The Role of Simulation in Strategic Manufacturing

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Abstract

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. This paper suggests benefits to industry resulting from the widespread, pervasive implementation of manufacturing simulation technology. Potential simulation impact areas are closely intertwined with strategic manufacturing. Yet, 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, and provide new types of simulation functionality that are not available today.

Keywords

Strategic manufacturing; manufacturing simulation; industrial strategies; interface standards

Background

Strategic manufacturing is a hot topic today. Steve Brown, author of Strategic Manufacturing for Competitive Advantage – Transforming Operations From Shop Floor To Strategy, suggests that it is the next step beyond lean manufacturing. Strategic manufacturing, as defined in Brown's text, is *viewing production-operations capabilities as a core competence, having a long term view of the business, being fully aware of all market opportunities, planning strategies to outperform competitors by targeting sectors in which it can compete while deliberately avoiding those in which it cannot, and engaging in horizontal and vertical partnerships.* He goes on to characterize strategic manufacturing in terms of corporate strategy, manufacturing strategy, product innovations, process technology, quality, materials management, and human resources. Manufacturing strategy "decisions will include investment in technology, expanding into new plants and adding capacity, strategic buyer/supplier relationships, the extent of joint ventures with other firms, the extent of vertical integration, and so on." (Brown, 1996)

Benefits of Simulation

The authors of this paper contend that manufacturing simulation should be treated as a key component of strategic manufacturing. What is manufacturing simulation? In The Handbook of Simulation, Jerry Banks defines simulation as:

"…the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history to draw inferences concerning the operational characteristics of the real system that is represented. Simulation is an indispensable problem-solving methodology for the solution of many real-world problems. Simulation is used to describe and analyze the behavior of a system, ask what-if questions about the real system, and aid in the design of real systems. Both existing and conceptual systems can be modeled with simulation." (Banks, 1998)

Manufacturing simulation focuses on modeling the behavior of manufacturing organizations, processes, and systems. Organizations, processes and systems include supply chains, as well as people, machines, tools, and information systems. For example, manufacturing simulation can be used to:

- Model "as-is" and "to-be" manufacturing and support operations from the supply chain level down to the shop floor
- Evaluate the manufacturability of new product designs
- Support the development and validation of process data for new products
- Assist in the engineering of new production systems and processes
- Evaluate their impact on overall business performance
- Evaluate resource allocation and scheduling alternatives
- Analyze layouts and flow of materials within production areas, lines, and workstations
- Perform capacity planning analyses
- Determine production and material handling resource requirements
- Train production and support staff on systems and processes
- Develop metrics to allow the comparison of predicted performance against "best in class" benchmarks to support continuous improvement of manufacturing operations

Other examples of manufacturing simulation applications include: the modeling and verification of discrete and continuous manufacturing processes (e.g., machining, injection molding, sheet metal forming, semiconductor fabrication), offline programming of robots and other machinery, site selection, layout planning, process and system visualization, ergonomic analysis of manual tasks and work area layout, evaluation of scheduling algorithms and dispatching rules, and business process engineering.

Simulation models are built to support decisions regarding investment in new technology, expansion of production capabilities, modeling of supplier relationships, materials management, human resources, and so forth – thus simulation supports many of the strategic manufacturing target areas identified earlier in this paper.

The authors contend that major long-term benefits could result from the widespread and pervasive implementation of manufacturing simulation technology. What do we mean by *widespread and pervasive*? The worldwide implementation of office automation software, such as word processors and spreadsheets, certainly fits this characterization. On the other hand, the engineers that have the greatest need for simulation systems use them far less frequently. The implementation of simulation systems within manufacturing could probably best be characterized as limited and sporadic. Our criteria for widespread use would suggest that most manufacturers would have or develop simulation models of their manufacturing operations. Pervasive would mean that simulation tools are used routinely and employed regularly for a broad set of tasks by product designers, manufacturing managers, manufacturing engineers, industrial engineers, process engineers, production planners, quality engineers, cost estimators, programmers, etc.

But why is simulation so critical to manufacturing strategy? The answer is simple. 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).

Recommendations of Industry Studies

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" (p. 3). In a discussion on simulation and modeling (p. 52), 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)

NIST Manufacturing Simulation and Visualization Program

Standard interfaces could help reduce the costs associated with simulation data exchange and model construction -- and thus could make simulation technology more affordable and accessible to a wide range of potential industrial users. In 1999, the National Institute of Standards and Technology (NIST) established a program in Manufacturing Simulation and Visualization (MS&V). The program is focused on the development of data interfaces and test methods for integrating manufacturing simulation and visualization applications to improve the accessibility and interoperability of this technology for U.S. industry.

The technical approach of the program is to: (1) identify critical manufacturing process and system simulation domains and associated types of simulation software applications, (2) analyze current and future trends for simulation and testing technology, (3) establish specification and testing methods, models, and metrics for validating simulation systems interfaces, (4) identify tools and models to be used in the specification development, prototyping, and testing processes, (5) construct a test bed containing simulation applications, prototype integration, testing tools, and test cases, (6) specify and develop architectures, data models, and interface specifications for integrating simulation applications, component modules, and reference libraries, (7) conduct experimental tests, industry demonstrations, and reviews to substantiate the validation and testing process itself, and (8) promote specifications as candidate standards within the national and international standards community.

The IMS MISSION Project

As a part of the MS&V Program, NIST is participating in and serving as the U.S. Regional Coordinator for an international collaboration in modeling and simulation. The collaboration is the Intelligent Manufacturing Systems (IMS, 2001) MISSION Project. The goal of MISSION is

"*to integrate and utilise new, knowledge-aware technologies of distributed persistent data management, as well as conventional methods and tools, in various enterprise domains, to meet the needs of globally distributed enterprise modelling and simulation. This will make available methodologies and tools to support the definition of appropriate manufacturing strategies and the design of appropriate organizations and business processes. This goal will be achieved by establishing a modelling platform incorporating engineering knowledge and project information which supports space-wise and control-wise design, evaluation and implementation over the complete enterprise life cycle. This will be the foundation stone for an architecture to support engineering co-operation across the value chain of the entire extended enterprise." (MISSION, 2001)*

Partners in MISSION include manufacturers, software vendors, academic and other research institutions, as well as government agencies in the United States, Japan, and Europe. Within the project, NIST is also responsible for the leadership of the Work Package 2 effort. Work Package 2 focuses on system architectures, data modeling, and interface-specification development. The other three technical work packages address: industrial requirements, simulation reference models and template libraries, and test case scenarios. Interface specification activities described in this paper were initiated under the MISSION Project.

One of the major focus areas for Work Package 2 is the development of architectures and interfaces for distributed manufacturing simulation. What is included within the scope of distributed manufacturing simulation?

- Multiple simulation software processes that are independently executing and interacting with each other. Simulation systems may have been developed by different software vendors. Modules may run on different computer systems in geographically dispersed locations.
- Distributed computing environments where other non-simulation manufacturing software applications are running and interacting with one or more simulation systems. Engineering systems may interact with simulation systems through service requests.
- Distributed manufacturing simulation systems that are comprised of multiple functional modules that together form a system, such as model builders, simulation engines, display systems, analysis tools, etc.

Why do we need to build distributed manufacturing simulation systems? Some reasons include: modeling of supply chains across multiple organizations where some information from each organization may be hidden from others, modeling multiple levels of manufacturing systems, providing capabilities that do not exist in a single simulator, hiding proprietary information about the internal workings of a simulation, creating low-cost run-time simulation models, taking advantage of computing power afforded by distributing execution, providing simultaneous access to models for users in different locations, and providing different numbers and types of licenses for different simulation activities (model building, visualization, execution, analysis).

Subsequent sections of this paper address: (1) factors affecting widespread, pervasive use of simulation, (2) a plan for developing solutions and standards to address the problems faced by simulation users today, (3) conclusions, and (4) references and sources of additional information.

Factors Inhibiting the Use of Manufacturing Simulation

Costs of Simulation Technology

One might argue that cost is the primary factor affecting widespread and pervasive use of manufacturing simulation technology. Although there are a number of issues, they could perhaps all be reduced down to a cost factor. This leads one to ask -- *Is simulation technology affordable?* The answer -- *It depends upon the user*. Some factors affecting an individual company's view of simulation affordability may include:

- the company's resources:
  - availability of discretionary funds
  - simulation skills and experience base of current staff or consultants (Rohrer, 1998)
  - existing information systems infrastructure (availability of required computer systems, related software applications, and databases)
- scope and complexity of the target simulation application area
- availability of turnkey or readily-adaptable simulation models and solutions
- availability and format of input data
- cost and risks of implementing manufacturing systems without the use of simulation

Licensing costs for some of the high-end simulation software packages are often viewed as a major factor. Commercial manufacturing simulation software packages range in price from about $500 to over $50,000 a seat. For more information on product availability and licensing costs, see (IIE Solutions, 1999). In fact, these costs are only "the tip of the iceberg." A more complete picture of the cost factors in the deployment of simulation technology includes:

- Computing hardware and peripheral devices
- Initial software licenses, options (plug-ins, translators, analysis tools), and maintenance upgrades
- Salaries of manufacturing domain experts, simulation specialists, consultants, and support staff
- Training classes, learning curves, and maintaining proficiency
- Requirements analysis and data acquisition
- Translation of existing company data
- Systems integration with other related manufacturing software applications and/or databases
- Development, maintenance, and configuration management of simulation models.

It is important to note that these costs must be weighed against the risks of not using simulation technology. There are countless case studies where companies have either realized significant cost savings or avoided major disasters through the effective use of simulation. Undoubtedly, if complex manufacturing systems are involved, simulation is probably the only reliable mechanism for predicting and evaluating the performance of the system under varying loads and operating conditions.

Data Interface Problems

Among the cost factors identified above, the "interoperability problem" is particularly significant. Interoperability includes a number of system integration, data translation, and model development issues. What is the nature of this problem?

1. Interoperability between other manufacturing software applications and simulation is currently extremely limited. By other applications, we mean product design, manufacturing engineering, and production management. The simulation software used to model and predict the behavior of manufacturing systems do not use the same data formats as the systems used to design products, engineer production systems, and manage production operations. Neutral interface specifications that would permit quick and easy integration of commercial off-the-shelf software do not exist. The only qualification that needs to be added is that most simulation systems have a capability for importing some form of two or three dimensional graphics data. Considerable manual intervention often required to make effective use of the graphics data within the simulation.

2. The cost of transferring data between simulation and other manufacturing software applications is often very high. Users must either re-enter data when they use different software applications or pay high costs to system integrators for custom solutions. In some cases, it may not be possible to integrate "closed systems" with simulation. By closed systems, we mean those with undocumented, proprietary data file formats.

3. The simulation model development process is labor-intensive. Vendors and industrial users alike have recognized that the development and maintenance of models of their production systems and resources is very costly. For example, the development of a detailed simulation model of a single machine tool may take an engineer 4 to 6 weeks. Models must now be custom developed for each simulation software package. Each industrial user must build his or her models of manufacturing systems, processes, and resources. This is true even if the models represent commercial off-the-shelf manufacturing equipment. If the industrial user has several different vendors' simulation packages, unique models must typically be reconstructed for each package. The models developed for one simulation system are of little or no use to another. The simulation development process is very much an ad hoc process. Texts provide high level guidelines, but model development is perhaps more of an art than a science.

Other Factors

Although it is impossible to fully describe all of the factors affecting simulation usage in this brief paper, several others are worth noting. It is the authors' contention that the solutions that will be proposed in the next section address not only the factors identified above, but these additional ones as well:

- Building simulation models from "scratch" is a time-consuming process. The pressures of manufacturing deadlines often do not permit adequate time for simulation model development and analysis.
- When a simulation involves a new manufacturing system, process, or technology, good reference models or historical data may not be available to support the development effort (Law, 2000).
- Simulation model developers typically require considerable training and a diverse set of skills to be effective in their job (Rohrer, 1998).
- Simulation models must be verified and validated. Does the model accurately represent the system or the process being modeled (Knepell, 1993; Balci, 1998)?
- Interpretation of the simulation output data might not be a simple, straightforward process. Even after considerable resources are invested in the development of simulation models, it may not be clear what action should be taken based upon the results.

The next section of this paper suggests some solutions to these problems.

Solutions for Making Simulation More Accessible

Identification of Target Areas for Cost Reduction

The previous section of this paper suggested areas where industrial users of simulation technology incur costs. How can these costs be reduced? For purposes of simplification, we will address this question by consolidating the previous discussions into three major target areas for cost reduction.

1. Acquisition, installation, and maintenance of commercial simulation software – This target area refers to the cost of selecting and acquiring a simulation software product, making it operational, training users, and keeping it up-to-date with new maintenance releases. Manufacturers normally pay these costs directly to simulation software vendors. In setting their prices, vendors must recover the costs of development, marketing, maintenance, technical support, and training materials. In the software industry, as compared to manufacturing industries, product development represents a large percentage of the total cost. On the other hand, manufacturing represents a relatively small percentage of the total. Manufacturing costs equate typically to the cost of printing software distribution media and manuals. Total product costs have been reduced in other non-simulation software markets through competition and the amortization of vendor development costs over a larger customer base. It would appear that the most viable solution to addressing this cost factor would be to follow the lead of other software sectors – find ways to increase the total simulation customer base within the manufacturing sector so that more product can be sold at lower cost per unit. How can this be done? Three thoughts come to mind:

- Educate potential customers on the benefits of simulation.
- Reduce the other costs associated with simulation technology (the bulk of the "iceberg").
- Simplify the problem of applying simulation technology to manufacturing problems, i.e., potential manufacturing customers are more likely to buy software if it is easy to use.

2. Development and validation of simulation models – This target area refers to the costs associated with the development of models to solve specific manufacturing problems. The recommended approach to the simulation modeling typically involves the following steps: (1) problem formulation, (2) setting of objectives and overall project plan, (3) model conceptualization, (4) data collection, (5) model translation into computerized format, (6) code verification, (7) model validation, (8) design of experiments to be run, (9) production runs and analysis, (10) documentation and reporting, and (11) implementation. (Banks, 1996).

How can the cost of this lengthy process be reduced? The solution would appear to be to simplify the model development process through modularization and the creation of re-usable simulation-model code and data. The development of neutral, vendor-independent data formats for storing simulation models could greatly improve the accessibility of simulation technology to industry by enabling the sharing and re-use of models. Such neutral, simulation-model formats could be used to develop sharable models by individual companies, simulation vendors, equipment and resource manufacturers, consultants, and service providers. Neutral formats would help enlarge the market for simulation models and make their development a viable business enterprise. Our proposed solution would include the specification of

- Simulation study templates for addressing classes of simulation problems
- Building block modules of manufacturing system components to be used in the templates
- Interfaces for interconnecting simulation component modules together
- Libraries of simulation reference data sets

Standards for each of these elements would reduce costs by allowing solutions to be shared by all software vendors and industrial users.

3. Exchange of data between simulation and other manufacturing software applications – Neutral input and output data formats are needed for sharing data among manufacturing simulation and other manufacturing software applications. Our approach to addressing the simulation data exchange problem would be to

- Identify the other manufacturing software applications that need to share data with simulation
- Determine what standards already exist for these applications
- Identify applicable elements of these standards for simulation, e.g., requirements analysis, scoping statements, information models, interface specifications, test data
- Coordinate or reconcile simulation standards efforts with these other standards activities

The next section formulates these thoughts into a strategy for simulation standardization.

Strategy for Manufacturing Simulation Standards

The development of new simulation standards is one way to help make this technology more accessible to industry. How big is the manufacturing simulation standards problem? It is difficult to say for sure. Hundreds, if not thousands, of commercial simulation software products are currently marketed to support various simulation application areas. Some products are focused on serving narrow niche areas. It is likely that the number and types of simulation applications will continue to grow rapidly in the coming years. Although it is difficult to estimate the size of this market, independent economic studies have estimated the manufacturing simulation and visualization software market in the range of $650 million dollars in the 2001 time frame.

For the most part, simulation applications cannot share data with each other or with other manufacturing software systems. NIST researchers have analyzed the simulation standards problem and identified five potential target areas for future standardization. These areas are briefly discussed below.

1. Distributed manufacturing simulation environments – Standards are needed to provide an infrastructure to enable the interconnection of different manufacturing simulation systems into distributed environments. This infrastructure needs to provide mechanisms to coordinate the initiation, execution, and shutdown of distributed simulations, enable data transfers, and provide time synchronization. The U.S. Department of Defense's (DOD) High Level Architecture (HLA) provides such mechanisms. The HLA was developed by the Defense Modeling and Simulation Office to provide a standard mechanism for integrating DOD simulations (Kuhl, 1999).

In IMS MISSION project meetings, the HLA was proposed as a solution for integrating manufacturing simulations. Manufacturing software vendors expressed concerns about the complexity of HLA and possible difficulties with its use as an integration mechanism. NIST responded to the concerns of simulation vendors and initiated work under the IMS MISSION project to address those issues. The focus of the work thus far has been to extend and adapt the HLA to make it easier to integrate existing commercial manufacturing simulation software (McLean, 2000). A prototype-integrated manufacturing simulation environment is under development using simulation systems from vendors participating in MISSION. The NIST-developed distributed manufacturing simulation adapter and the DMSO-sponsored HLA Run-Time Infrastructure (RTI) is being used to integrate the commercial simulation software.

2. Manufacturing simulation transactions –These transactions are needed to transfer information and simulated objects among distributed simulations while they are executing. Standard formats for transaction data would allow independently developed simulations to be integrated more quickly and effectively. Examples of possible transaction data types include:

- Orders and Status - customer purchase, shop production, material movement, shipping
- Plans – estimates, process routing and operation plans, schedules, forecasting data
- Negotiation - request for quotes, quote, inquiries, status reports, invoices
- Transferable manufacturing objects – component parts, work-in-process, finished products, material handling containers, vehicles

Two types of interface specifications are needed to support simulation transactions – one for describing manufacturing information content and another for defining the data-encoding scheme. Both types of interfaces should be based on other existing standards wherever possible. Manufacturing information content should be based upon the standards used by industry to share actual business data. For example, the ANSI Electronic Data Interchange (EDI) X12 specification might be used as a basis for describing the content of a number of different transactions (ANSI, 2001). X12 provides standards for the exchange of many different types of business data, e.g., purchase orders. Although manufacturing simulation developers might want to exchange purchase order data, they would probably only want to use a subset of the data elements contained within X12 specification for purchase orders. The subset of data that is relevant to simulation must be determined.

The Extensible Markup Language (XML) provides mechanisms for encoding data (Goldfarb, 2000). The IMS MISSION Project has taken the approach of using XML to encode all information that is transferred among simulations. To test out this approach, MISSION is currently developing a prototype distributed-simulation of a manufacturing supply chain using transactions encoded in XML. The supply chain is characteristic of that used to manufacture power tools. The transactions included in the prototype supply chain simulation are Generic Order, Generic Order Response, Shipping Order, Shipping Order Status, Product Forecast, Product Forecast Response, Manufacturing Production Report, Truck Dispatch Order/Log, and Shipment Report.

3. Simulation templates and model formats – Simulation model libraries could significantly reduce simulation development costs for industrial users. Neutral model formats would enable the development of simulation reference model libraries, generic templates, and application specific models, independent of the user's simulation environment. Neutral data formats should be defined for library models and templates to enable sharing among different vendor systems.

Commercial simulation systems typically have proprietary file structures for storing simulation models. They may also have a library manager for organizing and providing access to those models. This specification will establish guidelines for organizing simulation model libraries and establish neutral file structures for storing individual models to support sharing of models among simulation systems. XML will be considered as a possible encoding system for storing models. The development of neutral file specifications for simulation models is a major undertaking that will evolve over time.

4. Reference data sets – Manufacturing simulations typically use statistical distributions to model the behavior of systems. For example, statistical distributions are often used to model arrival times of jobs, job execution times, machine failures, and repair cycles. Usually the simulation analyst must develop his or her own models of this data. Often statistical distributions are simplified using what is called a triangular distribution. Often a triangular distribution may not be appropriate and lead to erroneous results and conclusions regarding the behavior of the system that has been simulated. There are currently no standard guidelines or data structures for representing this data for use in simulation. Standard formats for reference data and sharable reference libraries for these types of data would help to accelerate the modeling process and lead development of more realistic models.

5. Simulation study types and output data – The primary reason for manufacturing simulation is to conduct studies that help guide the manufacturing decision-making process. The type of study that is conducted determines the structure of the model as well as the input and output data that is required. Part of our strategy for future simulation standards is based upon the development of a taxonomy of simulation study topics. This taxonomy or classification scheme will categorize the different types of simulation studies that may be conducted within selected manufacturing domains. The taxonomy will identify the types of simulation studies that may be performed at different levels in the manufacturing organization, for example the supply chain level, major organizational unit level (manufacturing plants, warehouses, distributors, transportation networks, corporate headquarters, and retailers), and shop floor production system level. The taxonomy will help developers identify opportunities for the development of modular manufacturing-simulation libraries and interface standards in the future.

With respect to output data, conventional manufacturing simulation systems typically generate log files for simulation runs. The log files may record times when events occurred, computed metrics, key model parameters, and so on. The log files are used to analyze what happened during the simulation run and determine what actions should be taken as a result of the simulation. With a distributed simulation, it is likely that it will be necessary to reconcile the log files generated by multiple simulation federates. A common file structure will help facilitate reconciliation of data. Comma Delimited Format (CDF) is one output file structure that is often used by simulation systems today. We will also investigate using XML as a possible standard for tagging output data files.

Simulation Standards Consortium

Currently, there is no industrial standards organization that is focused solely on the development of manufacturing simulation standards. Under the IMS MISSION project, NIST established an organizational framework that could provide a basis for accelerating future manufacturing simulation standards efforts. A key element of this framework was the participation in the IMS MISSION Consortium of a number of simulation software vendors. These software vendors played a critical role in defining requirements and setting the technical direction of the IMS MISSION Project. Although the work started under MISSION is due to complete early in 2002, we expect to build upon its foundation.

We expect to form a new, simulation-standards consortium within the coming year to further the simulation research and standards activities initiated under the IMS MISSION Project and the Simulation Data Exchange (SDX) efforts (Moorthy, 1999; Moorthy, 2000). SDX is a mechanism for sharing plant layout and equipment specification data between layout modeling tools and simulation. The primary goal of the consortium will be to work to develop pre-competitive, neutral interfaces for manufacturing simulation. A technical basis for standardization will be established by working on foundation elements and those with the greatest common appeal to software vendors first. One of the first action items for the new consortium will be to identify and prioritize potential simulation-standardization areas.

A public announcement will be made to invite potential participants who have a stake in the development of simulation standards. Participants will be encouraged to join the consortium during the initial enrollment period. As in the MISSION Consortium, membership may be closed to newcomers once the consortium is formed. As a member of the new consortium, participants will be able to:

- Influence the direction for future simulation standards efforts
- Establish partnerships with other international researchers
- Track and leverage international research efforts in simulation standards
- Access research results and project deliverables from domestic and international participants
- Get a head start on the application of the latest distributed simulation technology and the development of prototype neutral interfaces.

The consortium will use a pre-competitive standards process developed by the NIST Systems Integration for Manufacturing Applications (SIMA) Program. As a part of this process a collection of specifications are developed that are called Initial Manufacturing Exchange Specifications (IMES). IMESs provide the means to meet the needs of the U.S. industry in the area of standards and testing methods by providing a structured approach to standards development, see (Kemmerer, 1997). They fill an important void in the manufacturing systems integration process as it exists today. Each IMES is developed through an industry review and consensus process.

Three types of IMESs have been identified: an interface specification between a human being and a software application; an interface specification between two or more software applications; and a reference information repository specification. Each IMES involves several components that define the integration aspect, specifies a definitive solution to the integration problem, and demonstrates the validity of the proposed solution. It contains a clear description of WHAT information the interface or repository MUST convey, and possibly HOW it is conveyed. The content is usually specified by an information model of all the objects and related information attributes which are covered by the specification.

To support the scope and domain specifications, the IMES addresses a particular example scenario, identifying an actual interface or information requirement derived from a real industrial problem. The proof of the value of the IMES to industry is the ability to build a prototype to the IMES, using the software applications actually used by the industrial practitioners, and solving the cited problem. To support the development of an IMES, standards projects have seven phases: identify/define the industry need, conduct requirements analysis, develop proposed solution, validate proposed solution, build consensus, transfer technology, initiate standardization. Each of these phases has a well-defined set of deliverables. During the last two phases software vendors are encouraged to begin to develop and offer commercial products that are based on the emerging standard.

Conclusions

Ultimately manufacturing simulation will have a major impact on the way products are manufactured. Due to the high costs of acquisition, integration, maintenance, limited interoperability, functionality, and performance -- simulation technology is not for everyone yet. Standard interfaces will increase the functionality and reduce the costs of implementing this new technology. This paper has identified several sets of simulation interfaces that need to be standardized. NIST expects to play a major role in helping industry implement simulation and virtual manufacturing technology through the development of interface standards.

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