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SIMULATION STANDARDS: CURRENT STATUS, NEEDS, AND FUTURE DIRECTIONS

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ABSTRACT

How could the manufacturing modeling and simulation process be improved? Today simulation analysts typically code their models from scratch and build custom data translators to import required data. Manufacturing simulations often are built as single monolithic software systems. The development of neutral, vendor-independent data formats for storing simulation models and transferring data could greatly improve the accessibility of simulation technology to industry. Simulation standards for these models and data could help to accelerate the modeling process and reduce modeling costs. How can we determine what simulation standards need to be developed? This panel will discuss simulation standards needs from the perspective of users, vendors, academia, and government.

1 INTRODUCTION

Manufacturing systems, processes, and data are growing ever more complex. Product design, manufacturing engineering, and production management decisions often involve the consideration of many interdependent variables, probably too many for the human mind to cope with at one time. These decisions often have a long-term impact on the success or failure of the manufacturing organization. It is extremely risky to make these major decisions based on "gut instinct" alone. Simulation provides a capability to rapidly conduct experiments to predict and evaluate the results of alternative manufacturing decisions. It has often been said that you do not really understand your industrial processes and systems until you try to simulate them. Industry technology leaders in many sectors, e.g., aerospace and automotive manufacturers, are making greater and greater commitment to the use of manufacturing simulation in the various stages of their manufacturing processes (Schrage 2000).

The development of simulation technology and supporting interface standards has been identified repeatedly by industry as a top research priority that promises high payback. One study stated that "Modeling and simulation (M&S) are emerging as key technologies to support manufacturing in the 21st century, and no other technology offers more than a fraction of the potential that M&S does for improving products, perfecting processes, reducing design-to-manufacturing cycle time, and reducing product realization costs." (IMTR 1998).

The National Research Council (NRC) has repeatedly identified simulation and modeling as a high priority research area. In a 1995 study, the NRC stated: "Ultimately the modeling and simulation capabilities resulting from the research outlined here should be able to support configuring and constructing a real factory for high-level performance (on multiple dimensions), as well as planning how best to operate it once it has been constructed. A concrete demonstration of these capabilities would be the creation of a platform capable of comparing the results of real factory operations with the results of simulated factory operations using information technology applications such as those discussed in this report. For modeling and simulation to serve manufacturing needs, two broad areas of research stand out for special attention: the development of information technology to handle simulation models in a useful and timely manner, and the capture of manufacturing knowledge that must be reflected in models." (NRC 1995)

The NRC also identified simulation and modeling as one of two breakthrough-technologies that will accelerate progress in addressing the grand challenges facing manufacturing in 2020. The study goes on to recommend advancement of "the state of the art by establishing standards for the verification, validation, and accreditation of modeling tools and models (including geometric models, behavioral models, process models, and cost and performance models). …Fulfillment of the recommendation would provide fundamental building blocks for the dynamic models and 'real-time' simulations of 2020." The study recommends research and development in "standards for software compatibility or robust software that does not need standards, … methods to make data accessible to everyone (protocols, security, format, interoperability), … interactive, 3-D, simulation-based visualizations of complex structures integrating behavioral, organizational, and people issues with other analyses, … methods to merge historical data with simulation systems, … simulation of alternative business processes." (NRC 1998).

In 1999, the National Research Council completed another study that also identified manufacturing simulation as a priority research area. The report, titled "Defense Manufacturing in 2010 and Beyond: Meeting the Changing Needs of National Defense" recommended that research and development be augmented in four priority areas, one of which is "modeling and simulation-based design tools" . In a discussion on simulation and modeling, the report goes on to state that "Techniques such as variation simulation analysis (VSA) and factory floor layout simulation can improve product performance. Assembly modeling can be used to complement simulations to determine if changing the order of steps in the assembly of a complex product can lead to labor savings and reduce variation... Combining three-dimensional product modeling with simulation techniques can help determine the cost of alternative manufacturing processes." (NRC 1999)

In spite of strong recommendations from committees of experts, little headway has been made on the development of new standards for the simulation industry. The panel that we have assembled is comprised of a diverse set of experts from the manufacturing, simulation software vendor, academic, government, and standards communities. The panel is charged with shedding light on the following issues and questions:

- Do the panelists agree with the conclusions and recommendations of the NRC and other studies regarding simulation and standards?

If not, why not? If so, then:

- What simulation standards need to be developed?
- How should we set priorities?
- What factors are inhibiting the development and implementation of simulation standards?
- What can be done to move the standards process forward?

The next sections present the initial thoughts and observations of the panelists on these topics and other related issues.

2 ROBERTO LU, THE BOEING COMPANY

Today's dynamic business environment demands dynamic actions. Dynamic actions are often taken using incomplete information. Competencies in modeling ever-changing dynamic systems based on partial information may directly influence the soundness of such decision making processes. Simulation modeling has been known for its value in raising confidence levels, leading to solid business decisions.

Operational simulation modeling was recently defined as number one among the top ten technologies at Boeing Commercial Airplanes. These ten technologies were categorized in three segments. Simulation was categorized under "Break Through" technology, which was placed on top of the "Enabling" and the "Core" technology segments.

Boeing Commercial Airplane's Manufacturing Research and Development group has been conducting simulation projects in the areas of factory layout optimization, resource forecasting, rate change, and production consolidations, new product processes. Simulation modeling exercises have been providing a quick and low-cost method to assess and minimize risks of change, streamline manufacturing processes, validating production capabilities, and visualize new systems.

The need for simulation modeling is obvious; the benefit of using results from modeling and simulation has been proven. Conducting faster simulation iteration is not only highly desirable, but also necessary to maximize the impact of the modeling. The approaches used for simulation-related data management vary among individual simulation practitioners. While the art of simulation continues to flourish, the continuity and the consistency of the simulation data usage may have not kept pace.

Why do we even need any standard associated with the already proven simulation modeling technologies, knowing that there are many proven, off-the-shelf software packages on the open market? Simply put, it is to enable the effectiveness and efficiency of practicing simulation modeling by means of increasing data reusability and consistency.

2.1 Industry Perspective

In an enterprise such as The Boeing Company, massive amounts of manufacturing and business-related data pass through computer clients and servers among various types and numbers of databases around the clock. A consistent incoming data format has been a serious challenge when there is a demand for a simulation modeling project. Data formats used to pass the results of simulation modeling exercises also vary.

The NIST–proposed, extensible markup language based (XML) simulation standard can potentially provide this needed element in simulation modeling. One may wonder: Who might use this proposed standard? How will it be used?

2.2 Use of Standards

In a typical engineering exercise, a part designed by a designer is later integrated into a product, which becomes a portion of an assembly. Integration of several separate assemblies is needed to construct major assemblies and structures for airplanes. Characteristics of parts, products, assemblies, and their respective resource requirements and processes can be organized in an XML-based document.

XML is the most logical choice of protocol since it is platform independent and widely accepted by almost all software packages. Few elements will need to be established to enable the implementation of an XML-based simulation standard in a corporation. The essential elements include the following:

- An XML document. This document lists all elements and attributes of the targeted manufacturing and business system.
- A matching XML schema that defines the types of elements and attributes in the XML document. The schema must validate the XML document and enlist necessary global and local groups.
- A set of application-specific XML style sheets for the simulation software. These style-sheets are meant to generate usable script files that can be deployed while users run simulation software.

2.3 User Perspective

Potential users of the simulation standards may consist of experienced simulation modeling practitioners, simulation information system architects, and average simulation users who do not possess in-depth discrete event simulation modeling knowledge. Experienced simulation modeling practitioners might wish to see the most complete coverage by the simulation standard possible. System architects might be more interested in the data protocol efficiency when passing contents of the simulation standard among various information domains and across networks. An average simulation modeling user might wish for a user friendly interface that provides a data input portal and a results feedback presentation panel as the minimum.

The NIST-proposed, XML-based, simulation standard provided broad and deep coverage of modeling-related entities. There is almost no limit to how far this type of standard can reach. This simulation standard proposed by NIST has successfully outlined a useful framework for experienced simulation practitioners to deploy their models. A case study in this regard has been addressed jointly by Qiao and McLean of NIST and Lu of The Boeing Company.

The efficiency and effectiveness of passing simulation modeling-related data across an entire company network may make or break the overall benefit perspective of this huge endeavor. This is the area where influences of a solid matching XML schema and application-specific XML style sheets can be observed. Innovative data protocol and hierarchy, based on the XML standard document, may need to be derived to gain data transaction speed across computing networks.

The data input portal should be a web-based application, using popular web browsers such as Internet Explorer and Netscape. Users might not possess knowledge of the data architecture or coding used in simulation modeling packages. Users would most likely have manufacturing or business-system process knowledge. Interactive questionnaires could help users to define model input criteria. Animated simulation result presentations with charts and graphs on the browser would help users to both validate input data, and use the simulation results for more accurate decision making, leading to better system performance. This form of looped, usable results enables additional dynamic system performance improvements.

Data formats for the whole system can be XML based. Automation among the XML document, its matching schema, software-specific style sheets, and Document Object Model (DOM) / Simple Object Access Protocol (SOAP) parser integration may be somewhat dependent on the type of the discrete event software used by the vendor. However, methods in doing the above can be executed in a consistent fashion – based on the NIST-proposed XML standard.

2.4 Future Possibilities and Potential Challenges

The rosy picture of this initiative painted in the previous section will only become reality when the following potential obstacles have been addressed and overcome:

- Computing system compatibility
- System security
- Industry user participation
- Software vendor participation
- Wide acceptance of the XML-based simulation standard
- Successful case study of all of the above.

It has been a great pleasure and honor to be part of this joint effort. The author deeply believes that ultimately simulation technology will be elevated to a level formerly thought to be unreachable.

3 CHARLEY HARRELL, PROMODEL SOLUTIONS AND BRIGHAM YOUNG UNIVERSITY

Any time software standards are being discussed or proposed, many different parties should be involved to guide the process if it is to succeed. Simulation standards are no different. Some of the primary stakeholders in simulation standards include users, vendors, relevant standards groups and educational institutions. This is a discussion of some of the key issues to consider from both vendor and academic perspectives. The primary focus will be on the vendor perspective with a brief discussion at the end from the point of view of an educator.

3.1 Vendor Perspective

In addressing the issue of simulation standards from a vendor perspective, there is a certain wariness as well as a wishful hope that is felt—wariness that it is another bandwagon headed down a bumpy, winding road to a dead end, and wishful hope that there might be an opportunity to expand markets and increase sales. Questions that are immediately raised by vendors when the topic of standards is raised are:

- What is the standard?
- What is it going to cost to support it?
- What is the business case for supporting it?

3.1.1 Defining the Standard

In defining the standard, the first question a vendor wants to know is what is being standardized? Are we talking about standardizing the user interface (GUI, etc.), modeling methodology (object-oriented, network diagramming, etc.), model file (SDX, XML, etc.), output reports (Excel, etc.), interoperability (HLA, etc.), simulation components, etc. What most standards-related discussions have focused on recently are model file standards, which require that a file structure and format be agreed upon that defines any model within a particular domain. The idea is to develop a neutral file format (NFF) much as has been done in the CAD industry with file standards such as DXF, IGES and STEP.

Much progress has been made in developing a NFF using the Simulation Data Exchange (SDX) specification. The SDX file format was originally developed as a common data format for generating discrete-event simulation (DES) models and 3D model animations directly from CAD drawings. In SDX, file attributes or properties of object or information categories are defined between [Begin] and [End] tags. It is a text file making it easy to read and understand. For more detailed information about the SDX file format, see (Moorthy 1999) and (Sly and Moorthy 2001).

The SDX format was a good first cut at an NFF for simulation data, but it also has limitations and compatibility problems. A more promising approach seems to be XML which is already beginning to show some success.

3.1.2 Assessing Development Costs

Development costs are not too difficult to assess once a standard is clearly defined. More difficult is determining who will do it, what other priorities will need to be delayed and what are the on-going maintenance costs? It is not uncommon for software companies to engage in development efforts in which the specification is not clearly defined resulting in wasted time and money. Vendors are keenly aware of the dangers of committing resources to a lost cause.

3.1.3 Developing the Business Case

There is a significant amount of justification required before most software companies are willing to invest in a new development project. The questions that a vendor needs to answer in order to develop a business case for supporting a simulation standard include the following:

- How will it impact sales in the short and long term?
- What is the economic risk if we don't support it?
- How will it impact our competitive advantage?

Impact on sales is the most important consideration since it is part of the cost/benefits analysis a company will conduct to justify the commitment. Increased sales will be a function of increased market share as well as an increased market. An increased market share will result if companies are willing to buy your product because it allows data to be shared with other applications and permits them to import models built using other products. The market itself expands as companies see that simulation can be easily integrated with other applications and share common data. Timing is often a crucial factor as well. By committing too early you may get early adopters but incur a much greater expense. By waiting until the market is ready there is less cost and much less risk, but you may lose industry leadership.

3.2 Academic Perspective

Academia's interest in simulation standards is in several different areas. First, consider the impact on teaching modeling languages. By learning the NFF for model definitions, students can learn much about simulation and, since the language is not product specific, the knowledge will be useful to them later regardless of the tool they use in industry. There are also new opportunities for research and developing models for training and education that are product independent.

4 PHILOMENA M. ZIMMERMAN, DEFENSE MODELING AND SIMULATION OFFICE

Interoperability, reuse, and responsiveness to the Department of Defense (DoD) modeling and simulation (M&S) needs are the holy grails for the Defense Modeling and Simulation Office (DMSO), and the broader M&S community. Advances in technology are moving the M&S community along on their quest. Technology alone will not ensure that the holy grails are found. It will also require formalization and stabilization of the technology mechanisms that helped the M&S community realize its quest.

The formalization of the technology can be achieved through the active creation and use of standards. Standards should be considered an enabling technology. Standards, by their very nature, are stable items; and stability is required to achieve international interoperability, information superiority, and rapid technology insertion. In part, this stability is achieved because standards from formal standards organizations, such as Simulation Interoperability Standards Organization (SISO), Institute of Electrical and Electronics Engineers (IEEE), and International Organization for Standards (ISO), are difficult to create and change. They require a significant investment of all resources, especially time. This is by design.

A large amount of time is required to allow for consensus opinions to be reached. Consensus does not mean unanimity – it means that a majority of the members involved in the creation of the standards do not disagree with the statements in the standards. The processes and time to create standards vary among standards organizations. However, regardless of whether the standards are created by consortium, or in an open, volunteer process, they all have the need for equal representation of opinions from their members as a basis for their stability. Voting rules on acceptance vary as well, but again, equal representation of opinions is critical to the success of the standards. Obviously, the standards must also be maintained and updated as the technologies mature.

Regardless of how the standards are created, or how long it takes to create them, it is important to remember that standards are constructed "on paper." The medium of capture is not nearly as important as the ideas that the medium contains. Nonetheless, the ideas in the medium, unless brought to fruition through implementation and usage, are just ideas. Part of the implementation requires some type of recognition and evangelization of the ideas. Within the DoD, the Services play an important role in that part of the standards process. Each Service has, or is in the process of creating, a standards body, which evaluates standards nominated by their constituents for application within their Service. Typically, the evaluation consists of a series of steps involving review by subject matter experts, users, interested parties, and management.

There are other venues that can be used by all those who either use, nominate, or create standards – the Defense Standardization Program (DSP), established by "Defense Cataloging and Standardization Act, Title 10, U.S. Code Chapter 145, Sections 2451-2457", approved July, 1952. Together with MI Circular A-119, "Federal Participation in the Development and Use of Voluntary Standards, they establish a policy of reliance on non-governmental standards whenever feasible and practical, and promote participation in their development. This practice helps ensure that the DoD is not reliant on single source solutions, and provides visibility into defense-related and non-defense related standards. Further, it promotes the use of new technologies in the commercial marketplace, and reduces the need for the preparation, and maintenance of military-only documents.

The DSP is important for another reason. Through participation in its programs, contributors have access to a wide variety of resources, including an infrastructure of 100+ standards offices in services and agencies listed in standardization directory, online databases that are links to other specification and standards, online alert service for changes to other standards, and program manager guidance. Additionally, the DSP is investigating the online availability of non-government standards for DoD users.

Some additional thoughts - standards are definitely in DMSO's charter. But we will not create standards without DoD Component input....DMSO does not manage simulations. As part of our technology transition, simulation components (technology) are often developed to try out a component - and then we look for a transition target to house, distribute, and manage the technology.

As for composable simulations, I could speak volumes. But every program at DMSO is building "Things" - components, processes, basis, standards - to support composability. We then work with the Services and combatant commands (such as SOCOM, JFCOM, etc) to make sure that they are "institutionalized" within DoD - that means that we look to the Services to build the Service policy and implementation guidance to use/take advantage of what DMSO has developed.

5 SWEE LEONG, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

Simulation technology holds tremendous promise for reducing costs, improving quality, and shortening the time-to-market for manufactured goods. Unfortunately, this technology still remains largely underutilized by industry today. A number of factors currently inhibit the deployment of simulation technology in industry today. The development of new simulation interface standards could help increase the deployment of simulation technology. Interface standards could improve the accessibility of this technology by helping to reduce the expenses associated with acquisition and deployment, minimize model development time and costs, limit the need for data translation, and provide new types of simulation functionality that are not available today.

Currently, no organization is focused solely on the development of manufacturing simulation standards. Often the companies that most need to be involved in the development of these standards can least afford the costs associated with extended involvement in the standards process. Standards processes tend to be multi-year efforts. Often regular meeting attendance involves considerable preparation time, as well as travel costs. A mechanism is needed to involve simulation vendors, users, and researchers in the simulation standards process, while minimizing the financial burden associated with participation in these activities.

The NIST Manufacturing Simulation and Visualization (MS&V) Program established the Simulation Standards Consortium to provide a basis for increasing awareness and involvement in the simulation-standards development process. The objective of the Consortium is to accelerate future manufacturing simulation standards efforts. The Consortium activities will build upon simulation research and standards work initiated under the NIST Systems Integration for Manufacturing Applications Program, the international Intelligent Manufacturing Systems (IMS) MISSION Project, Simulation Data Exchange (SDX), and the Software Engineering Institute's Technology Insertion Development and Evaluation (TIDE) efforts.

The primary goal of the Simulation Standards Consortium is to develop pre-competitive neutral interfaces for manufacturing simulation in the following areas: data transactions, storage and exchange formats, distributed manufacturing simulation environments, simulation case study types, simulation templates and model formats, and reference data sets.

Industry users, software vendors, other government agencies, research institutes, and universities with an interest in simulation standards are encouraged to join the Consortium. There will be an annual progress review meeting to allow participants to provide input, feedback, and adjust direction as appropriate to the project. Participants are encouraged to host meetings at their locations. NIST will serve as the central coordination point for interfacing and communicating with all participants.

A kick-off meeting was hosted on the NIST Campus in Gaithersburg, Maryland in February 2003. Participants included representatives from 19 organizations including from major simulation software vendors, major manufacturers, government and defense agencies, and academia. Many participants made presentations on the needs and requirements of simulation standards efforts.

The Consortium is seeking additional participants. Participants will have the opportunity to influence the direction of the standards-setting effort, establish partnerships with other researchers, access research results from other participants, and get a head start on the application of simulation technology and neutral interfaces. Participants who need funding should seek out other sources from either their own internal resources or other organizations that sponsor research projects, e.g., industrial organizations, Small Business Innovation Research (SBIR) Programs, National Science Foundation, other government research program sponsors, etc.

We plan to channel project results and Consortium outputs through the appropriate national and international standards organizations. The Consortium will engage the vendor community to: (1) obtain direction and feedback, and (2) encourage rapid and widespread commercial adoption and implementation of specifications and standards.

One of the first specifications provided to the Consortium participants for review and comment was an interface specification for machine shop data. In collaboration with the Software Engineering Institute's Technology Insertion Development and Evaluation (TIDE) project, NIST developed a generic machine shop data model as a part of the efforts to support the development of standard data interfaces (Lee, et al. 2003).

The initial goal of the data model will be used to support the integration among a manufacturing execution system (MES), a production scheduling system, and a prototype machine shop simulator that satisfy the needs of a real world machine shop operations. The plant layout data elements from the SDX effort are currently being incorporated into the model.

6 SUMMARY

A number of distinguished committees commissioned by the National Research Council and other organizations have recommended focused research efforts in manufacturing simulation technology and standards. Unfortunately, little progress appears to have been made in these areas in recent years. This panel has brought together experts with a diverse set of perspectives to offer observations on the current state of affairs with respect to simulation standards and make suggestions on ways standards development and implementation activities can be accelerated .

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REFERENCES

Integrated Manufacturing Technology Roadmap (IMTR) Modeling and Simulation Workshop Group and IMTR Roadmapping Project Team. 1998. *IMTR Roadmap for Modeling and Simulation.* Oak Ridge, TN: Integrated Manufacturing Technology Roadmapping Project Office, Oak Ridge Centers for Manufacturing Technology.

Lee, T., C. McLean, and G. Shao. 2003. A Neutral Information Model For Simulating Machine Shop Operations. In *Proceedings of the 2003 Winter Simulation Conference*, ed., S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morrice. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Moorthy, S. 1999. Integrating The CAD Model with Dynamic Simulation: Simulation Data Exchange. In Farrington, P.A., Nembhard, H.B., Sturrock, D.T., & Evans, G.W. (Eds.), *Proceedings of the 1999 Winter Simulation Conference* (pp. 276-280).

National Research Council (NRC), Committee to Study Information Technology and Manufacturing. 1995. *Information Technology for Manufacturing: A Research Agenda*. Washington, DC: National Academy Press.

National Research Council (NRC), Committee on Visionary Manufacturing Challenges. 1998. *Visionary Manufacturing Challenges for 2020,* Washington, DC: National Academy Press.

National Research Council (NRC), Committee on Defense Manufacturing in 2010 and Beyond. 1999. *Defense Manufacturing in 2010 and Beyond: Meeting the Changing Needs of National Defense.* Washington, DC: National Academy Press. (pp.3,52).

Schrage, M. 2000. *Serious Play: How The World's Best Companies Simulate to Innovate.* Boston, MA:Harvard Business School Press.

Sly, D. & Moorthy, S. 2001. Simulation Data Exchange (SDX) Implementation and Use. In Peters, B.A., Smith, J.S., Medeiros, D.J., & Rohrer, M.W. (Eds.), Proceedings of the 2001 Winter Simulation Conference (pp. 1473-1477).

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