paradigm required to support increased productivity is the separation of data from instructions. This paradigm was devised as the underlying solution to allocation of processors to processes in a single-OS parallel processing environment. By tracking what processes share what resources, the information required to determine if two processes are independent is available. The second paradigm, separation of architecture from language, is derived from the first. Together these two paradigms lead to properties in the lower boxes in each drawing that support dramatic increases in productivity.

Avoiding the Traps of Abstract Modeling

In the early days of computers, most modeling was done using mathematical representations. This took on various forms, e.g., nonlinear differential equations, partial differential equations, discrete time equations, linear system models, special forms of equations, queing models, etc. This general approach we will call *mathematical modeling*.

Based on research in modeling electrical networks, it is clear that one can permute forms of mathematical equations that become very difficult, if not impossible, to solve. Many times, terms that cause difficulties in such equations have no relation to the physical system being modeled, and need not be considered. Modelers who do not *recognize* these facts can get trapped into thinking that such equations must be solved. This is because high degrees of abstraction can cause difficulties in distinguishing extraneous mathematics from the important parts of a model. This trap is best avoided by using models that closely parallel the real physical system.

Electrical network theory, particularly as it has evolved to support Computer-Aided Design (CAD) of electronic circuits, is an excellent example of a more direct approach to modeling physical entities. This approach allows one to build models that directly represent the behavior of physical entities, at extremely elementary levels. Models of the detailed physical elements have been developed so that they can be interconnected graphically. These models contain sufficient information to automatically recognize these interconnections and produce behavior of the elements that corresponds to laboratory data. Since each of the elements behaves as it would when connected, the whole model behaves as the total system would, accounting for nonlinear and nonstationary effects. This is because the most elementary models closely represent the physical phenomena. We call this *modeling along physical lines*.

Modeling Along Physical Lines

The most significant factor affecting ease of understanding and validating models is the ability to directly relate submodels to the physical elements of a system - the CAD approach. GSS was conceived to support this concept. Simulation history is filled with the anguish of trying to modify simulations where there is little relation between the software structure and the physical elements. When one tries to understand how a particular physical phenomenon is modeled, it is usually difficult to pick out the parts of software routines that represent the physical elements, and how they come together to form a picture of the overall model.

Modeling along physical lines provides a number of benefits in terms of understanding, reuse, and sharing of models. Using GSS, this approach implies that one can identify the physical entity being modeled directly, as either an elementary or hierarchical model. It also implies that the model follows the operation of the physical entity, in terms of its operation from an input-output standpoint. This is opposed to an abstract approach, where a number of physical entities are modeled mathematically. Figure 3 shows a comparison of these approaches. The underlying difference is that the direct approach of modeling along physical lines may invoke more detail, and thus more memory and processing resources. However, experience has shown that it is difficult for one person to understand, and therefore reuse, another's abstract model.

GSS TECHNOLOGY	ABSTRACT TECHNOLOGIES
MODELS ARE EASY TO: - DERIVE - RIGHT FROM THE SPECS - BUILD - UNDERSTAND - VISUALIZE GRAPHICALLY - SUPPORT - REUSE	MODELS ARE DIFFICULT TO: - DERIVE - UNDERSTAND - SUPPORT - REUSE
ABSTRACTIONS ARE HARDLY USED - REQUIRES MORE MEMORY - SPEED INCREASES DIRECTLY WITH NUMBER OF PROCESSORS	ABSTRACTIONS ARE USED WHERE POSSIBLE - MEMORY IS SAVED - SPEED MAY BE INCREASED ON SEQUENTIAL MACHINES
MODELS ARE INDEPENDENT - THEY ARE NATURALLY PARTITIONED - GRAPHIC DRAWINGS ARE PRECISE - INSTANCES CAN RUN IN PARALLEL	MODELS LACK INDEPENDENCE - LITTLE RELATIONSHIP WITH PHYSICAL WORLD - DRAWINGS ARE ABSTRACT - INSTANCES CANNOT BE SEPARATED
PARALLEL PROCESSOR COMPATIBLE - DESIGNS ARE DIRECTLY COMPATIBLE - INDEPENDENT OF PROCESSOR COUNT - NO SPECIAL CONSIDERATIONS REQUIRED - NO SPECIAL PROGRAMMING REQUIRED	PARALLEL PROCESSOR INCOMPATIBLE - DESIGNS ARE NOT COMPATIBLE - GENERALLY GEARED TO PROCESSOR COUNT - REQUIRES VERY SPECIAL PROGRAMMING TECHNIQUES
HIGH TECHNOLOGY INVESTMENT (GRAPHICS / PARALLEL PROCESSORS)	HIGH PEOPLE TIME INVESTMENT (EVEN ON SEQUENTIAL MACHINES) MODELING 11/30/04

Figure 3. Modeling along physical lines, versus a high degree of abstraction.

Models that are built using GSS can easily achieve these goals provided certain standards and procedures are followed. These models then become valuable corporate assets. Concepts related to the structure of models that are easily built, validated, and reused by many organizations are described in the book **Building Reusable Models**, written by the staff at VSI. Copies can be purchased directly from VSI.

Listed below is a sampling of models and simulations provided to clients over the past twenty years. As simulations get large, or when simulations are required to play with other simulations, then users can use the GSS combined and distributed simulation environment to run multiple simulations over a network of distributed platforms, or run very large simulations effectively in a single OS parallel processor environment.

COMBINED SIMULATIONS

As requirements for simulations grow, and multiple equipments and systems must be represented to provide more realistic overall assessments of complex scenarios, it becomes necessary to bring models of many systems together into a single simulation. GSS has prevailed as the ideal framework for these large scale simulations, with models at varying resolutions and large numbers of moving platforms to insure validity of results.

DISTRIBUTED SIMULATIONS

As the need for combined simulations grow, the interaction of multiple simulations running together becomes a desired solution approach. This allows the area experts to focus on the problem they are trained to solve, as long as the inputs from sources that feed their environment are included. Most often, the interaction between these different systems affects the outcome of one or both, and must be accounted for as the scenario unfolds. Data coherency and time synchronization become the problems to solve, and these are automatically solved with GSS.

SIMULATIONS & MODELS

Below is are categories of models and simulations that have been built over the years. Most of these are available to be used for future projects.

- Digital and Analog Electronic Circuits
- Digital and Analog Radio Components
- Moving Platforms/Vehicles
- Sensors
- Communication Systems
- Control Systems
- Wireless, Accoustic, and Geographic Environments
- Personnel Decision Processes
- Business Markets
- Financial Markets
- Transportation Markets

VSI is known for its *General Simulation System (GSS)*, used internationally on a wide variety of simulation projects. Many models are on the shelf, representing entities that can be incorporated into various simulations. The *Run-Time Graphics (RTG)* system provides modelers with a development environment that makes it easy to build dynamic interactive graphics. For more information about our simulation technology, click on the *GSS* button after clicking on

Using GSS and the existing shelf of models built for various organizations, large scale simulations that used to take years to build - just 10 years ago - can be put together in weeks today at a small fraction of the cost.