A Core Manufacturing Simulation Data Information Model for Manufacturing Applications

Swee Leong
Y. Tina Lee
Frank Riddick
Manufacturing Systems Integration Division
National Institute of Standards and Technology
Gaithersburg, MD 20899-8260 U.S.A.
301-975-5426, 301-975-3550, 301-975-3892
leong@cme.nist.gov, leet@cme.nist.gov, riddick@cme.nist.gov

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ABSTRACT: *Simulation technology has been demonstrated to be an effective tool for reducing costs, improving quality, and shortening the time-to-market for manufactured goods in the manufacturing industry. But, there are a number of technical and economic barriers that hinder the use of this technology in the manufacturing industry. The cost of developing, implementing, and using simulation technology is high. The costs of integrating simulation systems with other manufacturing applications are even higher. There is always a need to transfer, exchange and share data between simulation and other manufacturing applications. Developing custom-built proprietary interfaces is too costly and makes using simulation technology prohibitive for most users. The development of reusable, neutral, standard interface, would make it easier and could help reduce the costs to integrate simulation and other manufacturing applications. NIST researchers in collaboration with industrial partners have been working on a standards development effort titled Core Manufacturing Simulation Data (CMSD) Product Development Group (PDG) under the guidelines, policies and procedures of the Simulation Interoperability Standards Organization (SISO). This paper presents the purpose of the CMSD effort, provides an overview of the CMSD Information Model, and describes an approach on how the CMSD Information Model is used to support the integration of manufacturing simulations.*

1.0 Introduction

The U.S. manufacturing industry continues to face challenges due to global competition, outsourcing, and consolidation. Simulation technology has been demonstrated to be an effective tool for reducing costs, improving quality, and shortening the time-to-market for manufactured goods.

The simulation model development process is time-consuming, labor-intensive and expensive. In many cases, simulation models are constructed from scratch. 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 models of manufacturing systems, processes, and resources. Through the merger and acquisition process, companies often acquire or inherit simulation packages from multiple vendors. To preserve the investment in these developed models, companies would like the capability to seamlessly integrate these models with neutral standard interfaces instead of relying on costly custom integration code. If the industrial user has several different vendors' simulation packages, unique models must be recreated 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.

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 simulation and manufacturing applications due to undocumented, proprietary data file formats.

Interoperability between other manufacturing software applications and simulation is currently extremely limited. Achieving interoperability involves addressing a number of system integration, data translation, and model development issues. The simulation software used to model and predict the behavior of manufacturing systems does 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 currently exist.

The National Institute of Standards & Technology staff has been working on an interface standards development effort titled “Core Manufacturing Simulation Data (CMSD) Information Model” to address the interoperability between simulation systems and other manufacturing applications. The CMSD effort is under the guidelines, policies and procedures of the Simulation Interoperability Standards Organization (SISO) [1].

The following sections present the purpose of the CMSD effort, provide an overview of the CMSD Information Model, and describe an approach on how the CMSD Information Model can be used to support the integration of manufacturing application and simulation.

2.0 Purpose of The CMSD Effort

2.1 Problem Statement

Manufacturing systems, processes, and data are growing and becoming more complex. Product design, manufacturing engineering, and production management decisions involve the consideration of many interdependent factors and variables. These often complex, interdependent factors and variables are too many for the human mind to cope with at one time. Whether the system is a production line, an operating room or an emergency-response system, simulation is a powerful tool that provides the capability to allow designers to imagine new systems, conduct experiments to observe behavior and evaluate the results of alternative decisions. Simulation can be used to study and compare alternative designs or to troubleshoot existing systems. However, a number of technical and economic barriers hinder the widespread and pervasive use of this technology in the manufacturing industry. The cost of implementing and using simulation technology is high. The cost of integrating simulation systems with other manufacturing applications is even higher. There is always a need to transfer and share data between simulation and other manufacturing software applications. Custom-built proprietary interfaces are too costly and are making it prohibitive for users to use simulation technology. The development of reusable, neutral standard interfaces would help reduce the costs associated with simulation model construction and facilitate data exchange between simulation and other manufacturing software applications. This would make simulation technology more affordable and accessible to a wide range of industrial users.

2.2 Benefits of Simulation Technology and Interface Standards

The development of simulation technology and neutral standard interfaces have been identified repeatedly by the manufacturing industry as a top research priority that promises high payback. The Integrated Manufacturing Technology Roadmap (IMTR) 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, and reducing design-to-manufacturing cycle time." [2]

The National Research Council (NRC) has repeatedly identified simulation and modeling as a high priority research area. It performed a study that 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 went on to recommend advancement of "the state of the art by establishing standards for the verification, validation, and accreditation of modeling tools and models. Fulfillment of the recommendation would provide fundamental building blocks for the dynamic models and 'real-time' simulations of 2020." The study also recommended 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." [3]

In 1999, the NRC 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.” [4]

Manufacturing simulation focuses on modeling the behavior of manufacturing organizations, processes, and systems including supply chains, as well as people, machines, tools, and information systems. Examples of manufacturing simulation applications include the modeling and verification of discrete event processes such as steel fabrication, machining, automotive assembly, aerospace assembly, semiconductor fabrication, inspection, human operator modeling, shop floor layout development, process and system visualization, ergonomic analysis, industrial manual and hazardous tasks evaluation, supply chain operations analysis and evaluation, and business process engineering.

2.3 Objectives of the CMSD Effort

Due to the lack of interoperability between simulation systems and manufacturing software applications, the CMSD effort was organized to address the issue. The CMSD Information Model defines a data specification for efficient exchange of manufacturing data in a simulation environment. The specification provides a neutral data format for integrating manufacturing software applications with simulation systems. The initial effort is focusing on machine shop data definitions. The plan is to extend the data specification to include supply chain, aerospace assembly operations, automotive vehicle assembly operations, plant layout, and other relevant manufacturing and simulation information.

The CMSD specification, when completed, will satisfy the following needs:

- Enable data exchange between simulation systems, other software applications, and databases
- Support the construction of manufacturing simulators
- Support testing and evaluation manufacturing software
- Support manufacturing software application interoperability

3.0 Overview of the CMSD Specification

3.1 Goals

The CMSD Information Model [5] has been developed with the following goals in mind: (1) to foster the development and use of simulations in manufacturing operations, (2) to facilitate data exchange between simulation and other manufacturing software applications, (3) to enable and facilitate better testing and evaluation of manufacturing software, and (4) to increase manufacturing software application interoperability.

3.2 Technical Approach

The primary objective was to develop data structures for exchanging manufacturing data between various manufacturing software applications, including simulation. The idea was to use the same data structures for managing actual production operations and for simulating the manufacturing shop. The rationale was that if one structure can serve both purposes, the need for translation and abstraction of the real data would be minimized when simulations are constructed. It is also recognized that maintaining data integrity and minimizing the duplication of data were important requirements. For this reason, each unique piece of information appears in only one place in the model. Cross-reference links are used to avoid the creation of redundant copies of data.

3.3 Scope

The CMSD Information Model (CMSDIM) describes the essential entities in the manufacturing domain and the relationships between those entities that are necessary to create manufacturing simulations. This information model will facilitate the exchange of information between simulation and other manufacturing software applications. Although the information defined in this model may be associated with one or more different manufacturing domains such as process planning, scheduling, inventory management, production management, or supply chain management, the model is not intended to be an all-inclusive definition of the entire manufacturing or simulation domain. There is no implied or explicit provision in the model for the direct specification of the execution behavior of a manufacturing entity in a simulation or other manufacturing application. This means that while a process can be defined that specifies a particular part resource in a particular state may be processed on a particular machine resource for a certain amount of time, the method that a simulation should use to implement this process is not specified. No support is provided for the creation of programming language or simulation language executable constructs, or the association of such constructs with the manufacturing-related entities that can be defined in the CMSD Information Model.

3.4 CMSD Specification

This section presents the CMSD specification's modeling languages, the major Unified Modeling Language (UML) [6] packages, and the major data categories.

3.4.1 Modeling Languages

The CMSD Information Model provides neutral definitions for information needed to integrate simulation systems with manufacturing software applications. The CMSD Information Model is presented in two different documents: (1) the information model defined using the Unified Modeling Language (UML); and (2) the information model defined using the eXtensible Modeling Language (XML) [7].

3.4.2 Major UML Packages

The CMSD Information Model's UML representation has been organized using UML packages, see Figure 1. UML packages, depicted as file folders, are UML constructs that can be used to organize model elements into groups. UML packages make UML diagrams simpler and easier to read. A brief description of each package is presented below.

The CMSD Information Model consists of the following major UML packages:

- CMSD package
  The CMSD package is the top-level package of the CMSDIM. It provides a grouping and model management function for all of the other packages defined in the architecture. All of the other packages are either directly or indirectly nested within this package.

- Support package
  The Support package provides a grouping and model management function for four sub-packages. These sub-packages contain definitions for basic data types and data elements for various applications. Examples of these data elements include commonly-used data structures and referenced data elements.

- Resource Information package
  The Resource Information package contains definitions for the resources (employees, machines, stations, etc.) used in manufacturing, the skills associated with human resources, and setup information required for the efficient operation of machine resources.

- Production Planning package
  This package contains definitions for information necessary to plan for effective manufacturing operations. It contains definitions for organizations, shifts, process plans, and operation and maintenance definitions.

- Production Operations package
  This package contains definitions for information about the state manufacturing operations that are either currently taking place or that have been already planned for. This includes information about orders for the manufacture of parts, jobs that state which manufacturing operation will take place using which resources, and schedules showing job or order information for given resources over a specific time period.

- Part Information package
  This package contains information about the products that will be produced as a result of the manufacturing process. Bill of materials information is also defined in this package.

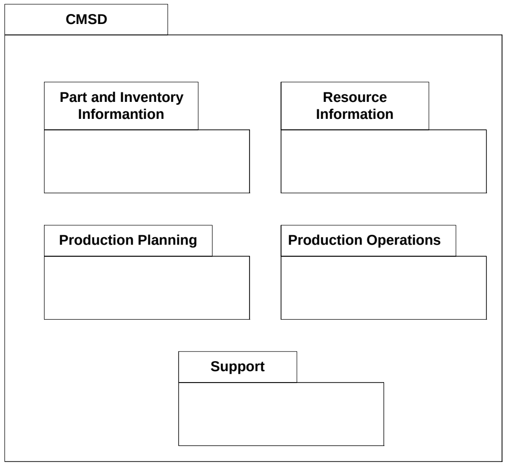

Figure 1. CMSD UML Package Diagram

3.4.3 Major Data Categories

The major categories of manufacturing information that are defined in this information model include:

• Organization is used to maintain organizational structure, contacts and address information for the manufacturing organization and its customers and suppliers.
• Calendar identifies the shift schedules that are in effect for a period of time, breaks and holidays.
• Resource describes all the resources that may be assigned to tasks in the shop. The resource types available in the shop environment include: stations and machines, cranes, employees, tool and fixture catalog items, and user-defined type of resource.
• Skill definition lists the skills that an employee may posses and the levels of proficiency associated with those skills.
• Setup definition typically specifies tool or fixture setups on a machine. Tool setups are typically the tools that are required in the tool magazine. Fixture setups are work holding devices mounted on the machine. Setups may also apply to cranes or stations.
• Operation definition defines the operations that may be performed at a particular station or group of stations in the shop.
• Maintenance definition defines preventive or corrective maintenance to be done on machines or other maintained resources.
• Part provides elements for part specifications, group technology codes, customers, suppliers, as well as links to bill of materials, process plans, drawings, part models and other references.
• Bill-of-materials cross-references the parts and quantities required in a hierarchical bill-of materials structure.
• Inventory identifies the instances and locations for part, materials, tool, and fixture inventory.
• Process plan specifies a set of process plans that are associated with production and support activities for a particular part or parts. A process plan has routing sheets and operation sheets that correspond to the job and task level in the work hierarchy.
• Work is used to specify a collection of a hierarchy of production orders, jobs, and tasks. It is also used to specify a collection of internal support orders for maintenance activities, inventory picking, and tool preparation.
• Schedule lists planned assignment or mapping of work to resources and resources to work.
• Revision specifies information about a set of revisions of the subjects. Information included in the element are each revision's description, date, creators, etc.
• Probability distribution specifies distributions that are used to vary processing times, breakdown and repair time, and availability of resources, etc.
• Reference describes the information about reference materials that support or further define that data elements contained within the CMSDIM data structure.

4.0 Concept of Applying the CMSD Information Model

This section describes an approach on how the CMSD Information Model can be used to develop integration among manufacturing applications.

Figure 2 depicts the role of the standards interfaces. The information model/XML schema serves as a neutral data format for representing and exchanging manufacturing application data. With the neutral data format, XML parsers, CMSD Import/Export Functions (to/from Database Management System (DBMS) translators and to/from XML translators), and manufacturing application data can be represented in working forms (structured, in-memory representations), in database tables, or in XML instance documents. The XML parsers, "to/from DBMS translators," and "to/from XML translators" are custom-built software programs. XML parsers convert XML schemas' data elements to structural in-memory presentations, such as C++ data structures. "To/from DBMS translators" and "to/from XML translators" allow manufacturing application input/output data to be converted among a user's data format, database structures, and XML document formats.

To facilitate the use of the CMSD Information Model to integrate manufacturing applications, two translators will be developed at NIST. One converts an XML instance document to a Microsoft Access database; the other converts a database back to XML. XML data structures, which are parsed from the XML Schemas, are used as intermediate representation. A graphical user interface (GUI) system will also be generated to execute various functions, such as import, export, and translator execution.

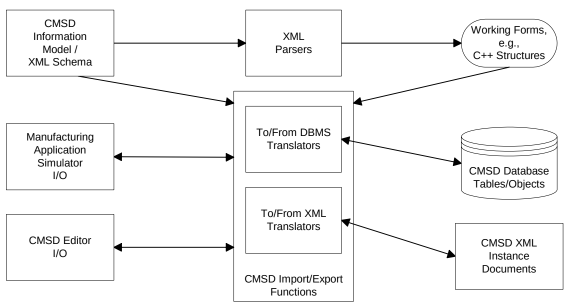

Figure 2: Standard data interfaces based on the CMSD Information Model

An example that demonstrates how manufacturing data are exchanged among Manufacturing Application "A", Manufacturing Application "B", and Manufacturing Application "C" is depicted in Figure 3. Data exchanging is through the CMSD Import/Export functions.

A. Data export procedures:

1. Extracting manufacturing application data from the manufacturing application datastore.
2. Converting the abstracted data to the CMSD XML file.
3. Exporting the CMSD XML file.

B. Data import procedures:

1. Extracting data from the CMSD XML file, as required.
2. Reformatting the CMSD file from XML format to a manufacturing application's internal file format.
3. Importing the reformatted manufacturing data to the manufacturing application.

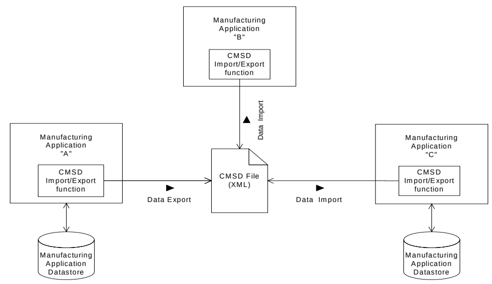

Figure 3. Manufacturing Data Exchange Example

5.0 CMSD Product Development Group Status

The CMSD Product Development Group (PDG) was established at the SISO Fall 2004 Simulation Interoperability Workshop (SIW). A key activity of the CMSD PDG was to generate a CMSD Information Model. A draft version of the CMSD Information Model in UML was released for review and comment in early 2006 on the SISO CMSD PDG discussions page. The version was an update and enhancement to the "strawman" specification titled " NIST Shop Data Model and interface Specification." [8] A CMSD Information Model in the XML schema is to follow. Comments have been collecting since the release of the draft document. A meeting was held at the SISO 2006 Spring SIW to discuss some of the comments. Meetings are scheduled at the SISO Simulation Interoperability Workshops to provide an update on the status and activities of CMSD PDG. Interested partners in the simulation and modeling community are encouraged to participate and take an active role in the CMSD PDG. Current participants include representatives from the Defense Modeling and Simulation Office, The Boeing Company, Ford Motor Company, General Motors, John Deere, Volvo Car Company, AutoSimulation, Delmia, FlexSim, Geer Mountain Software, ProModel, Rockwell Software, Simul8, University of Arizona, and George Washington University.

6.0 Conclusions

Manufacturing simulation technology will have a major impact on the way products are manufactured. Standard interfaces will increase the accessibility, interoperability, functionality, and reduce the costs of implementing simulation technology. The major long-term benefits of this interface standards development effort could result from the widespread and pervasive implementation of manufacturing simulation technology. NIST staff is collaborating with partners in helping industry implement and deploy simulation and virtual manufacturing technology through the development of standard interfaces.

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Author Biographies

Y. TINA LEE is a computer scientist in the Manufacturing Simulation and Modeling Group at NIST. She joined NIST in 1986. Her major responsibility in recent years has been to develop information models to support various manufacturing application areas. Previously she worked at the Contel Federal Systems and at the Sperry Corporation. She received her BS in Mathematics from Providence College and MS in Applied Science from the College of William and Mary. Her e-mail address is <leet@nist.gov>.

SWEE LEONG is a senior manufacturing engineer in the Manufacturing Simulation and Modeling Group at the National Institute of Standards and Technology (NIST) Manufacturing System Integration Division since 1994. Previously he worked at Ford Motor Company, John Deere, and IBM. His research interests are in modeling and simulation applications for the manufacturing industries and engineering tools integration program at NIST. Currently, Swee manages the Simulation Standards Consortium at NIST. He received a Bachelor and Master Degree in Industrial Engineering from Purdue University in West Lafayette, Indiana. He is a senior member of the Society of Manufacturing Engineers. His e-mail address is <leong@nist.gov>.

FRANK RIDDICK is a computer scientist in the Manufacturing Simulation and Modeling Group in The National Institute of Standards and Technology (NIST) Manufacturing Systems Integration Division. He has participated in research and authored several papers relating to manufacturing simulation integration and product data modeling. He holds a Master's Degree in Mathematics from Purdue. His email address is <riddick@nist.gov>.