Current Activities Related to the Core Manufacturing Simulation Data Standards Development Effort

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ABSTRACT: *The Core Manufacturing Simulation Data (CMSD) specification, developed by researchers at the National Institute of Standards and Technology, provides neutral structures for the efficient exchange of manufacturing data in a simulation environment. The CMSD effort is being developed under the guidelines, policies, and procedures of the Simulation Interoperability Standards Organization (SISO) to address interoperability issues affecting simulation systems and other manufacturing applications. This paper describes some of the activities related to the CMSD standards development effort, including comparison of CMSD to other specifications in the domain, pilot implementations of the CMSD specification at automotive assembly plant, and the simulation of inventory systems in a generic automotive assembly simulation.*

1. Introduction

Manufacturing systems, processes, and data are expanding both in size and in complexity. The manufacturing industry is increasingly reliant on information technology to support activities throughout the product's life cycle. Interoperability, the ability to communicate product data across different production activities, is essential to the productivity and competitiveness of today's information-based manufacturing industry. A study performed by the Research Triangle Institute estimates that imperfect interoperability imposes costs of at least one billion dollars each year on the members of the U.S. automotive supply chain [1]. The majority of the cost is attributable to the time and resources spent correcting and recreating data files that are not usable by their receiving parties. Solving interoperability problems can significantly reduce costs for the U.S. automobile and other industries.

Much evidence is available to indicate that a number of companies in the manufacturing domain have made efforts to provide better system integration, and almost all of these efforts have proved to be either inefficient or incomplete [1]. Interoperability between manufacturing software applications and simulation applications is also extremely limited. "Quality" interoperability ensures unambiguous, reliable, effective, and efficient information sharing and exchange within an integrated manufacturing or simulation-based manufacturing environment. A number of efforts intended to improve interoperability between information-based manufacturing applications are currently in progress.

The Core Manufacturing Simulation Data (CMSD) specification [2] of Simulation Interoperability Standards Organization (SISO) [3] defines neutral structures for the efficient exchange of manufacturing data in a simulation environment. The scope of the CMSD specification overlaps with some existing manufacturing data specifications, especially in the area of manufacturing operations management. As a part of the effort to develop CMSD, two related manufacturing data specifications were examined. These specifications are ISA-95 [4] and the Open Applications Group Integration Specification (OAGIS) [5, 6].

The rest of the paper is organized as follows. Section 2 overviews the CMSD, ISA-95, and OAGIS specifications. Section 3 provides a comparative analysis of these specifications and discusses the need for CMSD given there are existing standards in this area. Section 4 describes CMSD's recent development and implementation activities. The paper concludes with Section 5 where a summary of the paper is presented.

2. Interoperability Specifications

2.1 Core Manufacturing Simulation Data (CMSD)

National Institute of Standards and Technology (NIST) researchers, in collaboration with industrial partners, have been working on a standards development effort titled Core Manufacturing Simulation Data (CMSD) under the guidelines, policies, and procedures of the SISO [3].

The CMSD specification provides a means to define information about many kinds of manufacturing objects such as resources, parts, and process plans. It provides a neutral framework that facilitates the creation of collections of related manufacturing information suitable for use in the creation or enhancement of manufacturing simulations and other manufacturing applications. The entities defined in this framework represent a core set of the manufacturing entities and relationships needed for manufacturing simulation. The CMSD is represented in two different ways: Unified Modeling Language (UML) diagrams and eXtensible Modeling Language (XML) Schemas [7, 8]. Below is a description of some of the major categories of CMSD information.

- **Calendar** information describes the groups of shifts (and their related break and holiday information) that are in effect for a specified time period.
- **Resource** information describes the people and equipment that perform manufacturing activities. Resources in the CMSD are used to represent stations, machines, cranes, employees, tools, and fixtures.
- **Skill definition** information describes the skills that an employee resource may possess and the levels of proficiency associated with those skills.
- **Setup definition** information describes how resources may be configured to perform a task, how long it takes to configure the resource, and how long it takes to change from one configuration to another.
- **Part** information provides a means to specify the characteristics of the materials and subcomponents that are used to make end products.
- **Bill-of-materials** information provides a means to specify the subcomponent parts and the quantities of those parts that are needed to make an end product.
- **Process plan** information specifies the set of production activities needed to transform materials and subcomponents into finished products.
- **Maintenance plan** information defines the preventive or corrective maintenance actions to be done on machines or other maintained resources.
- **Work** information provides a means to create descriptions of the production activities that will be used to produce a product, along with estimates of the effort necessary to carry out those activities.
- **Schedule** information lists the production activities that have been planned to occur during a specified time period.
- **Probability distribution** information provides a means to specify statistical distributions that can be used to indicate process variability.
- **Layout** information provides a means to specify spatially-oriented characteristics and interrelationships for the logical and physical entities that are used to carry out production activities. This category is newly added into the CMSD specification. The topic of this layout extension activity is discussed in Section 4.1.

2.2 ISA-95

ISA-95, developed by the Instrumentation, Systems, and Automation Society (ISA), is the international standard for the integration of enterprise and control systems [4]. The Enterprise/Control Integration Committee (ISA-SP95) of ISA has developed and is continuing to work on a multipart series of standards that define the interfaces between enterprise activities and control activities, based upon the Purdue Reference Model for Computer Integrated Manufacturing [9]. The goal is to reduce the risk, cost, and errors associated with implementing these interfaces. The standard can be used for several purposes, for example, as a guide for the definition of user requirements, for the selection of Manufacturing Execution System (MES) suppliers, and as a basis for the development of MES systems and databases.

ISA-95 consists of models and terminology. The ISA-95 information models are defined using UML diagrams, and these models can be used as the basis for the development of standard interfaces between Enterprise Resource Planning (ERP) and MES systems. There are five parts of the ISA-95 standard.

- **Part 1: Models and terminology** consists of standard terminology and objective models, which can be used to decide which information should be exchanged.
- **Part 2: Objective model attributes** consists of attributes for every object that is defined in Part 1.
- **Part 3: Activities models of manufacturing operations management** defines production activities and information flows. It focuses on

the functions and activities at level 3, Production/MES Layer, of the Purdue Enterprise Reference Architecture.

- **Part 4: Objective models and attributes for manufacturing operations management** defines object models that determine which information is exchanged between MES activities. The models and attributes are the basis for the design and the implementation of interface standards.
- **Part 5: Business to manufacturing transaction** defines business-to-manufacturing transactions and manufacturing-to-business transactions that may be used in relation to the object models defined in Parts 1 and 2.

2.3 Open Applications Group Integration Specification (OAGIS)

The OAGIS standard, developed by the Open Applications Group Inc. (OAGi), is an effort to provide a canonical business language for information integration [5]. The OAGIS framework supports Service-Oriented Architecture, web services, and Electronic Business using eXtensible Markup language (ebXML) [10].

OAGIS provides a means to define business messages in the form of Business Object Documents (BODs) and example business scenarios that provide example usages of the BODs. BODs are the business messages or business documents that are exchanged between software applications or components, between companies, across supply chains, and between supply chains. To support multiple actions on a common business object (Noun), OAGIS BODs have been designed to make use of common Nouns on which a given action (Verb) may be applied. Shipment, PurchaseOrder, Quote, and Requisition are examples of Nouns. Acknowledge, Cancel, Get, Show, Sync, and Update are examples of Verbs. AcknowledgeShipment, ShowPurchaseOrder, and GetQuote are examples of BODs. As different industries have different needs, OAGIS must be extensible in order to allow industry verticals to plug in information that is needed in their industry. For this reason the BODs have been designed to be extensible, while providing a common architecture and content for integration [5, 6].

In OAGIS, business scenarios identify the business applications and components being integrated and the BODs that are used. OAGIS provides example scenarios that can be used as a starting point for integration. By identifying a scenario that most closely matches the user's needs, it is possible to identify the messages needed to achieve the needs.

OAGIS covers data exchange requirements for business systems and applications, including manufacturing and operations management systems. The current release, OAGIS 9.2, includes 494 business messages and 61 business scenarios that can be used to integrate business applications. OAGIS Release 9.2 expands the footprint of the specification to directly support Process Manufacturing with the addition of two new Nouns: Production Performance and Production Schedule. These Nouns are based on the ISA-95 specification as part of an ongoing convergence effort to normalize manufacturing interoperability standards for process, discrete, and mixed-mode manufacturing using the ISA-95 and OAGi models [11].

3. Specifications Comparison

This section presents an overview of a comparison of the CMSD, ISA-95, and OASIS specifications. The viewpoint of the comparison is how manufacturing simulation data representation can best be supported. The specifications' background information (such as standardization level, availability, modeling language or tool used, and file exchange format) and content information (such as scope, domain coverage, application supported, and attribute definition accuracy) are examined.

The key findings of this comparison study are:

- For the specification's availability, CMSD is free to the general public. The ISA-95 specification is free to ISA members; it requires a royalty payment from non-members. The OAGIS offers free specification download with registration required.
- CMSD supports job shop manufacturing, not flow shop. ISA-95 and OAGIS focus on flow shop or continuous process manufacturing, but they claim to support both modes.
- ISA-95 defines a framework, including a common terminology, abstract models, and transactions, for enterprise-control system integration. The emphasis is on good practices for integration of manufacturing with other enterprise systems. The data models are in UML, and a digital representation of a data exchange format is not provided.
- OAGIS defines business messages and identifies business processes or scenarios that allow businesses and business applications to communicate. The OAGIS framework includes enterprise, commerce, and manufacturing functionality with emphasis on business process interoperability.

- ISA-95 does not provide a machine interpretable form. An XML implementation of ISA-95 named Business To Manufacturing Markup Language (B2MML) is an implementation of ISA-95. B2MML, developed by the World Batch Forum, is not a formal standard. There is an effort underway to harmonize OAGIS, ISA-95, and B2MML [11].
- OAGIS, ISA-95, and B2MML often allow users to define attributes of the objects or entities as needed. This flexible approach makes it hard to develop software tools to interpret the data. When exchanging data, these attributes can't directly be interpreted without providing pre-negotiated definitions.
- CMSD supports discrete event simulation on manufacturing operations and 2D layout.

4. Current Activities of CMSD

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. An updated draft version of the CMSD specification was released for review and comment in the Fall 2006 on the SISO CMSD PDG discussions page. The version included all the major information categories listed in Section 2.1 except the Layout information category. Comments have been collecting since the release of the draft document. The development of the CMSD is still ongoing. Frequent update meetings are held within SISO SIWs and also at the Winter Simulation Conferences.

Sections 4.1 - 4.4 describe recent tasks performed under the CMSD project. Section 4.1 is about plant layout definition, a new data category item included in the CMSD specification. Sections 4.2 - 4.4 are tasks involving CMSD and the integration of the manufacturing systems. These tasks allow the CMSD PDG and its collaborators to assess the feasibility of using CMSD to integrate manufacturing applications and simulations and to uncover the potential for new modifications and/or extensions.

4.1 CMSD Extension - Layout

Since many simulation applications have a need to provide basic visualizations of the manufacturing entities and facility operations being simulated, the CMSD PDG decided to extend CMSD to support layout information to expand the potential number of applications in which CMSD-based information exchange can be used. The layout portion of the CMSD specification provides a means to specify information about the spatial characteristics of the areas in which production activities are carried out and the objects within those areas. This information includes:

- Coordinate system, spatial dimension, placement, and transformation information for graphical representations of the manufacturing entities in a layout.
- Definitions, placement, and transformation information for textual and symbolic annotations added to a layout to foster greater understanding of the layout.
- Associations relating the spatially-oriented information about manufacturing with other information about that entity defined in other parts of the CMSD specification.

A complete set of UML classes and diagrams, and matching XML schema definitions have been created for the layout extensions to CMSD. Verification activities are being performed to determine the extent to which the extended CMSD specification can be used to exchange layout information.

4.2 Volvo Car Implementation Project

The CMSD specification was used in a project that involved the exchange of stored production performance data with a simulation of the paint shop operations of a car manufacturing plant. The simulation is based on the paint shop operations at a Volvo Car Corporation plant in Sweden. It was built for a Swedish research project, Factory Analyses in Conceptual Phases Using Simulation (FACTS) [13, 14], which focuses on the work procedure of developing new and modified production systems. FACTS is interested in using standardized simulation data structures to achieve efficient data collection in the conceptual stages of production development programs. This project was used to validate the utility of the structures in the CMSD specification and to gather requirements for future enhancements. CMSD was originally developed to support job shops, but the results of this study indicate that it is possible to extend CMSD to also support flow shops [15].

4.3 Interoperability Testing on Generic simulation of Automotive Assembly

To facilitate future interoperability testing and training, scientists at NIST are working on a project to develop distributed, integrated manufacturing simulations for automotive manufacturing. These simulations address four different areas of application: the supply chain, the assembly plant, the engineering systems, and the shop floor level. Several applications have been developed as a part of the project.

- Final assembly plant simulation – a Delmia Quest simulation of the operations of an automobile final assembly plant has been developed. Data defining the process times, part routing, consumed parts, and initial inventory for each step in the process was defined using the CMSD specification and read in at initialization time.
- Automotive supply chain simulation – a simulation using Rockwell Automation's Arena was developed that modeled each supply chain member, the exchange of order and acknowledgement messages for each part in the supply chain, the exchange of shipment and receipt messages between supply chain partners for each part in the supply chain, and the change in inventory levels due to part consumption and resupply.
- Integrated final assembly plant/supply chain distributed simulation – the Delmia Quest final assembly plan simulation and the Arena supply chain simulation were modified to operate as federates in distributed simulation using the High Level Architecture (HLA) [16]. Messages (HLA interactions) based on OAGIS BODs were used to exchange information about orders, transportation request, and inventory levels for the production activities being simulated.

Future plans for this work include adding a simulation of suppliers operations and/or machine level operations to the distributed simulation. [17].

4.4 Volvo Trucks Implementation Project

In another project that was a part of the FACTS project, CMSD was used to store data describing the production operations of a Volvo Trucks assembly plant. A stand alone application was developed to collect and analyze raw data from the real production line and to create a CMSD file to store and exchange the data. Two simulations of the same production line were created, one using Unigraphics' Plant Simulation and the other using InControl's Enterprise Dynamics product. The CMSD file was used to initialize each of the simulation applications. After a series of simulation runs, the simulation outputs were compared to ensue that similar results were produced. The success of this integration showed that CMSD could be used to store the data needed for a simulation of the production operations, and that multiple simulation tools could be used with a CMSD file.

To speed up the development of the simulation applications, generic and reusable interface components for CMSD-file communication were developed in each of the simulation tools. The use of these interface components reduces the effort needed to either modify an existing simulation to support data in a CMSD file, or to create a new CMSD-based integration.

Taken together, these applications provide a system that includes raw data analysis, data reformatting, CMSD interfacing, and simulation model execution. Based on this result, a generic methodology for the development of CMSD interface components that can be integrated with discrete event simulation tools has been developed [18].

5. Summary

Developing mechanisms for the efficient exchange of information between simulations and other manufacturing tools is a critical problem. For many areas of manufacturing, neither representations for the information nor mechanisms for exchanging the information have been agreed upon. The CMSD specification is being developed to address some of these issues. This paper briefly describes and compares the CMSD specification with the ISA-95 and OAGIS specifications. From this analysis, CMSD's unique role is identified. CMSD facilitates the exchange of manufacturing life cycle data in a simulation environment, whereas ISA-95 and OAGIS are not focused on this problem. The paper also describes some of the current activities associated with the CMSD development effort, including the specification's extension to support plant layout, pilot implementations of the CMSD specification at the Volvo Cars paint shop operations and at the Volvo Truck engine assembly line, and CMSD's use in the development of a generic automotive assembly and inventory management simulation.

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