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Systems Integration for Manufacturing Applications

Biennial Report

Fiscal Years 1999-2000

James E. Fowler
Mark Carlisle

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National Institute of Standards and Technology
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Introduction

The Systems Integration for Manufacturing Applications (SIMA) Program is an intramural effort being undertaken at the National Institute of Standards and Technology (NIST) to support the application of information technologies to the manufacturing domain. Initiated in 1994, the Program works with industry to develop technology solutions enabling integration of the systems used in the engineering and manufacturing of various kinds of products. The plans for the Program were originally described in [1] and were updated in 1997 [2]. Program activities and project accomplishments for previous years have been documented in [3], [4], and [5]. The purpose of this document is to report on two fiscal years of the Program's technical activities: 1999 and 2000 (FY99-FY00). The intended audience for this document includes private sector organizations and federal agencies collaborating with NIST, other agencies participating in the federal Information Technology Research and Development (ITRD)[1] effort, and the general public. This report is available via the SIMA website (http://www.nist.gov/sima/) or by electronic mail request to the SIMA Program Office secretary (simasec@nist.gov).

This report is comprised of three major sections: the SIMA Overview, the Project Accomplishments, and the Appendices. The SIMA Overview section provides a high-level description of the Program's goals, technical efforts, progress, and results. The Project Accomplishments section provides individual descriptions for technical projects funded in FY99 and FY00. Each project description includes a summary of the project's technical accomplishments along with a list of the project's collaborators. The Appendices to the report include a description of the organization of the Program (Appendix A), tables summarizing all collaborators enumerated in each of the project descriptions (Appendix B), a list of publications completed by the projects (Appendix C), and a list of products available from the projects (Appendix D).

SIMA Overview

NIST's SIMA Program is the agency's coordinating focus for its activities addressing the information interface needs of the U.S. manufacturing community. Specifically, the SIMA Program performs the following activities:

- Develops standards and tests for information exchange and interface protocols addressing lack of interoperability in manufacturing systems.
- Provides online access to NIST-resident capabilities supporting engineering and manufacturing technologies.

These efforts allow manufacturing industries to use information technologies for productivity improvements in manufacturing activities. In the context of the SIMA Program the phrase "manufacturing activities" is broader than simply operations on the shop floor; it also includes activities such as the research conducted to devise new products and processes, the design of products and processes, the engineering analysis of prospective solutions, the planning of manufacturing operations, the scheduling of production operations, the engineering of production capabilities, and the myriad of other information-intensive activities performed in industry today. All such activities are conducted using software systems and these systems require information interfaces in order to communicate with each other. Those information interfaces may be realized as application programming interfaces, as data exchange mechanisms, or as the mechanisms through which users interact with the software systems. The primary focus of the SIMA Program is the development and testing of information interfaces that provide scientists, engineers, and manufacturing personnel with the capability to share information among different activities, among different application software components within manufacturing enterprises, and throughout the entire supply chain.

1. The federal government's initiative in High Performance Computing and Communications has been subsumed by the overarching multi-agency ITRD effort. For more information, see http://www.itrd.gov.

Background

The U.S. government initiated the High Performance Computing and Communication (HPCC) Program in 1991 with the High Performance Computing Act (Public Law 102-194). The government's effort was intended to accelerate the development of future generations of high performance computers and networks and the use of these resources in the government and throughout the U.S. economy. The four original components[2] of the HPCC Program were augmented in FY94 with a new component known as Information Infrastructure Technology and Applications (IITA) [6]. The IITA component supported research and development efforts that would enable integration of critical information systems and demonstrate feasible solutions to problems of national importance [7]. Twenty-first century manufacturing, i.e., advanced manufacturing processes and products, was one of the challenges to be addressed by IITA activities [8]. Concurrent with the addition of IITA, the SIMA Program was initiated at NIST to address the manufacturing information interface issues implicit in the IITA objectives. Later, recognizing the HPCC Program's continuing successes and broadening scope, the HPCC Program was renamed as the Information technology Research and Development Program (ITRD) and the components of the Program were refocused into Program Component Areas (PCAs) [9]. There continues to be evolution in the structure and focus of the constituent elements of the ITRD effort; both NIST and its SIMA Program continue to coordinate technical directions with other Federal agencies participating in ITRD.

Major Technology Efforts

SIMA technology efforts stem from both the short- and long-term needs of U.S. manufacturers and their software suppliers. Industry needs evolve in response to technology and market realities, thereby resulting in corresponding changes in the SIMA Program's project portfolio over time. Twenty (20) projects comprised the SIMA Program in FY99 and FY00. These projects addressed a wide range of industry manufacturing domains: chemical products, electrical products, materials, mechanical products, and constructed facilities. In this section, the focus is on the technology areas addressed in the projects. As illustrated in Figure 1, the Program is organized into two technology areas: Interface Standards and Information Access. Appendix A of this document provides additional organizational details of the Program. Each technology area is discussed in more detail below.

Interface Standards Efforts

The foundation for all efforts in the SIMA Program is the development, testing, and standardization of information specifications enabling communication among the multitude of software applications used in manufacturing industries. The present state of affairs is such that there is no guarantee that these software applications can do anything more than send unintelligible data to one another. Still it stands to reason that, for example, the software used to design products should be able to provide design data to the software that is used to plan the manufacturing of the design. In reality, engineers and other technical staff spend time recreating data in one software system that already exists in another, devising ad hoc data translation solutions, acquiring unique point-to-point translation services, and remedying the errors that many of these work-arounds introduce. This *lack of interoperability* among software systems exists whether they are resident on the same computer, accessible to each other on the same intranet, or accessible to each other on a wide-area network.

To address these interoperability issues, SIMA projects work in conjunction with industry collaborators to identify the requirements for the information that needs to be exchanged among engineering and manufacturing software applications. These requirements form the basis for the information models from which interface specifications are derived. With formal interfaces, specifications in hand, prototype implementations of information exchange mechanisms can be developed to help validate the accuracy and utility of the specifications. These tests typically lead

2. High Performance Computing Systems; National Research and Education Network; Advanced Software Technology and Algorithms; Basic Research and Human Resources.

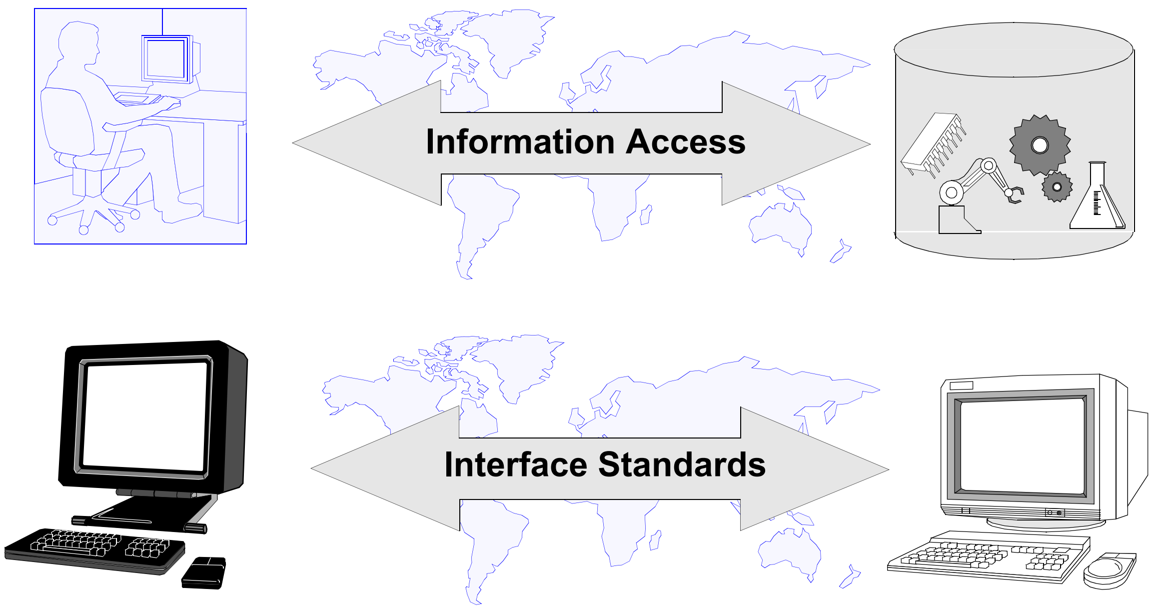


Figure 1. SIMA Technology Areas

to pilot implementations in industry to further increase the robustness of the interoperability solution and to verify the business case for the solution (i.e., Is the prospective cost of the solution justified by the increase in efficiency? Is it less error-prone than existing methods?). With support from the manufacturing users and software developers, the interface specifications can be submitted to standards developing organizations, e.g., the International Organization for Standardization (ISO) or the Object Management Group for further development and eventual standardization. These interoperability solutions have the effect of improving the degree of integration between particular software systems and ultimately increasing manufacturing productivity [10].

Given that the process for developing interface specifications is fundamental to many SIMA efforts, the Program has documented a methodology for their development. The methodology produces Initial Manufacturing Exchange Specifications (IMES). IMESs are information interfaces which can take the following forms:

- An interface specification between a human and a software application
- An interface specification between two or more software applications
- A reference information repository specification

The third type of IMES refers to a specification for the contents of a repository (typically a database) that is used to provide information to many activities, but the contents of which are updated by only a single process (typically an administration process).

The IMES Process

An IMES is developed through an industry review and consensus process and is accepted by the manufacturing community as a definitive solution to a particular interoperability problem. The IMES process involves seven phases. The execution of these phases need not occur sequentially -- some may overlap while others may occur in parallel. Figure 2 illustrates the seven phases showing how results from each phase are used by the others. The individual phases are described as follows:

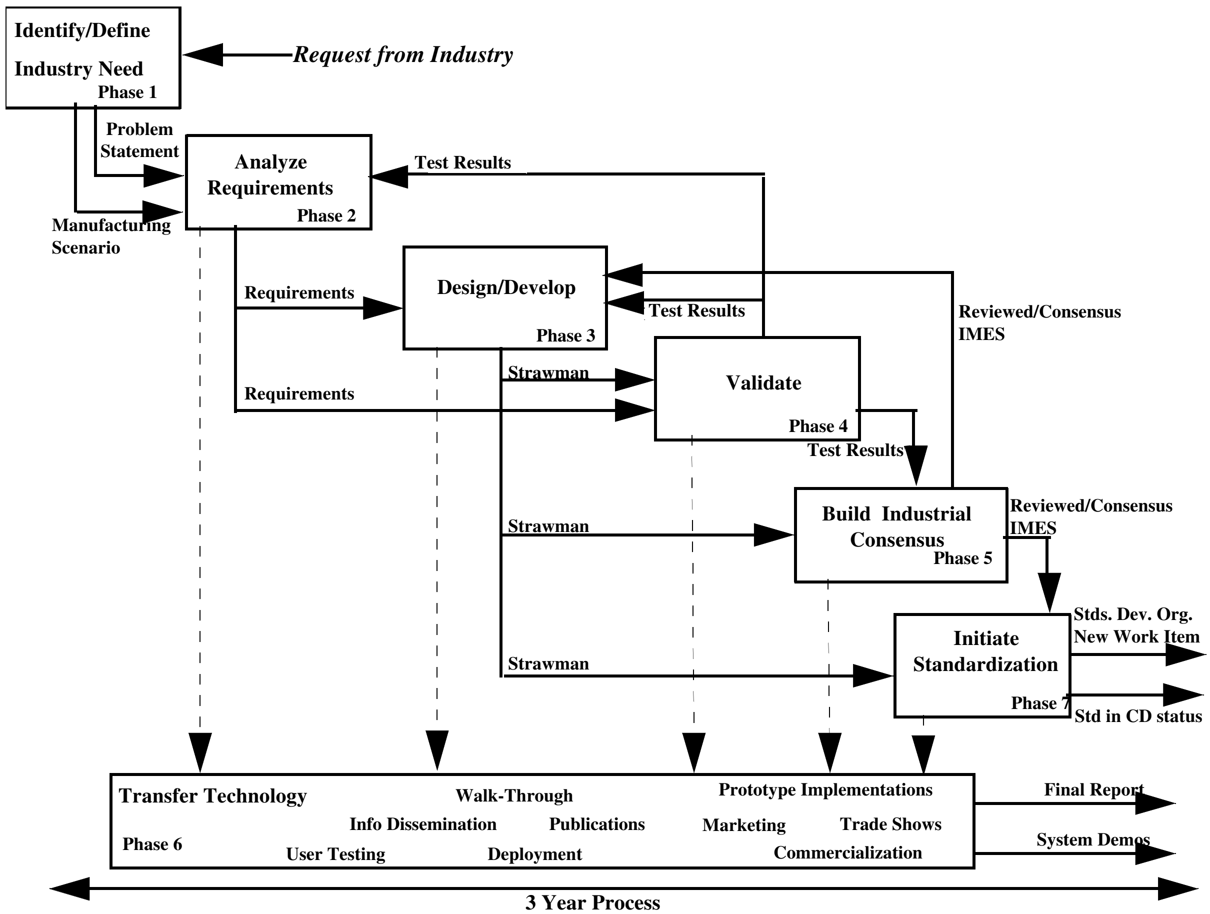


Figure 2. IMES Process Activities

Phase 1: Identify/Define Industry Need
The initial activity of IMES development is identifying and documenting an industry need, manufacturing scenario, or problem statement to define the scope and manufacturing domain of the proposed project. This need could be identified in several ways. Industrial collaborators are to be involved in defining this need.

Phase 2: Analyze Requirements
This IMES development phase consists of analyzing the current situation within the manufacturing scenario to understand current capabilities, prior attempts at a solution, and specific needs that must be accommodated in the proposed IMES solution. A requirements specification is the primary desired output from this project phase. Such a specification will enable widespread industry review of the detailed requirements that a solution must satisfy in a form that is understandable by the majority of the target manufacturing community.

Phase 3: Design/Develop
This IMES development phase consists of the actual design, development, and documentation of the proposed IMES technical solution that satisfies the requirements specified in the previous phase. The solution may consist of a combination of deliverable types, including information model(s), interface protocol(s), or process model(s), as required by the problem to be solved. The primary output of this phase is the initial version of the strawman proposal for external review.

Phase 4: Validate
A validation phase is required to ensure the completeness, validity, and usability of the proposed IMES solution. Validation activities may take several forms, including: prototype implementations, detailed walk-through with domain experts, or a comparison with known references. A proposed solution with demonstrated prototype implementations and validation test results makes a much stronger case for standardization. The documented test results (obviously based upon the prototype implementation, test environment, test suites, or other validation tools) are considered the primary output of this phase.

Phase 5: Build Consensus
By definition, an IMES is developed from an industry consensus viewpoint. Whereas most IMES development phases require some collaboration or interaction with industrial counterparts, this phase of IMES development requires interaction with a large segment of the target manufacturing community. This interaction can be accomplished through technical workshops, user group meetings, correspondence, or site visits. IMES development projects should endeavor to obtain and accommodate as much input and feedback from industry as possible in the proposed project solution. True consensus may never be reached. This project phase is deemed necessary, however, for positioning and delivering a quality-proposed strawman for standardization to an appropriate standards development organization. This phase is differentiated from the actual standardization process to allow and encourage other consensus-building activities without the potential constraints and procedures required by standards organizations. The primary deliverable of this phase is an updated Strawman IMES resulting from the consensus-building activities. In some cases, significant comments and suggestions may indicate the need for the project to iterate back to the IMES Design/Develop Phase 3.

Phase 6: Transfer Technology
One of the primary missions of NIST is to provide technology transfer of NIST research results to industry. The SIMA Program supports this mission. IMES development efforts will include aspects of technology transfer to publicize, market, and transition project activities and results to industry or standards development organizations. Technology transfer should be an ongoing project activity. Various methods of technology transfer can be employed at the various stages of the IMES development effort to supply industry collaborators and the manufacturing community with current information. The primary deliverables for this phase consist of a final report and system demonstrations.

Phase 7: Initiate Standardization
Since an IMES is a proposed standard solution to a manufacturing integration need, IMES development efforts must include interaction with appropriate standards development organizations to initiate this standardization. These activities may include attending standards meetings, participating on various standards committees, or writing project correspondence with standards development organization conveners. The objective of this phase is to initiate the proposed standards work (either as a new work item or modifications to existing standards/work items) to a point where it will be self-sustaining within the standards development organization.

IMES Progress

Three of the SIMA projects have identified a total of eight IMES development efforts. Table 1 depicts the IMESs under development and their stage of completion in the IMES process as of the end of FY00. Many IMESs identified in previous editions of this report have evolved into standards in various states of development and are represented in the next section. It is worth noting that there is a burgeoning number of consortia, trade associations, and so on that have elected to provide a home for nascent standards efforts. Hence the number of IMESs reported here has dropped in comparison to previous years, but the total number of interoperability standards in process has grown.

Standards Progress

Eleven projects are contributing to the development or testing of standards that have entered the formal standardization process (and hence are not considered IMESs). Specifications in these stages of development are typically those that have been in development for at least two years. Table 2 summarizes the thirty-eight (38) standards to which the projects have been contributing.

As these standards become more fully deployed in industry it will become practical to assess the effects they are having on specific interoperability problems, and to assess the NIST contributions to those benefits. In the interim, the SIMA Program has already initiated efforts that will lay the foundation for future assessments. One recently completed effort is a study of the interoperability costs incurred by companies in the U.S. automotive supply chain [12]. That study identified annual costs of one billion dollars owing to problems in the exchange of technical data amongst the numerous engineering and manufacturing software applications used by those companies. The costs identified included expenditures for additional engineering labor to fix errors resulting from inaccurate data exchanges and time-to-market delay costs. The study indicated that these costs were likely to be representative of the interoperability costs experienced in other transportation manufacturing industries as well (e.g., aerospace). The information interfaces and interoperability solutions resulting from the SIMA Program are expected to play a significant role in reducing the interoperability costs that manufacturers are incurring.

Project Name	**Identify Industry Need**	**Analyze Requirements**	**Develop Solution**	**Validate Solution**	**Build Consensus**	**Technology Transfer**	**Initiate Standardization**
Product Engineering Program	Design Knowledge Core Product Model	❍	❍	❍			
	Design Rationale	❍	❍				
	History-based Modeling	❍	❍				
Materials Informatics Resources: MatML	Materials Markup Language (MatML)	❍	❍	❍	❍		
Intelligent Unit Process Control in Next Generation Open Manufacturing Systems	Generic Control Node Shell Specification	●	❍	❍	❍	❍	
	Human Oversight Interface Specification	●	❍	❍	❍		
	Message Suite Specifications	●	❍	❍	❍	❍	❍
	Plan Interface Specifications	●	❍	❍	❍	❍	

TABLE 1. **IMESs by Project.** The topic area for each IMES is listed in the Industry Need column. The ❍ symbol indicates on-going work in the corresponding IMES phase, the ● symbol indicates work in that phase is complete, and no symbol at all indicates that no work has occurred in the corresponding IMES phase.

Project Name	**Standard Designation**	**FY00 Status**[a]
Dimensional Inspection Information Exchange	ISO 10303-219 Industrial automation systems and integration: Product data representation and exchange: Part 219: Application protocol: Exchange of dimensional inspection information	Preliminary Work Item
Electronic Commerce for the Electronics Industry (ECEI)	IPC[b]-2510: Generic Computer Aided Manufacturing Descriptions for Printed Boards and Printed Board Assembly (GenCAM)[c]	Published/ Pending ANSI[d] Approval
	IPC-2541: Generic Requirements for Electronic Manufacturing Shop Floor Equipment Communication	Official Representative Proposal
	IPC-2571: Generic Requirements for product Definition Exchange (PDX)	Working Draft
	IPC-2572: Sectional Requirements for Quoting Data Definition Exchange (PDX)	Working Draft
	IPC-2578: Sectional Requirements for Bill of Material Data Definition Exchange (PDX)	Working Draft
	ISO/IEC 10303-210: Electronic assembly, interconnect, and packaging design	International Standard
	RosettaNet[e] PIP 2A9: Query Electronic Component Technical Information	Published
Information Technology Metrology for Manufacturing Program	ASME[f] B89.4.10 Coordinate Measuring Machine Software	Public Review
	ISO/CD 10303-14 Industrial automation systems and integration: Product data representation and exchange - Description Methods: Part 14: The EXPRESS-X Language Reference Manual	Committee Draft
	ISO 10303-34 Industrial automation systems and integration: Product data representation and exchange: Conformance testing methodology and framework: Abstract test methods for application protocol implementations	International Standard
	ISO/DIS 10360-6 Geometrical product specifications: Acceptance and reverification test for coordinate measuring machines: Part 6: Estimation of errors in computing Gaussian associated features	Draft International Standard
	ISO 15530-4 Geometrical product specifications: Coordinate measuring machines: Techniques for determining the uncertainty of measurement: Uncertainty assessment using simulation	Working Draft

TABLE 2. **Standards Efforts by Project**

Project Name	**Standard Designation**	**FY00 Status**[a]
Manufacturing Enterprise Integration Program	ISO/CD 10303-28 Industrial automation systems and integration: Product data representation and exchange: Part 28: XML representation for EXPRESS-driven data	Committee Draft
	OMG Data Acquisition from Industrial Systems	Request for Proposals
	OMG Product Data Management Enablers (v1.3)	Adopted
	OMG Product Data Management Enablers (v2.0)	Request for Proposals
Manufacturing Simulation and Visualization Program	OMG Distributed Simulation (v2.0)	Request for Proposal
Predictive Process Engineering Program	ISO/WD 16100-1 Industrial automation systems and integration: Manufacturing software capability profiling: Part 1: Framework for interoperability	Working Draft
	ISO 18629-1 Process specification language: Overview and basic principles	Working Draft
	ISO 18629-10 Process specification language: Core representations	Working Draft
Product Engineering Program	ISO 10303 Industrial automation systems and integration: Product data representation and exchange: Application protocol: Rapid prototyping and layered manufacturing	Preliminary Work Item
	ISO/WD 10303-108 Industrial automation systems and integration: Product data representation and exchange: Part 108: Integrated application resource: Parametrization and constraints for explicit geometric product models	Working Draft
	OMG CAD Services Interface (v1.0)	Request for Proposals
Product Data Standards for the HVAC/R Industries	IAI[g] Industry Foundation Classes Release 2.X	Final Release
Product Data Standards for the Process Plant Industries	ISO 10303-221 Industrial automation systems and integration: Product data representation and exchange: Part 221: Application protocol: Functional data and their schematic representation for process plants	Committee Draft
	ISO 10303-227 Industrial automation systems and integration: Product data representation and exchange: Part 227: Application protocol: Plant spatial configuration	International Standard
	ISO 10303-227 Industrial automation systems and integration: Product data representation and exchange: Part 227: Application protocol: Plant spatial configuration (Edition 2)	New Work Item

TABLE 2. **Standards Efforts by Project**

Project Name	**Standard Designation**	**FY00 Status**[a]
Sensor Integration	IEEE[h] 1451.1-1999 IEEE Standard for a Smart Transducer Interface for Sensors and Actuators - Network Capable Application Processor Information Model	National Standard
	IEEE 1451.2-1997 IEEE Standard for a Smart Transducer Interface for Sensors and Actuators - Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats	IEEE Standard
Standards for Exchange of Instrument Data and NIST Chemical Reference Data	ASTM[i] E1947-98 Standard Specification for Analytical Data Interchange Protocol for Chromatographic Data	National Standard
	ASTM E1948-98 Standard Guide for Analytical Data Interchange Protocol for Chromatographic Data	National Standard
	ASTM E2077-00 Standard Specification for Analytical Data Interchange Protocol for Mass Spectrometric Data	National Standard
	ASTM E2077-00 Standard Guide for Analytical Data Interchange Protocol for Mass Spectrometric Data	National Standard
	NCCLS[j] AUTO3-A Laboratory Automation: Communications with Automated Clinical Laboratory Systems, Instruments, Devices, and Information Systems	Approved Standard
	NCCLS AUTO4-P Laboratory Automation: Systems Operational Requirements, Characteristics, and Information Elements	Proposed Standard
	OMG Laboratory Equipment Control Interface Specification	Request for Proposals

TABLE 2. Standards Efforts by Project

a. The status identified for each standard is in the vernacular particular to the responsible organization.

b. The Association Connecting Electronics Industries (IPC) is an industry trade association.

c. GenCAM is a suite of 8 standards. The parent standard (IPC-2511A) is furthest advanced in the standardization process.

d. The American National Standards Institute (ANSI) is the national standards body for the U.S.

e. RosettaNet is an industry consortium of electronic components, information technology and semiconductor manufacturing companies.

f. ASME International is an accredited standards setting technical organization.

g. The International Alliance for Interoperability, Inc. (IAI) is a technical standards setting organization.

h. The Institute of Electrical and Electronics Engineers, Inc. (IEEE) is an accredited standards setting technical organization.

i. The American Society for Testing and Materials (ASTM) is a formal standards developing organization.

j. The National Committee for Clinical Laboratory Standards (NCCLS) is a formal standards developing organization.

Information Access Efforts

The Internet provides an information access capability that continues to evolve and grow with each passing month. Information resources are now available at the user's desktop with only a few keystrokes. With many thousands of information resources however, users are potentially overwhelmed, unable to find what is needed, and unable to use resources efficiently if found because of incompatibilities. Moreover, the veracity of information found on the Internet is frequently called into question. Yet the scientists and engineers responsible for creating new products and processes must have reliable, accurate, and timely access to technical data of known quality in order for their efforts to be successful.

The SIMA Program effort in providing Internet access to technical data is addressing such issues. This effort builds on NIST's well-respected Standard Reference Data Program (SRDP), which serves the U.S. technical community by collecting published technical data and determining their reliability. NIST's SRDP offers evaluated scientific data collections that together represent the world's largest collection of evaluated scientific data. These data collections are drawn from the more than 1,000,000 technical papers reporting research published each year in the fields of chemistry, physics, materials science, and engineering. The information in those papers includes numeric data used by U.S. scientists and engineers in their daily work of research, testing, and product/process development. The private sector does not offer the evaluated data services performed by NIST because preparation of reliable scientific databases is not a commercially viable activity. Reliable data requires evaluation, the assessment of data accuracy by expert scientists and engineers. With its strong technical staff, NIST sets the world benchmark for evaluation capability.

The SIMA Program adds value to NIST's existing SRDP effort by making these data collections available to any user with an Internet connection. This not only improves the penetration of these data in the technical community but also ensures that the data the users are depending on are the latest evaluated. In addition, the evolving technical capabilities of Internet browsers enable new mechanisms for interacting with these data collections. These include innovative search capabilities based on graphical input from users, interactive manipulation of data graphs, as well as outputs from the data collections that can be directly incorporated into the software on the user's local computer. Seven SIMA projects are involved in these SRDP efforts and have demonstrated considerable success as evidenced by the significant usage of their online data collections by industrial sites.

The SIMA Program also continues to explore related needs for online access to technical information as well as online access to technical capabilities. Other areas of work include efforts to make interactive versions of widely used NIST references in mathematics available on the Internet. While the technical community is reaping immediate benefits from these types of capabilities, we expect that the continuing evolution of both Internet technologies and the information interfaces developed in the other parts of the SIMA program will together provide even greater information access benefits in the future.

SIMA Vision

The premise for the SIMA Program is that the information technology infrastructure supporting the product realization environment should enable seamless communication of information among business enterprises, people, software systems, and hardware systems. It is our belief that the major technology areas in the Program - interface standards and information access - address the significant technical challenges implied by that premise. Yet the number and variety of software systems used in manufacturing enterprises continues to grow; and with that growth comes the corresponding combinatorial explosion in the number of interfaces necessary to achieve seamless communication among them. While SIMA efforts are addressing near-term priorities for the information interfaces needed by U.S. manufacturers, they cannot address all current information interface needs or the greater needs anticipated for the future. Recognizing this, the Program is devoting some of its resources to investigating how future standards can be developed so that software systems can negotiate seamless communications on their own. Hence a vision for the SIMA Program was developed and is illustrated in Figure 3. The bulk of the work currently pursued by the Program is in the development of common models of data. Those models, manifested as IMESs or standards, enable current and near-term interoperability solutions. Coupled with formal representations of semantics, those models could allow for more powerful software integration techniques, such as the automatic generation of data translators. Human intervention would still be involved, specifically in the codification and resolution of semantic intent. A further advance would be a semantic infrastructure enabling self-describing systems so that, at least in well-defined domains, software systems would be able to recognize the possibility of intelligent communication and carry it out. The ultimate solution would be software systems that autonomously determine semantic equivalence, resolve semantic mismatches, and thus perform seamless communication on their own.

While we are a long way from achieving this vision, its pursuit is necessary if we are to escape the increasingly resource-intensive work of manually addressing interoperability issues. The technical efforts targeted at specific interoperability problems continue to add to the foundational knowledge needed to achieve the vision. Hence the short-term benefits of the Program manifest themselves as solutions to specific interoperability problems. But the lasting impact of the Program may well be the legacy of methods, standards, and practices for improving the integratability of software systems.

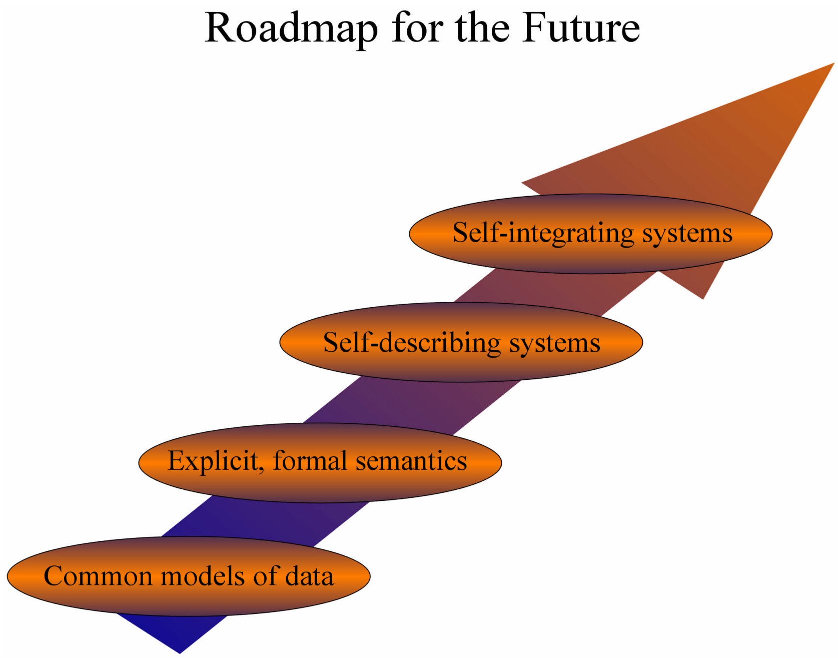


Figure 3. The SIMA Vision

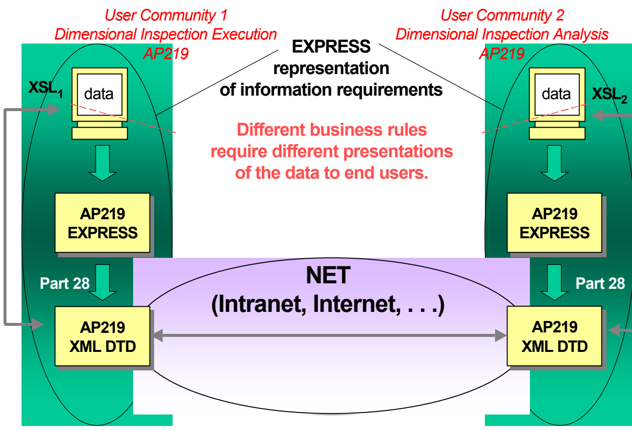
Project Accomplishments

The following descriptions provide summaries of each SIMA Program technical project. Project summaries are organized by program environment element. (See Appendix A for a description of the organization of projects.) Each project summary provides a brief description of objectives, accomplishments, and collaborations. Detailed information on any project may be obtained by contacting the principal investigator listed for that project.

Interface Standards Project Summaries

IS1: Dimensional Inspection Information Exchange

Principal Investigator: Theodore Vorburger
Telephone: (301) 975 - 3493
E-mail: theodore.vorburger@nist.gov



AP219 web analysis implementation

The objective of this effort, initiated in FY00, is to develop and demonstrate an information standard for dimensional inspection information exchange. The mechanical parts industries, particularly the automotive and the aerospace industries, have been seeking ways to comprehensively integrate inspection plans, raw inspection data, and inspection analyses into their manufacturing software environment. The Dimensional Measuring Interface Standard (DMIS) [13] is one example of ongoing work in industry towards the above objective. DMIS provides a mechanism for integrating dimensional inspection planning and execution systems. However, DMIS does not address the need to integrate data resulting from inspection processes with subsequent reporting of that data nor with the original design and its dimensional tolerances. To enable the exchange of inspection information among the many functions that create and use it, a sound information model must be developed. These functions include design, dimensioning and tolerancing, inspection process planning, execution of inspection, modification of inspection plans, analysis of results, reporting, and archiving. ISO 10303 (informally known as the STandard for the Exchange of Product model data, or "STEP" [14]) now includes a work item to develop an application protocol for dimensional inspection (AP219) [15]. The aim of this project will then be to contribute to the standardization of AP219, complete a prototype implementation to validate the information requirements of AP219, and work effectively with industrial teams and related standards bodies to deploy AP219 in production systems.

Significant FY00/99 Accomplishments

- Developed an application reference model for AP219 taking into consideration compatibility with existing STEP standards.
- Conducted a special harmonization meeting between developers of AP219 and the DMIS National standards committee to ensure compatibility among these specifications.
- Initiated efforts in conjunction with DaimlerChrysler and others to develop a prototype implementation of AP219 for web-based analysis of inspection data.

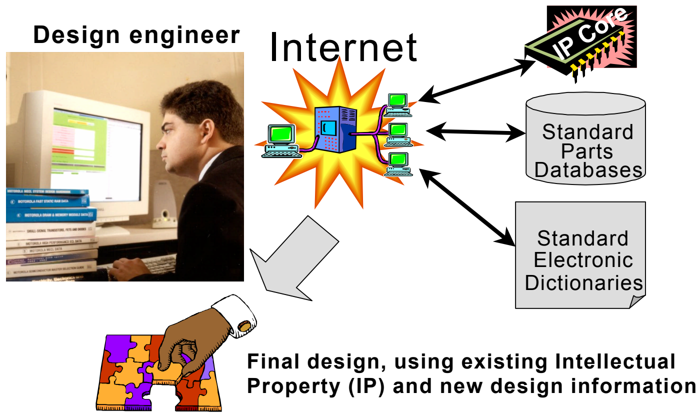
Collaborations

- Boeing, for identification of information requirements for the emerging AP219 specification.
- Brown and Sharpe, for identification of information requirements for the emerging AP219 specification as well as for implementation considerations.
- Daimler Chrysler, for coordination and development of a prototype implementation of the emerging AP219 specification for web-based analysis of inspection results.
- LK Metrology Systems Inc., for identification of information requirements for the emerging AP219 specification as well as for implementation considerations.
- Metrology Automation Association, for validation of emerging AP219 implementations.
- Tecnomatix Technologies Ltd., for identification of information requirements for the emerging AP219 specification as well as for development of a prototype implementation of AP219 for web-based analysis of inspection results.
- University of North Carolina, for identification of information requirements for the emerging AP219 specification.

IS2: Electronic Commerce for the Electronics Industry (ECEI)

Principal Investigator: Kevin Brady
Telephone: (301) 975 - 3644
E-mail: kevin.brady@nist.gov

The objective of this effort is to contribute to the technical development of the component information infrastructure for the electronics industry. This infrastructure enables the transfer of technical information among the manufacturers of electronic parts and those who need electronic parts for the design, manufacture, and repair of electronic systems. Technical areas addressed by ECEI efforts include the fundamental terminology used to describe components, the representation of the component data, capabilities to access component data and incorporate it into the product lifecycle. The project also addresses manufacturing information technology problems that exist at the intersection of manufacturing and electronic commerce systems. Results of ECEI efforts include contributions to the content of neutral data exchange specifications; validation of those specifications through prototype and pilot efforts with industrial partners; and, harmonization of the competing specifications originating in different consortia, trade associations, and formal standards organizations. Assisting in the development of standards in this domain is crucial to allow U.S. electronics manufacturers to take advantage of the global marketplace and to enable the acceleration of business practices such as the search for, and brokering of, component information via the Internet.



Engineering of electronic products via the Internet

Significant FY00/99 Accomplishments

- Developed conformance test software for the GenCAM specification that is available through www.gencam.org as well as on a CD-ROM available from the Association Connecting Electronics Industries (IPC). The conformance test software has been demonstrated at various industry conferences. The software has been maintained and updated to be consistent with changes in the GenCAM specification. In addition, project staff have made significant contributions to the development of the GenCAM specification itself.
- Provided leadership to the National Electronics Manufacturing Initiative (NEMI) Factory Information Systems Technology Implementation Project and the Virtual Factory Information Interchange Project.
- In conjunction with RosettaNet, NEMI, and the Open Application Group, harmonized specifications for manufacturing supply chain management and data exchange.
- Established a testbed for evaluation of software agent technologies in the context of electronics industry business processes. Developed and tested a multi-agent system for quoting and bidding on printed circuit boards, emulating the process that takes place between original equipment manufacturers and electronics manufacturing services.
- Contributed to the development of the QuickData specification and released a reference implementation of the specification that was demonstrated at multiple industry conferences. Continued to maintain and update the reference implementation in conjunction with additions to the QuickData specification. Added other features such as secure socket layer security.
- Developed and demonstrated a prototype software tool enabling update and maintenance of the terminology dictionary being developed by RosettaNet.

Collaborations

- Association Connecting Electronics Industries (IPC), for development of standards supporting the flow of information across the electronics manufacturing supply chain.
- Agile Software, for validation of draft specifications relating to exchange of product information in electronics industry supply chains.
- Automata Design Inc., for analysis of requirements for electronics parts registries and catalogs.
- CommerceNet, for development of frameworks for electronic commerce.
- Defense Advanced Research Projects Agency, for work with the Electronic Technology Office on issues relevant to DARPA objectives.
- EOG, for analysis of component information needed to support assembly of printed circuit boards.
- FTL Systems, for development of software tools supporting virtual components.
- Georgia Institute of Technology, for pilot evaluation of evolving electronics industry interchange specifications.
- Object Management Group, for development of specifications relating to electronic commerce and software agents.
- National Electronics Manufacturing Initiative, for development of technology roadmaps and coordination of industry pilot projects.
- National Aeronautics and Space Administration, for analysis of component information and parts libraries requirements.
- Netfish Technologies, for prototype evaluation of emerging standards for electronic commerce.
- Pennsylvania State University, for coordination of standards development activities.
- RosettaNet, for development of electronic commerce specifications and evaluation of their utility.
- SEMATECH, for analysis of requirements relating to semiconductor manufacturer needs.
- Silicon Integration Initiative, for development of electronic component information standards and software testing tools.
- Surface Mount Equipment Manufacturers Association (SMEMA), for development of interface specifications for printed circuit board manufacturing equipment.
- University of Maryland Baltimore County, for investigation of component information in electronic design automation.
- University of Virginia, for investigation of standards testing issues.
- Viewlogic Systems Inc., for analysis of electronic component data requirements in electronic engineering and design software.

IS3: Information Technology Metrology for Manufacturing Program

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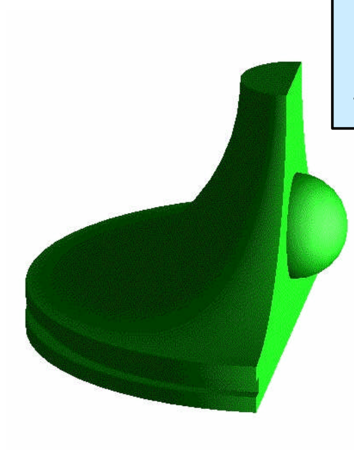
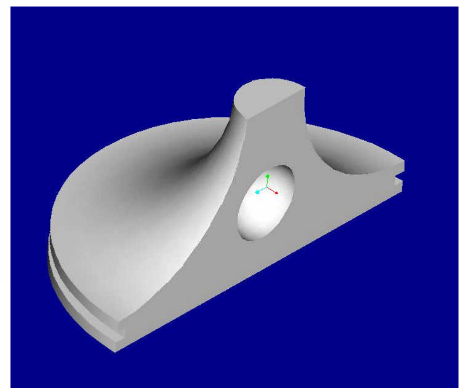


Test Case: Revolved Object with Void
Test the processing of information elements adv_brep_shape_rep, brep_with_voids and elements used in their construction (CC6).



STEP test artifact

The objective of this effort is to develop and provide formal methods, reference artifacts, and testing services that U.S. industry needs for continuous improvement of manufacturing software interoperability and information reliability. The approach is to identify the elements common to individual measurement issues, to synthesize these common elements into the principles underlying rigorous testing approaches, and to codify these principles into a set of formal methods that can be applied over a wide spectrum of manufacturing problem domains. By working with industry, staff will identify and enumerate types of software testing relevant to systems integration, determine how those testing mechanisms relate to one another, develop a lexicon of testing terminologies, investigate the methodologies and metrics relevant to systems integration testing and software behavior characterization, and develop best-in-class approaches. This research and development will lead to a measurement infrastructure for manufacturing IT. These fundamental research efforts will be conducted in parallel with applied research efforts that seek to solve the near-term problems faced by industry in the areas of manufacturing software conformance and interoperability, manufacturing software accuracy, and the interactions of “systems of systems.” Work on these nearer-term efforts will be grounded in the requirements expressed by industry and conveyed to NIST through workshops, standards committee meetings, and industrial partnerships. Specifications resulting from developed technical solutions will be disseminated through research publications and standards organization submissions. Software testing tools developed as part of these efforts will be disseminated as appropriate for further development by commercial organizations.

Significant FY00/99 Accomplishments

- Contributed to ISO 10303 Part 32 - “Conformance Testing Methodology and Framework: Requirements on Testing Laboratories and Clients,” which has since been accepted as an international standard.
- Contributed to ISO 10303 Part 34 - “Conformance Testing Methodology and Framework: Abstract Test Methods,” which has since been accepted as an international standard.
- Implemented the EXPRESS Web Server that provides web-based access to several software tools useful for developers and users of ISO 10303 (STEP) and ISO 10303-11 (EXPRESS).
- Implemented a demonstration illustrating how XML and other web standards could be used to interactively browse an annotated EXPRESS model.
- Completed and released Version 2 of the NIST Expresso software tool. Expresso is used to validate STEP schemas and STEP translator conformance.
- Led a session at the World Automation Congress (June 2000) on “Component-based Standards Development for Manufacturing.” The session included presenters from industry, government, and academia.
- Contributed to the implementation of a STEP conformance certification program, resulting in certification of several major CAD systems and the determination that the U.S. Product Data Association (US PRO) and the French GOSET conformance verification methods are functionally equivalent. US PRO and GOSET can now issue certification of conformance based on each other’s testing results.
- Delivered the EXPRESS-X (ISO SC4 WG11 Part 14) specification. EXPRESS-X defines mappings between information models defined in EXPRESS. The EXPRESS-X language allows creation of alternate representations of EXPRESS models and mappings between EXPRESS models and other applications.

Collaborations

- Automotive Industry Action Group, for evaluation and deployment of STEP capabilities in production environments.
- Boeing, for development of conformance testing and vendor certification requirements.
- Environmental Research Institute of Michigan, for development of software tools to test STEP implementations.
- National Aeronautics and Space Administration, for validation of the Object Management Group (OMG) Product Data Management (PDM) Enablers specification.
- PDES Inc., for validation of conformance testing tools through pilot implementation projects and for investigation of solutions to STEP interoperability issues.

IS4: Intelligent Unit Process Control in Next Generation Open Manufacturing Systems

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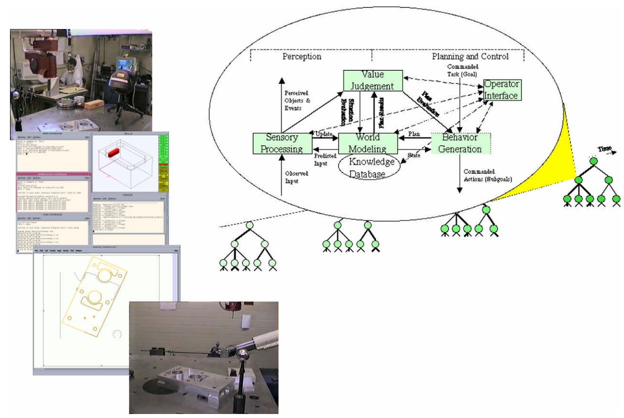

Intelligent architecture applications

The objective of this effort is to enable intelligent unit-process component integration for next-generation manufacturing systems through interface standardization, testing, and architectural analysis. Intelligent control is a critical enabler for realizing increases in productivity and quality during production. Industry roadmaps call for intelligent control capabilities such as self-diagnostics, adaptive control, error compensation, thermal and load compensation, and tool wear and breakage monitoring. Achieving these advances requires real-time sensing, process control, and behavior prediction to take appropriate action in unexpected situations. These capabilities are the essence of intelligence at the unit process level. Realizing them requires common approaches to representing knowledge in models for real-time control, agreed-upon interfaces for adding modular functionality, and an architecture for fitting all of this together. Hence three primary thrusts comprise our approach: 1) in collaboration with industry, develop and perform tests, test methods, and performance measures in a set of testbeds, 2) research and engineer solutions to problems cited in industry roadmaps to enable intelligent control, and 3) participate in efforts to specify standards. Within each of these thrust areas, we will address the problems of three major classes of unit process equipment – inspection systems, machine tools, and robots. Through this project structure, we can efficiently address the near-term, high-priority problems currently identified by industry as well as the longer-term problems likely to arise in pursuit of the challenges expressed in industry roadmaps.

Significant FY00/99 Accomplishments

- Completed design and implementation of a multi-level, reference architecture software infrastructure upon which software testbeds addressing specific industry problems can be implemented.
- Developed and demonstrated feature-based planning, inspection, and control, highlighting results of developing, validating, and testing standards-based interfaces for planning and execution in conjunction with reference architecture software infrastructure. Standards validated, demonstrated, and revised as a part of this work included multiple parts of ISO 10303 (informally known as the STandard for the Exchange of Product model data, or "STEP") and the national Dimensional Measuring Interface Standard.
- Completed documentation of the Open Modular Architecture Controller (OMAC) Application Programming Interface (API) covering significant aspects of the specification. Initiated implementation of a suite of OMAC API validation tools.

Collaborations

- Advanced Technology and Research Corp., for implementation of open architecture concepts and supporting tools.
- Association for Manufacturing Technology, for identification of issues relevant to improved manufacturing processes.
- Carnegie Mellon University, for work with The Robotics Institute on manufacturing system component interfaces for modular systems and software agents.
- Catholic University, for development of architecture concepts, feature-based control, information standards as well as prototype implementations.
- Drexel University, for development of experimental planning and learning components as well as performance metrics for intelligent systems.
- Enhanced Machine Controller Consortium, for development of software environments enabling implementation of open architecture concepts.
- Metrology Automation Association, for analysis of requirements for information standards relating to inspection processes and for validation of prototype implementations.
- Next Generation Inspection System Consortium, for analysis of requirements for enhanced inspection process capabilities.
- Open Modular Architecture Controller (OMAC) Users Group, for development of interface specifications for machine controllers.
- Pathway Technologies Inc., for development of software supporting simulation of architecture concepts.
- Real-time Innovations Inc., for investigation of control system design tools and technology transfer of control system architecture concepts.
- University of Delaware, for application of architecture concepts to complex mechanisms.
- University of Maryland, for development and testing of advanced planning functions.

IS5: Manufacturing Enterprise Integration Program

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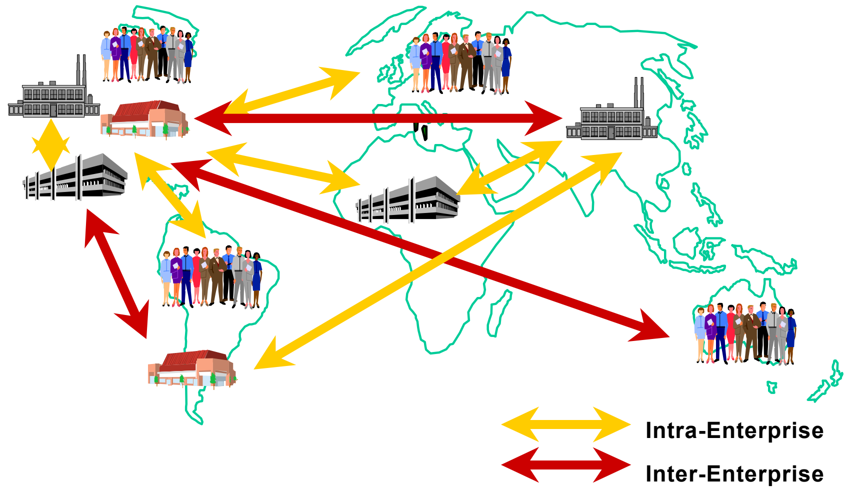
The objective of this effort is to provide U.S. industry with standards and tools that facilitate the integration of high-level manufacturing enterprise systems within and across enterprises. Towards this end, program technical staff will develop four primary classes of products:

- Analyses that document issues of concern to the manufacturing community regarding the adoption of leading-edge information infrastructure technologies and standards
- Models that represent the information, processes, structure, and behavior of manufacturing enterprise systems
- Prototype systems that demonstrate feasibility of standards-based solutions and emerging technology solutions to manufacturing enterprise integration problems
- Standards that document consensus agreements regarding terminology, information, specifications, methods, and architectures that specify the structure and enable the integration of enterprise systems



Typical global exchange scenario

The program uses a systems approach to develop a top-level set of enterprise reference model standards, manufacturing operational models, system architecture models, system interface standards, and manufacturing information standards. It is examining the non-traditional notions of systems that are embodied in the emerging field of autonomous agents and it is contributing to the emerging notion of self-integration. Engineering and analysis of manufacturing systems will provide the basis for development of interface standards and information model standards. Traditionally, such engineering and analysis yields static models of manufacturing activities and information flows. We are now beginning to leverage techniques used in manufacturing simulation to perform dynamic analysis of this view of manufacturing systems. As developments in process representation begin to mature, it is expected that those results also will be applied. Whether static or dynamic, these models provide the basis for the functional decomposition of manufacturing software.

Significant FY00/99 Accomplishments

- Demonstrated remote collaboration for a robotic arc welding testbed. Engineers in several locations were able to simultaneously view welding operations and related data, discuss resulting issues, and recommend corrective measures.
- Led efforts resulting in a formal liaison between ISO TC184/SC4 and TC184/SC5 to discuss standardization of the Process Specification Language (PSL) and its relationship to self-integrating systems.
- Provided key contributions to the Object Management Group's Manufacturing Domain Task Force (MfgDTF) Roadmap document and created a new roadmap for the MfgDTF Manufacturing Execution Systems roadmap.
- Provided key technical contributions to the Object Management Group Manufacturing Domain Task Force (MfgDTF) PDM Enablers specification. Contributions include work to harmonize the specification with other related specifications, a Guide for Decision Makers, and a Resource for Implementors.

Collaborations

- Advanced Micro Devices, for validation of the Advanced Process Control framework.
- American Production and Inventory Control Society (APICS), for identification of resource management issues characteristic of particular manufacturing models.
- Borg-Warner Automotive, for pilot evaluation of collaborative work mechanisms.
- Honeywell, for validation of the Advanced Process Control framework.
- Intelligent Automation Inc., for investigation of software agent systems.
- Oak Ridge National Laboratory, for investigation of software agent systems.
- Software Engineering Institute, for investigation of software component and software agent issues.
- Stanford University, for investigation of software agent infrastructures.
- Sun Microsystems, for investigation of collaborative work mechanisms for engineers in distributed manufacturing environments.
- Supply Chain Council, for investigation of supply chain models.
- TeamWave Software, for development of software tools enabling collaborative work mechanisms.
- University of Cincinnati, for investigation of software agent infrastructures.
- University of Maryland, for investigation of ad hoc collaborative work mechanisms.
- University of Michigan, for development and pilot evaluation of collaborative work mechanisms.
- University of Saskatchewan, for investigation of collaborative work mechanisms.

IS6: Manufacturing Simulation and Visualization Program

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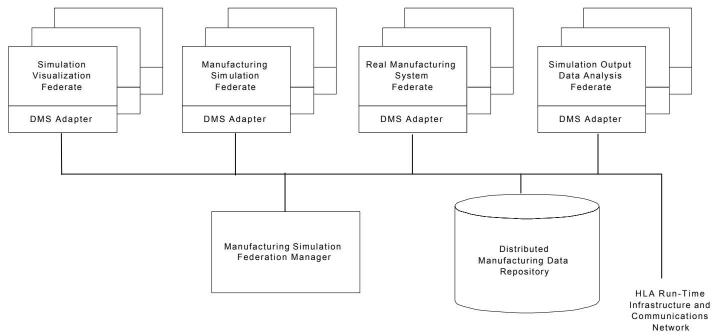

Distributed simulation architecture

The objective of this effort is to reduce the cost, increase the accessibility, and improve the interoperability of manufacturing simulation technology for U.S. industry through identification, development, and evaluation of data interfaces and methods for integrating manufacturing simulation applications with each other and with other manufacturing software applications. Standardized interfaces, component model libraries, and modeling techniques promise to reduce the cost and increase the accessibility of manufacturing simulation technology for U.S. industry. A major focus for the program is the identification and specification of data interfaces for various manufacturing simulation applications. The program will achieve its near-term objectives through work carried out with external collaborators, the international Intelligent Manufacturing Systems Program, the Navy Maritech Program, and the Object Management Group (OMG) Special Interest Group in Distributed Simulation (SIMSIG). The technical approach of the MS&V Program is to:

- Identify critical manufacturing process and system simulation domains and associated types of simulation software applications.
- Analyze current and future trends for simulation and testing technology.
- Establish specification and testing methods, models, and metrics for validating simulation systems interfaces.
- Identify tools and models to be used in the specification development, prototyping, and testing processes.
- Construct a testbed containing simulation applications, prototype integration, testing tools, and test cases.
- Specify and develop architectures, data models, and interface specifications for integrating simulation applications, component modules, and reference libraries.
- Conduct experimental tests, demonstrations, and reviews to substantiate the validation and testing process itself.
- Promote specifications as candidate standards within the national and international standards community.

Significant FY00/99 Accomplishments

- Established the U.S. team to the international Intelligent Manufacturing Systems (IMS) MISSION project.
- Developed two initial prototypes (in C and Java programming languages) of the IMS MISSION High-Level Architecture (HLA) simulation adapter.
- Developed specifications and XML data types for a power-tool manufacturing supply chain demonstration scenario. Presented the demonstration at an international IMS meeting in May, 2000.
- Demonstrated the NIST-developed Distributed Manufacturing Simulation Adapter and a shipyard repair and conversion simulation model at a National Shipbuilding Research Program Workshop, August, 2000.
- Developed specifications for a simulation environment, simulation model, and interfaces for a shipyard simulation and then demonstrated HLA integration using a Promodel simulator.

Collaborations

- Arizona State University, for investigation of mechanisms for modeling manual manufacturing operations and interfaces for simulation systems.
- AutoSimulation Inc., for integration of scheduling and simulation applications with upstream and downstream functions.
- Black and Decker, for provision of test parts and manufacturing data.
- Defense Modeling and Simulation Office, for investigation of the suitability of HLA to the Mission Project and distributed manufacturing simulations.
- Delmia Corporation, for integration of distributed simulation applications with upstream and downstream functions.
- EAI - CimTechnologies, for integration of distributed simulation applications with upstream and downstream functions.
- Florida International University, for investigation of manufacturing simulation and integration with upstream and downstream functions.
- Intelligent Manufacturing Systems MISSION Project, for work with this international consortium on development of neutral interfaces for simulation software.
- Knowledge Based Systems Inc., for integration of distributed simulation applications with upstream and downstream functions.
- Micro Analysis & Design Inc., for integration of distributed simulation applications with upstream and downstream functions.
- Motion Factory, for modeling of manufacturing operations.
- Musahi University, for development of object-oriented simulation modeling and business process models for supply chain management.
- Nyamekye Research and Consulting Firm, for development of simulation and activity-based costing models.
- Pennsylvania State University, for investigation of distributed manufacturing simulation and neutral model formats.
- ProModel Corporation, for integration of distributed simulation applications with upstream and downstream functions.
- Systems Modeling Corp., for integration of distributed simulation applications with upstream and downstream functions.
- Tecnomatix Technologies Inc., for integration of distributed simulation applications with upstream and downstream functions.
- University of Arizona, for development of a manufacturing scenario to be realized via the distributed manufacturing simulation for the Mission Project.
- University of Iowa, for investigation of distributed manufacturing simulation and simulation models.
- University of Illinois, for investigation of manufacturing simulation and virtual reality interfaces.
- University of Maryland, for investigation of architectures for distributed simulation.
- Virginia Polytechnic Institute, for investigation of mechanisms for integrating assembly process specifications with manufacturing visualization languages and interfaces.

IS7: Materials Informatics Resources: MatML

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The objective of this effort, initiated in FY00, is to develop a new materials information language, MatML, an application of the eXtensible Markup Language (XML) for storing, transmitting, and processing materials data distributed via the Internet. This effort will address issues of materials data interpretation and interoperability by defining a computer-sensible representation that avoids the ambiguities inherent in encoding schemes such as HyperText Markup Language (HTML). The approach taken will be to enlist the participation of worldwide stakeholders in materials information for agreement on the scope of MatML. With their input, we will (1) develop a draft MatML representation, (2) test the draft specification through application in existing materials databases, and (3) promulgate a validated MatML specification in relevant standards developing organizations.

The MatML project logo

Significant FY00 Accomplishments

- Assembled the MatML Working Group (see collaborators enumerated below).
- Designed, developed, and implemented a MatML Web Site providing capabilities for external contributors to participate in MatML development (see http://www.ceramics.nist.gov/matml/matml.htm).
- Led the MatML Working Group to define the scope and specifications for MatML.
- Developed the Annotated MatML Document Type Definition, which is the syntactic and semantic formalism that describes the new markup language and provides English-language descriptions of the components of MatML along with sample code wherein materials property data is "marked up."

Collaborations

The following are members of the MatML Working Group:

- ABB ALSTOM Power (UK)
- Aluminum Association
- ASM, International
- Atomic Weapons Establishment (UK)
- The Boeing Company
- CenTOR
- Colorado School of Mines
- ESM Software
- Ford Motor Company
- Information Analysis Center, Iowa State University
- Lawrence Berkeley National Laboratory
- Massachusetts Institute of Technology
- MSC Software
- NRIM (Japan)
- University of Delaware
- Virtual School of Molecular Sciences (UK)
- William Andrew Publishing

IS8: Predictive Process Engineering Program

Principal Investigator: Kevin Jurrens
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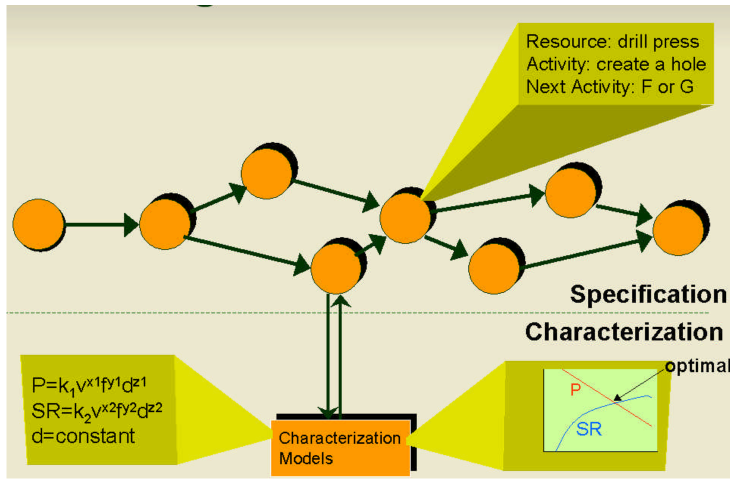
The objective of this effort is to develop standard manufacturing process specifications and application interface specifications to allow companies to better document, understand, and refine their processes, as well as exchange necessary process information among different functions both within their organization and among partnering organizations. Increasingly diverse software tools to capture, depict, simulate, analyze, and control processes cannot realize their potential to exchange process information freely in the absence of a robust, standard, formal method for representing processes. Key challenges in defining this neutral process representation include defining a common understanding of the semantic meanings of terms for describing process and developing multiple syntactic interpretations of these semantic descriptions. Once determined, these semantics will enable mapping between, for example, object-oriented, Knowledge Interchange Format (KIF) [16] and relational applications. Interaction between the conceptual product design, planning, and process functions would allow increased optimization of the manufacturing process. However, in current practice, conceptual design, process/resource selection, cost estimation, detailed design, and process planning are performed independently, without integrated software tools. This is primarily because conceptual design systems, computer-aided design (CAD) systems, cost estimating systems, and process planning systems are not designed for interoperability. Program staff will develop an initial specification of standard interfaces to enable such interoperability.



Integrated view of process

Significant FY00/99 Accomplishments

- Introduced the Process Specification Language (PSL) into the ISO TC184/SC4 and SC/5 sub-committees as a Preliminary Work Item. A joint SC4/SC5 working group will pursue development of PSL as a standard.
- Completed the first pilot implementation of PSL, successfully integrating the IDEF3-based ProCAP process modeling tool with the C++-based ILOG scheduler. In the on-going second pilot implementation, completed development of a translator from the MetCAPP planning and costing system to PSL. Work continues on a translator from PSL to the Quest simulation application.
- Conducted the Second PSL Roundtable in January 1999. Process representation experts reached consensus on the content of the PSL Version 1.0 specification and identified application areas and directions for the project to pursue.
- Developed an initial integrated Conceptual Design and Conceptual Process Planning activity model that defines the context in which conceptual design and process planning information can be shared and software interoperability can be enabled. Also developed an initial object model for Conceptual Design and Conceptual Process Planning Integration. This model specifies requirements for developing standard interface protocols.
- Gained ISO approval to incorporate the DPPI object model into Part 2 (Information Models for Interoperability) of the ISO 16100 standard for Manufacturing Software Capability Profiling and Interoperability.

<u>Collaborations</u>

- Bosonics, for development of neutral interface specifications enabling integration of process planning and cost estimating systems.
- Consortium for Advanced Manufacturing International (CAM-I), for work with CAM-I's Process Planning and Model Driven Engineering projects to enhance and extend models for integration of design and process planning.
- Defense Advanced Research Projects Agency, for work with the DARPA-sponsored Process Interchange Format group.
- Ford Motor Company, for work on the development of models for integration of design and process planning.
- Georgia Institute of Technology, for investigation of scenarios for information exchange between design and process planning.
- Ingersoll Milling Machines Company, for development of mechanisms to integrate design and process planning systems.
- Knowledge Based Systems Inc., for work on the development of the PSL and on pilot implementations.
- Knowledge Technologies International, for prototype implementation and validation of models for design and process planning information.
- Lockheed Martin Tactical Aircraft Systems, for development of mechanisms to integrate design and process planning systems.
- Oak Ridge National Laboratories, for work with the Collaborative Technologies Research Center to extend the PSL to encompass concepts necessary for software agent-based simulations and on the development of PSL tutorials.
- Pennsylvania State University, for investigation of extensions to PSL for manufacturing process planning.
- TechnoSoft Inc., for prototype implementation and validation of models for design and process planning information.
- University of Maryland, for work with the Institute for Systems Research on language development issues as well as for work with the Department of Mechanical Engineering to model cost estimating in process planning.
- University of South Carolina, for work with the Center for Information Technology on language translator theory.
- University of Toronto, for work with the Enterprise Integration Laboratory on the development of core language semantics.

IS9: Product Data Standards for the HVAC/R Industries

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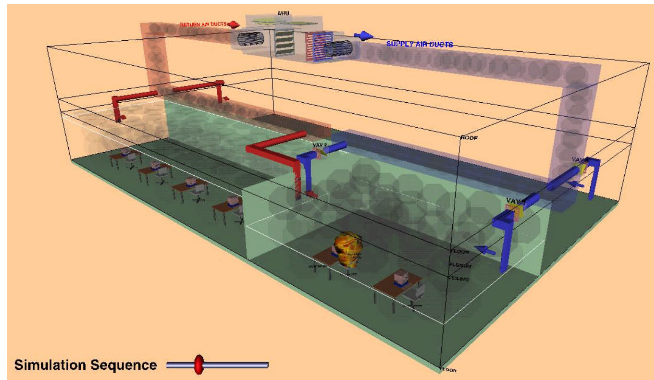

Simulation of smoke transport by HVAC system

The objective of this effort, initiated in FY00, is to develop a standards-based information infrastructure supporting the design, analysis, specification, procurement, installation, operation, and maintenance of heating, ventilation, air-conditioning, and refrigeration (HVAC/R) systems. Heating, ventilation, air-conditioning, and refrigeration systems are essential elements of any facility, be it a building, plant, or ship. Increasingly, facility owners are striving to optimize not just the performance and reliability but also the life-cycle cost of their HVAC/R systems. Complete and timely information must be shared among all the people who deal with HVAC/R systems if facility life-cycle goals are to be achieved. In addition to the manufacturers of components, these people include designers, analysts, specifiers, procurers, installers, operators, and maintainers. Typically, the information to be shared about HVAC/R systems covers mechanical equipment, ducting and piping, power, sensors and controls; it must deal with both intrinsic and installed form, fit, function, and behavior. This information must be melded appropriately with information about the spaces or processes to be conditioned by the systems. This information must be sufficiently rich to enable not only optimized operation but also automated diagnosis and recovery from fault conditions. The emerging demand on the part of facility owners for integrated, holistic control of all facility systems means this information must be available in a form consistent with other systems. The technical approach of this effort initially will address file-based exchange of explicit, static product data. Following that, the work will be extended to include control algorithms and other dynamic functional and behavioral information, and to deal with fault detection and diagnostic applications.

Significant FY00 Accomplishments

- Expanded an existing simulation of building systems, the Virtual Cybernetic Building Testbed (VCBT), to allow for investigation of more complex building system dynamics. In addition, constituent software components of the VCBT were enhanced to allow for integration of planned systems and capabilities.
- Developed initial database implementations of the Industry Foundation Class (IFC) specification to serve as platforms for investigation of the capabilities of the specification.
- Developed XML representations of the data needed to drive existing NIST-developed HVAC simulations and developed mechanisms for mapping those representations to that of the IFC-based databases.

Collaborations

- International Alliance for Interoperability, for development of specifications relating to HVAC/R in Building Services Domain projects.
- Lawrence Berkeley National Laboratory, for work toward the development of the Department of Energy building energy simulation program.
- Mannheim University of Applied Sciences, for investigation of the validity of emerging specifications relating to HVAC/R.
- National Institute of Building Sciences, for analysis of information requirements for HVAC/R in conjunction with the Facilities Maintenance and Operation Committee.
- U.S. Army Corps of Engineers, for work toward the development of the Department of Energy building energy simulation program.

IS10: Product Data Standards for the Process Plant Industries

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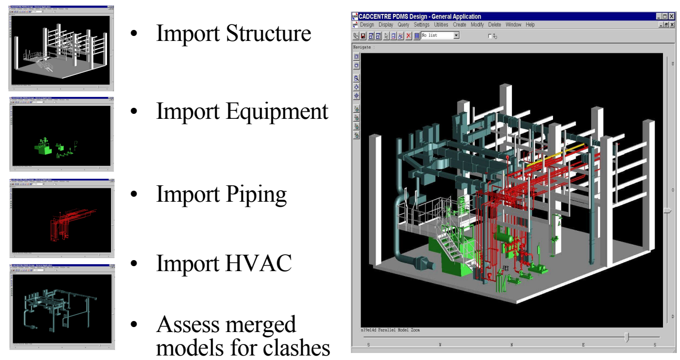

Demonstration of AP227 use

The objective of this effort is to develop and demonstrate data exchange standards that reduce life-cycle costs for the design, construction, operation and maintenance of industrial facilities. The U.S. process plant industries seek to improve their project delivery capabilities through improved work processes and the integration of information systems, e.g., the exchange and sharing of information among computerized systems and operators. The many computerized systems in use can be integrated only at great cost because of their incompatible proprietary representations of information. Standard, neutral, information representations and exchange methods are needed that allow system vendors to be innovative and yet allow system users (process engineers to piping fabricators to construction planners) to exchange and share information about process plant projects automatically and reliably. The ISO 10303 (informally known as the STandard for the Exchange of Product model data, or "STEP") application protocols (APs) are providing a base technology for the needed information. STEP APs must be developed to meet the needs of the process plant industries. The approach to be followed is to:

- Investigate U.S. industries' capabilities, problems, and potential improvements (work processes and technologies) in the piping delivery process, i.e., detailed design, fabrication, inspection, installation and testing of piping systems.
- Work with stakeholders to improve ISO 10303-227 [17] for exchanging information about piping systems and equipment and to develop an extension to ISO 10303-227 to support the exchange of piping fabrication, inspection and installation information.
- Work with industry on pilot projects to test and demonstrate the use ISO 10303-227.

Significant FY00/99 Accomplishments

- Assessed international ballot comments on the committee draft version of the Process Engineering Data application protocol specification (ISO 10303-231) [18] and developed a plan for moving the evolving specification forward to draft international standard status.
- Completed the international standard version of the Plant Spatial Configuration (Edition 1) application protocol specification (ISO 10303-227). Provided recommendations for an industry-driven, test-case-development process that has been adopted by ISO TC184/SC4. In conjunction with industry partners, demonstrated initial implementations of the standard at industry conferences and presented results from pilot use by companies such as Merck.
- Established an industry advisory team for improving piping system delivery. Through three workshops with the team, identified priorities and documented requirements for pipe prefabrication and inspection information exchange capabilities.
- Initiated a new work item for a 2nd edition of ISO 10303-227 based on the recognized interest of the U.S. process plant and shipbuilding industries.

Collaborations

- Bechtel, for development, testing, and deployment of ISO 10303-227 as well as investigation of issues related to piping prefabrication and inspection.
- Black & Veatch, for development of ISO 10303-227 as well as an industry roadmap for information exchange standards for the process and construction industries.
- Construction Industry Institute, for analysis of construction industry supply chain performance.
- Dow, for work to extend ISO 10303-227 to cover piping fabrication, inspection, and installation.
- DuPont, for development, testing, and deployment of ISO 10303-227, for standards coordination efforts, and for establishment of an Owners/Operators forum.
- H.B. Zachary, for work to extend ISO 10303-227 to cover piping fabrication, inspection, and installation.
- Merck, for development, testing, and deployment of ISO 10303-227 and for standards coordination efforts.
- National Shipbuilding Research Program, for work with the Maritech Program on extensions to ISO 10303-227 as well as analysis of requirements for delivery of piping and HVAC systems for industrial facilities.
- PIEBASE, for coordination of projects to develop and demonstrate specifications for exchange and sharing of process plant information.
- PlantSTEP Inc., for deployment of ISO 10303-227 and on development of extensions to that standard.
- POSC (Petrotechnical Open Software Corporation), to identify industry requirements for standards to support data sharing over the lifecycle of process plants.
- Process Data eXchange Institute of AIChE (pdXi), for development of information specifications for process engineering.
- Process Industry Practices, for improvements to the piping delivery process.
- Stanford University, for work with the Center for Integrated Facilities Engineering on issues related to the use of electronic commerce for the design, engineering, and maintenance of process plants.
- The Shaw Group Inc., for work to improve the piping delivery process and extensions to ISO 10303-227 to cover piping fabrication, delivery, and installation.
- U.S. Navy, for work with the Navy Industry Digital Data Exchange Standards Committee (NIDDESC) on extensions to ISO 10303-227.

IS11: Product Engineering Program

Principal Investigator: Ram Sriram
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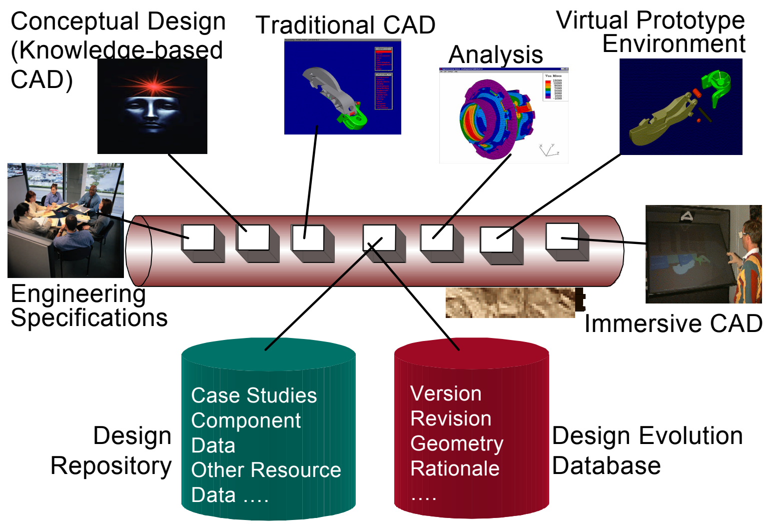

Interoperability of CAD and product engineering systems

The objective of this effort is to develop information protocols for interoperability of computer-aided design and product engineering systems, providing a basis for future standards. Specifically, the primary needs for the next generation of computer-assisted design, manufacturing, and engineering (CAD/CAM/CAE) software systems are interoperability among software tools, collaboration among distributed designers and design teams, integration of data and knowledge across a product development cycle (from design, to analysis, to manufacturing and beyond), as well as knowledge capture, exchange, and reuse. The research and development efforts within this program, ranging from specification and standards development to technology development and prototype implementation, strive to provide the foundation that will support the creation of next-generation product development tools, thereby increasing the efficiency and productivity of U. S. industry in the 21st century.

Significant FY00/99 Accomplishments

- Hosted a workshop on “Design/Manufacturing Integration: Standards and Implementation Issues” in November 1998.
- Organized and chaired ISO TC184/SC4 Parametrics workshops in San Francisco (January 1999), Orlando (July 1999), and at NIST (May 2000).
- Developed a comprehensive Function-Assembly-Behavior model addressing shortcomings in existing function, form, and behavior representations.
- Completed first draft of a set of information models that define the core artifact representation required for product development to serve as a foundation for interoperability among next-generation CAD/CAM/CAE applications. Also created a relational data model based on the core representation, as well as a relational database that uses this data model.
- Completed development of a Solid Interchange Format for Layered Manufacturing (SIF-LM) and submitted the format to ISO TC184/SC4 for consideration as a preliminary work item. SIF-LM has the capability to represent components, assemblies, and sets of assemblies.

Collaborations

- Advanced Technology Institute, for development of information exchange specifications for parametric geometry and for history-based geometric modeling.
- Arizona State University, for development of information exchange specifications for parametric geometry.
- Black & Decker, for analysis of product development processes and as a source of data.
- Carnegie Mellon University, for development of formalisms representing behavior of devices.
- Cummins Inc., for development of interfaces supporting integration of immersive CAD systems with traditional CAD systems.
- Defense Advanced Research Projects Agency, for joint work in the Enabling Next Generation Design (ENGEN) project, the Rapid Design Exploration and Optimization (RaDEO) project, and in the development of information exchange specifications supporting rapid prototyping technologies.
- FunSTEP, for development of information exchange specifications for parametric geometry.
- Helisys Corporation, for development of information exchange specifications supporting rapid prototyping technologies.
- Honeywell, for development of information exchange specifications supporting rapid prototyping technologies as well as for development of information exchange specifications for parametric geometry.
- Indian Institute of Technology, for development of information exchange specifications supporting rapid prototyping technologies.
- International Business Machines Co., for development of information exchange specifications for parametric geometry.
- Nihon Unisys, for development of information exchange specifications for parametric geometry.
- Paccar Inc., for development of interfaces supporting integration of immersive CAD systems with traditional CAD systems.
- SRI International, for development of information exchange specifications supporting rapid prototyping technologies.
- Stanford University, for development of information exchange specifications supporting rapid prototyping technologies.
- Syracuse University, for investigation of tolerancing issues in assembly representations.
- U.S. Navy, for work with the Office of Naval Research on development of information exchange specifications supporting rapid prototyping technologies.
- University of Maryland, for development of methods and software tools supporting knowledge-based design.
- University of Michigan, for development of information exchange specifications supporting rapid prototyping technologies.
- Virtual Assembly Technology Consortium, for development of interfaces supporting integration of immersive CAD systems with traditional CAD systems.
- Washington State University, for development of interfaces supporting integration of immersive CAD systems with traditional CAD systems.

IS12: Sensor Integration

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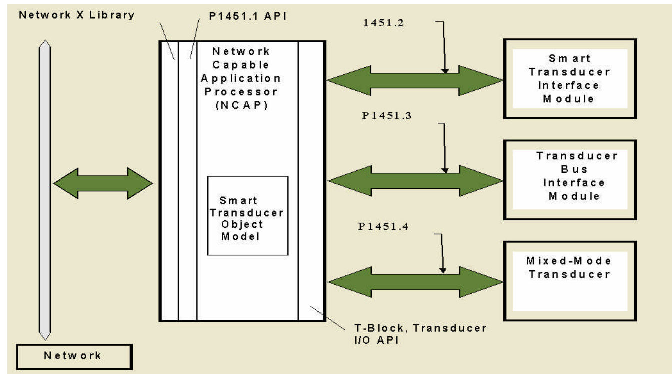
The objective of this effort, initiated in FY00, is to work with industry to complete the development, validation, and testing of standard interfaces for smart sensors. The standards developed will enable sensor devices to interface with common networking technologies. Through these standardized interfaces, sensor data will move seamlessly from the process level through the controller level to the enterprise level. Sensors and actuators are essential components that are used in a wide range of applications in industrial automation, manufacturing process control, machinery monitoring and control, semiconductor device manufacturing, and facility automation. Typical sensors include miniature electronic devices and micro-electro-mechanical systems (MEMS) that measure pressure, acceleration, flow, force, temperature, vibration, torque, position, and many other characteristics. In-process sensing techniques, capable of providing feedback for process control, are important means for achieving improved process quality and reduced manufacturing costs. With the emergence of the Internet and related technologies, sensor makers are integrating smart sensing, digital communication, and networking technologies into their products, allowing for more efficient operations and maintenance through local or wide-area networks. NIST is taking the approach of integrating the Institute of Electrical and Electronics Engineers (IEEE)1451 standard interfaces [19] with Internet-based technology for manufacturing systems integration. The result will be to solve the sensor-to-network interoperability problem for manufacturing systems integration.



Integration of sensor data

Significant FY00/99 Accomplishments

- Developed a software infrastructure that serves an implementation platform for prototyping aspects of the IEEE 1451.1 smart transducer interface specifications. The software infrastructure has been tested for compatibility with various common commercial and open source operating systems.
- Implemented a subset of the IEEE 1451.1 specifications and demonstrated functionality with an embedded network-capable application processor for temperature sensing.

Collaborations

- Aeptec Microsystems, for development of mechanisms for sensor integration with wireless networks based on IEEE 1451.
- Agilent Technologies, for development of the IEEE 1451 specifications, implementations, and tests.
- Boeing, for development of the IEEE 1451 specifications, implementations, and tests.
- Brüel & Kjær, for development of the IEEE 1451 specifications, implementations, and tests.
- Endevco, for development of the IEEE 1451 specifications, implementations, and tests.
- Kistler Instrument Corp., for development of the IEEE 1451 specifications, implementations, and tests.
- Oak Ridge National Laboratories, for development of the IEEE 1451 specifications, implementations, and tests.
- PCB Group/The Modal Shop, for development of the IEEE 1451 specifications, implementations, and tests.
- Wilcoxon, for development of the IEEE 1451 specifications, implementations, and tests.

IS13: Visualization and Virtual Reality for Collaboration and Manufacturing

Principal Investigator: Sandy Ressler
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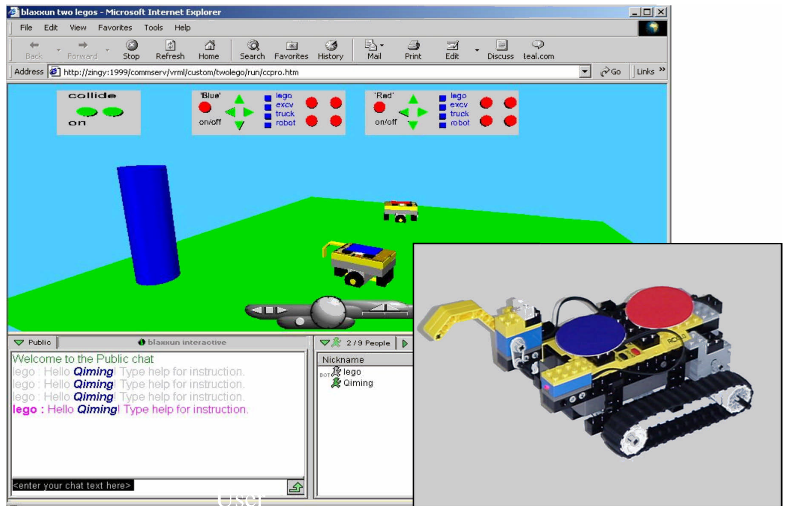
The objective of this effort is to assist in the definition, development, and validation of the infrastructure underlying Virtual Environments (VEs). Businesses are investigating the use of VEs for a variety of applications, e.g., as collaborative environments for distributed design, as real-time data-driven emulations of physical production facilities that can be remotely monitored, and so on. In order to integrate representations of physical entities and data from the physical world into VEs, a variety of enabling standards have emerged. These include the Virtual Reality Modeling Language (VRML) [20], Moving Pictures Expert Group - 4 (MPEG-4) [21], and Synchronized Multimedia Integration Language (SMIL). Additional specifications continue to emerge, creating the need to assist in the validation of the enabling infrastructure through (1) prototype software development that leverages existing commercial capabilities, and (2) participation in the multiple, relevant, standards-setting bodies.



Testbed for incorporation of real objects into virtual world

Significant FY99/00 Accomplishments

- Completed a prototype VRML-based multi-user shared environment (“Smart Room”) that demonstrated various capabilities for interfacing between the physical world and the virtual environment. These capabilities included a six-degree-of-freedom position tracking device, a server for control of cameras in both the physical and virtual environment, a generalized serial port server for interfacing devices with the virtual environment, and a broadcast system for distribution of the environment over a network.
- Contributed to the development of a demonstration illustrating how a collaborative virtual environment could be used to facilitate trouble-shooting of a welding cell by a collection of geographically distributed engineers.
- Completed JVEDI - “Java Virtual Environment Device Interfaces” - a server to link VRML environments with serial port devices and made the server software publicly available.
- Elected to the Board of Directors for the Web3D Consortium.

Collaborations

- blaxxun interactive, for the creation of multiuser environments.
- Knowledge Revolution, for investigation of the use of VRML in conjunction with their software.
- Web3D Consortium, for participation in the development of VRML content.

Information Access Project Summaries

IA1: Computerized Access to Full Structural Crystallographic Data

Principal Investigator: Vicky Lynn Karen
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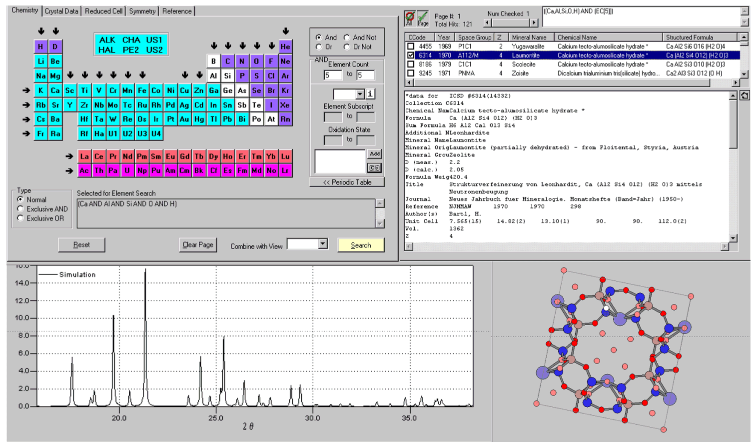
The objectives of this effort are (1) to make inorganic crystal structure data readily accessible via the Internet using a modern database management system, and (2) to offer additional functionality through the development of software tools for the calculation and standardization of derived data items as well as modules for intelligent access of scientific data. The Inorganic Crystal Structure Database (ICSD) is a comprehensive compilation of crystal structure data of inorganic compounds currently containing approximately 55,000 entries and covering literature from 1915. Data items include chemical, physical and bibliographic information as well as crystallographic data such as cell parameters, space group, and x,y,z positional parameters, among others. The crystalline structure of inorganic materials is of interest to analysts in areas such as materials design, properties prediction, and compound identification. By using a modern database management system to manage the ICSD, NIST will make it possible to use the database as a tool to investigate, predict, and modify crystal structure and solid state properties and to gain increased understanding of material properties. This should open the way to advances in manufacturing applications and help companies to lower costs, increase research efficiency, and accelerate product discovery and development cycles. Ultimately, manufacturing methods may become more automated with improved in situ measurement capability and better processing control.



ICSD user interface and examples of search results

Significant FY99/00 Accomplishments

- Completed relational database design including data dictionary, entity relationships, archival, and derived data.
- Completed the importing of archival data into database management systems.
- Developed underlying search algorithms, implemented graphical user interface modeled after the periodic table of the elements, and capabilities to analyze search results using crystallographic parameters.

Collaborations

- Fachinformationszentrum Karlsruhe, Gesellschaft für wissenshaftlich-technische Information mbH (FIZ Karlsruhe), for development of the Inorganic Crystal Structure Database.

IA2: Digital Library of Mathematical Functions

Principal Investigator: Daniel Lozier
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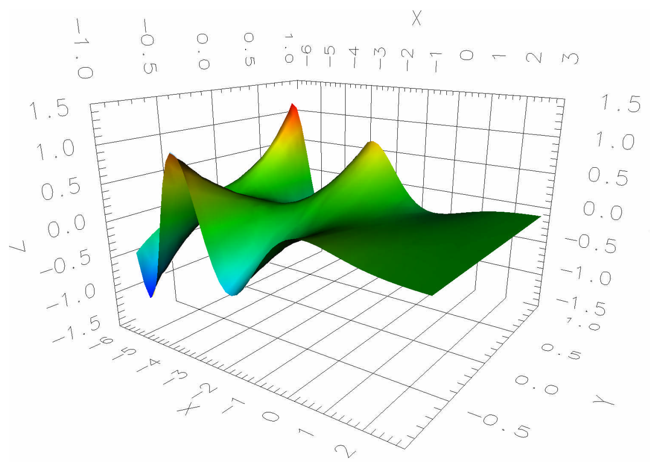
Advanced manufacturing processes depend upon basic mathematical data and procedures. The definition and properties of the higher mathematical functions, such as the error, the Bessel, and the Legendre functions, are particularly important because they arise so frequently in applications. The objectives of this effort are (1) to develop and standardize a comprehensive, ongoing, and authoritative body of information on the notation, properties, computation, and applications of the higher mathematical functions, and (2) to present this data free of charge on the Internet in the form of an interactive library of mathematical functions. We anticipate that design engineers will use the Digital Library of Mathematical Functions (DLMF) directly in some cases, integrating it into their own online information systems. Others will rely primarily on commercial mathematical software systems, which themselves will benefit from an online, standardized source of reference data for the functions that they provide.



Manipulable graph of a special function of a complex variable

This effort is a successor to the Handbook of Mathematical Functions [22] published by NIST (then the National Bureau of Standards) in 1964. This classic reference work, known simply as AMS 55, contains formulas, graphs and tables that characterize the higher functions of applied mathematics. These functions are often known as special functions; examples are Bessel and Legendre functions, elliptic integrals, and classical orthogonal polynomials. Such functions are used extensively in mathematical analysis that forms the foundation of the engineering and industrial processes that are used in manufacturing applications. As a definitive source of standard mathematical reference data, AMS 55 has had an enormous impact on scientific and technological practice. In spite of its continued popularity, AMS 55's technical content is current only up to about 1960, and its strong emphasis on mathematical tables is no longer as relevant as before. Many mathematical and computational advances have occurred in the intervening years, and many new applications of special functions have emerged. Thus, the Digital Library of Mathematical Functions will be a “new AMS 55” that is expected to meet the needs of the 21st century.

Significant FY99/00 Accomplishments

- Released a prototype, public website illustrating the concept for the DLMF. The website is also used to solicit ideas and feedback. (See http://dlmf.nist.gov.) A password-protected portion of the website was established for project contributors.
- Award for financial support of authors and validators external to NIST received from the National Science Foundation (NSF) under the auspices of its Knowledge and Distributed Intelligence program.
- Authors for all chapters have been identified and all authors’ contracts will be signed by January 2001. Outlines for all chapters have been accepted by NIST and two draft chapters have been delivered for review.
- Numerous conference presentations on the progress of the DLMF have been given throughout the world and a DLMF exhibit was presented at the largest mathematical meeting held in the U.S. This same exhibit was displayed at an annual event showcasing significant projects supported by NSF at the Rayburn House Office Building for elected officials and their staff.

<u>Collaborations</u>

- CWI, the National Research Institute for Mathematics and Computer Science in the Netherlands, for development of DLMF content.
- George Washington University, for development of search capabilities in the DLMF.
- INRIA, the French National Institute for Research in Computer Science and Control, for development of DLMF content
- MathSoft, Inc. for development of computer-interpretable DLMF content suitable for downloading into computer algebra systems.
- National Science Foundation, for support of external efforts on behalf of the DLMF.
- North American OpenMath Initiative, for development of a standard for communicating mathematical objects between computer programs.
- OpenMath Consortium, for development of a standard for communicating mathematical objects between computer programs.
- Faculty at the following universities are collaborating with the DLMF effort toward development and/or editing of specific sections of the materials to contained therein:
  - American University of Sharjah
  - Beloit College
  - California Institute of Technology
  - City University of Hong Kong
  - Dalhousie University, Canada
  - Delft University of Technology, The Netherlands
  - Drexel University
  - Free University Amsterdam, The Netherlands
  - George Washington University, Washington DC
  - Iowa State University, Ames
  - J. Kepler University, Research Institute for Symbolic Computation, Austria
  - Macalester College
  - Massachusetts Institute of Technology
  - Pennsylvania State University
  - Purdue University
  - San Diego State University
  - Stanford University
  - University College, London
  - University of Abertay Dundee, Scotland
  - University of Bristol, England
  - University of California, Santa Barbara
  - University of Kent at Canterbury, England
  - University of Edinburgh, Scotland
  - University of Essen, Germany
  - University of Leeds, England
  - University of Lille, France
  - University of Maryland, College Park
  - University of Southampton, England
  - University of St. Andrews, Scotland
  - University of Washington, Seattle
  - University of Wisconsin, Madison
  - University of Wisconsin, Milwaukee
  - Washington University, St. Louis

IA3: Integration of NIST Standard Reference Data into Information Networks

Principal Investigator: Robert Dragoset
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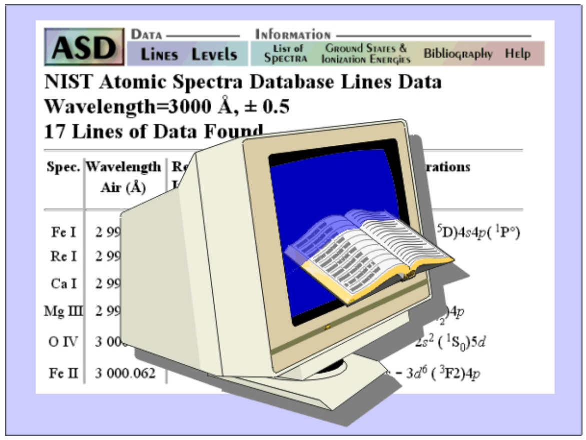
E-mail: robert.dragoset@nist.gov



Desktop access to physics reference data

The objective of this effort is to make physical reference data available via the Internet (http://physics.nist.gov/data) in the most effective manner and by using industry-defined standards and formats so that it may serve as part of an integrated technical information system. Scientific, engineering, regulatory and other technical data are vital to U.S. industry. This information is used at all stages of a product's life cycle. It also supports the scientific and engineering research community. The large number and varying quality of data sources ranging from handbooks, technical journals, special publications, and data safety sheets, to government agency databases, and databases provided by groups such as professional societies and trade associations, make it difficult to locate the proper source for required data. Today, the Internet allows the possibility of immediate access to thousands of data sources. A well-designed system for accessing these data will allow researchers and technologists to obtain the latest information, with the required quality, at a reduced cost, and in a timely manner. NIST is heavily involved in all aspects of the production, evaluation, use, and dissemination of technical information. Both numeric data and bibliographic databases are provided together with the means for a user to search these databases intelligently. The dissemination methods used are very effective and are designed to appropriately deliver to the users of each database the information in the most effective form.

Significant FY99/00 Accomplishments

- Developed and released a new version of the NIST Atomic Spectra Database. This database has a completely new engine and vastly expanded data that integrates its atomic energy level information with its transition probability information.
- Developed and released the Atomic Spectral Line Broadening Bibliographic Database.
- Three new web radiation dosimetry databases, ESTAR, PSTAR, and ASTAR, have been developed and released. In real time, these databases calculate, tabulate, and plot stopping-power and range tables for electrons, protons, or helium ions using user-specified energy values. A special interface feature formats the data output in a form suitable for incorporation into a spreadsheet. Additionally, the FORTRAN source code and PC executables can be downloaded by all users. (See: http://physics.nist.gov/Star.)
- The Elemental Data Index was developed in order to provide access to the on-line holdings of the NIST Physics Laboratory. It is intended to simplify the process of retrieving online scientific data for a specific element. Data accessible through this index include: atomic spectroscopic data, electron-impact ionization cross sections, x-ray

and gamma ray absorption data, radiation dosimetry data, radionuclide half-life measurements, isotopic compositions and atomic weights, and atomic reference data for electronic structure calculations. Other Physics Laboratory databases were modified to allow access to data through the Elemental Data Index.

- Added capabilities for users to download the FORTRAN source and executable code for the XCOM: Photon Cross Sections Database.
- Designed and created the "Microwave Molecular Spectral Databases" for diatomics (121 molecules) and triatomics (53 molecules).
- Designed and created the "X-ray Transition Energies Database" containing 91 elements and 53 transitions.
- Updated the "Electron-Impact Ionization Cross Section Database" with a new graphical interface and 21 additional molecules.
- Updated the "Atomic Weights and Isotopic Compositions" by adding the relative atomic masses of the 346 isotopes.
- Updated the "Searchable Bibliography on the Constants" with 293 new entries and the "Bibliographic Database on Atomic Transition Probabilities" with 441 new entries.
- Demonstrated the ability of a remote program to query a NIST database (i.e. machine-to-machine transfer of data).

Collaborations

- Committee on Data for Science and Technology (CODATA) of the International Council for Science, for agreement on published values of fundamental physical constants.
- Council on Ionizing Radiation Measurement and Standards (CIRMS), for data needs in the fields of medical radiation diagnostics and therapy, radiation protection, and radiation effects.
- Harvard-Smithsonian Center for Astrophysics, for development of the atomic spectroscopy database.
- National Aeronautics and Space Administration (NASA), for work with the Astrophysics Division to provide atomic spectroscopic data.
- Oak Ridge National Laboratory, for work with the Radiation Safety Information Computational Center to provide calculations of x-ray absorption in materials.
- University of Melbourne, for development of the X-ray form factor, attenuation, and scattering database.
- University of Nebraska, for work on the electron-impact ionization cross section database.
- University of New Brunswick, for development of a database of ground state energy levels for certain small molecules.

IA4: Online Access to NIST Chemical Reference Data

Principal Investigator: Gary Mallard
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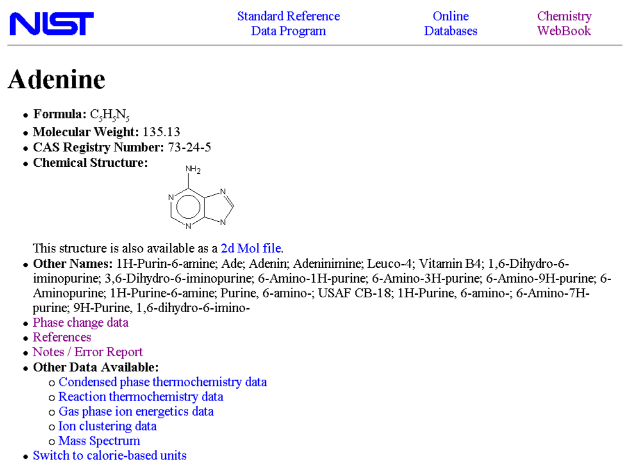
The objective of this effort is to make NIST chemical reference data available via the Internet (http://webbook.nist.gov/chemistry/) and to develop the tools and mechanisms necessary to make all NIST chemical data uniformly accessible. For this system to be successful the user must be able to determine quickly what compounds are present and what data on those compounds are provided. The approaches being pursued to achieve this objective are:

- Developing robust software tools for accessing NIST chemical databases through a uniform method of specifying chemicals, including by means of chemical structure drawings.
- Expanding the structure of the NIST Chemistry WebBook and customizing its algorithms to support a wide variety of database software, contents, and functions.
- Implementing the import of chemical structure drawings to the NIST Chemistry WebBook and including them as a query technique.
- Providing for user feedback on the power and robustness of NIST tools and by analysis of usage statistics.



Example of search result from Chemistry Webbook

Prior work on this project established the basic components of a system for distributing NIST standard reference data over the Internet. A wide range of chemical reference data is now available to the public via the NIST Chemistry WebBook. The types of data available as a result of this project include the following:

- Thermochemical data for gas and condensed phase species
- Thermochemical data for selected chemical reactions, including heat of combustion data
- Physical property data relating to phase changes
- Ion energetics data
- Mass spectra
- Ultraviolet and infrared spectra

In order to provide easy data access, several methods have been developed over the last three years for specifying the data required by the user. Searches based on chemical formulas, chemical names (including synonyms), partial chemical formulas, Chemical Abstract Service registry numbers, or selected physical property values are easily available. Improvements in the quality of data presentation will continue to focus on more extensive use of graphical displays in addition to the tabular (numerical) display of data. The applets developed will be further generalized to generate interactive graphic displays, enabling scientists to interpret and utilize data more quickly. Where multiple measurements are available, displays will allow easier review and comparison of measurements. The use of graphical displays will be extended beyond the current properties - fluid property data, vapor pressure data, and enthalpy data. The tools for displaying these data are readily extensible to other data types. Where possible, graphical data is transmitted in its most compact form, a mathematical formula. This will reduce transmission delays and provide improved server performance under heavy usage loads.

Significant FY99/00 Accomplishments

- Added capabilities for chemical substructure searching by users. Two methods of substructure search were set up. The first allowed for very general substructure searching by use of a chemical drawing tool applet. The user can use this tool or any of the commercial packages that produce common chemical structure file formats. Either the output of the JAVA applet or the submitted file will then be used to drive the query. The second method is a simpler, functional-group approach. The user can specify that the search should return all compounds that have a specified structural component (called functional group), e.g., alcohols, or ketones. This less sophisticated search does not need the applet and is simpler to use.
- A new version of the NIST Chemistry WebBook was released in February 2000 that includes new data (e.g., an ion cluster database and a gas phase heat capacity database) and additional user features. Additional equation plotting routines were developed to allow the user to show and expand equation based data using client side computational resources.

Collaborations

- Dow Chemical, for development of tools for estimation of thermochemical data using modern quantum chemistry techniques.
- Gaussian Inc., for work to make the NIST Chemistry WebBook available to multiple users directly from other software.
- Reaction Design, for work to make the NIST Chemistry WebBook available to multiple users directly from other software.
- University of Maryland, for evaluation of data for chemical thermodynamics.
- University of Tennessee, for evaluation of data for ion thermochemistry.

IA5: Standards for Exchange of Instrument Data and NIST Chemical Reference Data

Principal Investigator: Gary Kramer
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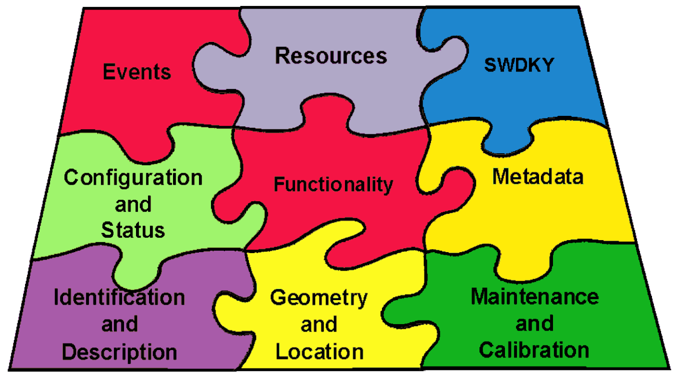

System capability dataset

The objectives of this effort are (1) to develop information models supporting data exchange standards in analytical chemistry for instrument-to-instrument, instrument-to-application, and application-to-application interchanges, and (2) to evaluate current industry standards applicable to the interchange of NIST reference data. Many critical decisions in manufacturing and engineering depend on reliable chemical data about materials and chemical reactions. Often this data comes directly from instruments in chemical analysis laboratories. This effort intends to make standard reference data in analytical chemistry data, especially data coming directly from instruments, more readily available to engineers and scientists in U.S. manufacturing industries. The interchange and storage of analytical chemistry data has long been hampered by multiple, incompatible data formats. Our approach is to work with standards developing organizations, such as ASTM[1], and with trade associations to contribute to the development and validation of analytical data interchange standards. In addition, with the increase in automation of laboratory equipment and the need to integrate different instruments into a cohesive whole, this effort has also been working to provide a standard mechanism to represent instrument functions. This work has been expanded to a system-level view providing a laboratory controller with what it needs to know about the devices it controls and also supplies information about device relationships and dependencies.

Significant FY99/00 Accomplishments

- Presented project progress at several significant events, notably at Object Management Group (OMG) Life Sciences research meetings, at annual LabAutomation Conferences in San Diego, CA, and at the CODATA 2000 conference.
- Advanced several specifications further in the standardization process, including four Analytical Data Interchange Standards in ASTM, five laboratory automation standards in NCCLS[2], and have begun the process of standardization of a laboratory equipment communication interface in OMG.

Collaborations

- Creon Software GmbH, for development of instrument control interface models.
- Fachhochschule Wiesbaden, for development of instrument control interface models.
- Los Alamos National Laboratory, for implementation and validation of instrument control interface specifications.

1. Formerly known as the American Society for Testing and Materials.
2. Formerly known as the National Committee for Clinical Laboratory Standards

IA6: Web-Based Bioinformatics Databases

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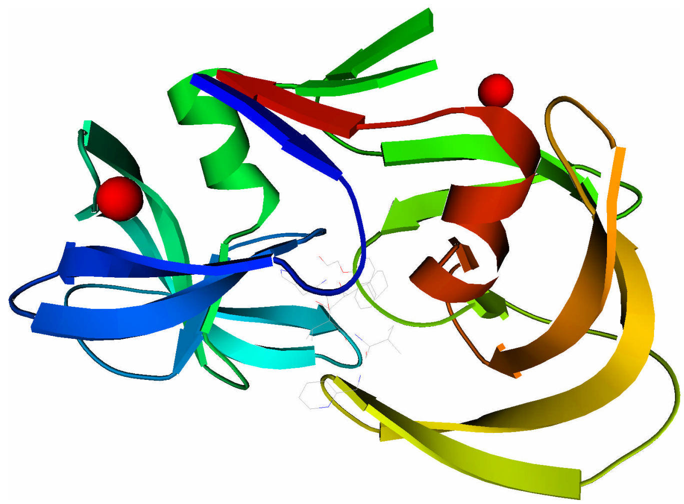
The objective of this effort is to provide access to databases that contain evaluated data on the properties, structures, and interactions of biological macromolecules. One database is the Protein Data Bank, an international archive serving as the major repository of experimental information on the structures of proteins, including the actual location of individual atoms with respect to one another. Another database pertains to data characterizing the recognition by one molecule of a suitable reaction site on another. This is useful in drug design, where considerable effort is being expended to discover and develop molecules that "recognize" and bind to specific target molecules.



HIV protease structure

The last decade has seen an amazing explosion in the field of bioinformatics. Today the management of large sets of biological data, and the mining of the information contained therein, is an activity that is transforming biology. Remarkably, much of this data is based on a small number of fundamental building blocks, such as the four nucleic acids of DNA and the 20 amino acids of proteins. Modern experimental techniques continuously identify new proteins and other biological macromolecules, formed from these building blocks that regulate biological function and determine biological form. Characterizing these molecules in terms of structure, properties and interactions is probably the most needed activity in molecular biology today. Developing bioinformatics systems to handle the resulting information is equally important.

NIST and its collaborative institute, The Center for Advanced Research in Biotechnology (CARB), are at the forefront of experimental and computational research in this area. NIST and CARB have also become important participants in bioinformatics. The work proposed here builds upon these strengths and is intended to provide the U.S. biotechnology community with reliable data on important classes of biological macromolecules and their interactions, while taking advantage of the modern networking and computation power in making these data available.

Significant FY99/00 Accomplishments

- Significantly improved the uniformity, completeness, and quality of the archival data contained in the Protein Data Bank. Database entries for ribonucleases, immunoglobins, oxygen transport proteins, lysozymes, and other key families of interest to pharmaceutical industries have been improved. Citations have been corrected. Enzyme data has been verified. Resolution and r-factor data have been verified. All these steps contribute to the reliability of search results for PDB users. See http://rcsb.nist.gov/.
- Initiated development of an Internet-accessible resource for macromolecular software.
- Initiated work on the development of data specifications for macromolecular structures determined by nuclear magnetic resonance techniques in order to assure consistency with the quality of data determined by X-ray crystallography.
- Completed the development of an Internet-accessible database implementation of molecular recognition information (see http://www.bindingdb.org). Continuing work in this area is taking place under the auspices of the University of Maryland with support from the National Science Foundation.

<u>Collaborations</u>

- National Institutes of Health, for support of external researchers contributing to the development of the Protein Data Bank.
- National Science Foundation, for support of external researchers contributing to the development of the Protein Data Bank.
- Research Collaboratory for Structural Bioinformatics, for management, curation, and research relevant to the development of structural bioinformatics databases. Other principles in this consortium are the San Diego Supercomputer Center of the University of California San Diego and the Biochemistry Division of Rutgers University.
- U.S. Department of Energy, for support of external researchers contributing to the development of the Protein Data Bank.
- University of Mississippi Medical Center, for development of the molecular recognition database.
- University of Wisconsin, Madison, to promote standards for nuclear magnetic resonance (NMR) macromolecular structure data.

IA7: Web-based Neutron Science

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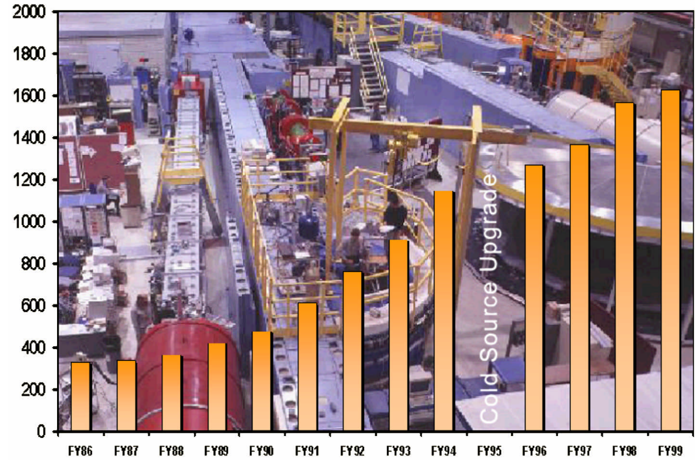

NCNR research participants

The objective of this effort is to develop Internet-based computational tools for users of the NIST Center for Neutron Research (NCNR). Tools for visualization and interactive analysis of neutron scattering data will greatly facilitate the planning and analysis of neutron scattering experiments by researchers from universities, government and industry in a broad range of scientific and engineering disciplines. When these tools are readily available over the Internet, scientists and engineers will be able to assess the applicability and potential benefits of neutron methods for their particular research interests. The tools envisioned would enable these scientists and engineers to perform virtual experiments based on the performance characteristics of specific scattering instruments at the NCNR assessing the feasibility of prospective measurements. Other tools for remote monitoring of ongoing experiments will enable collaborators to interact more effectively with colleagues carrying out experiments at the NCNR. Existing computer codes for displaying and analyzing data will also be adapted for use via common browser software. As a result, the unique features of neutron radiation as a probe of the nanoscale structure and dynamics of materials will become more widely recognized, and the NCNR's facilities more effectively utilized, by scientists and engineers nationwide.

Significant FY99/00 Accomplishments

- Released a suite of downloadable software tools enabling users of small angle neutron scattering (SANS) instruments to reduce and analyze experimental results.
- Provided Internet-accessible capabilities for viewing real-time images of data collected on SANS instruments as well as viewing of one of the instruments itself.
- Provided Internet-accessible interface for simulating the results of SANS experiments based on over 20 scattering models.

Collaborations

- Argonne National Laboratory, for work with the NeXus project on the development of an exchange format for neutron and synchrotron scattering data.

Conclusion

The premise of the SIMA Program is that the multitude of software systems used in manufacturing activities do not interoperate as well as required. The SIMA Program's project leaders work with their industrial partners to identify the context-dependent information needs among manufacturing enterprise activities and to define solutions addressing those needs. By maintaining a neutral perspective in the development and testing of information interfaces for engineering and manufacturing, the Program ensures that validated solutions addressing the common requirements of both users and software providers can be adopted.

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Appendix A: Program Organization

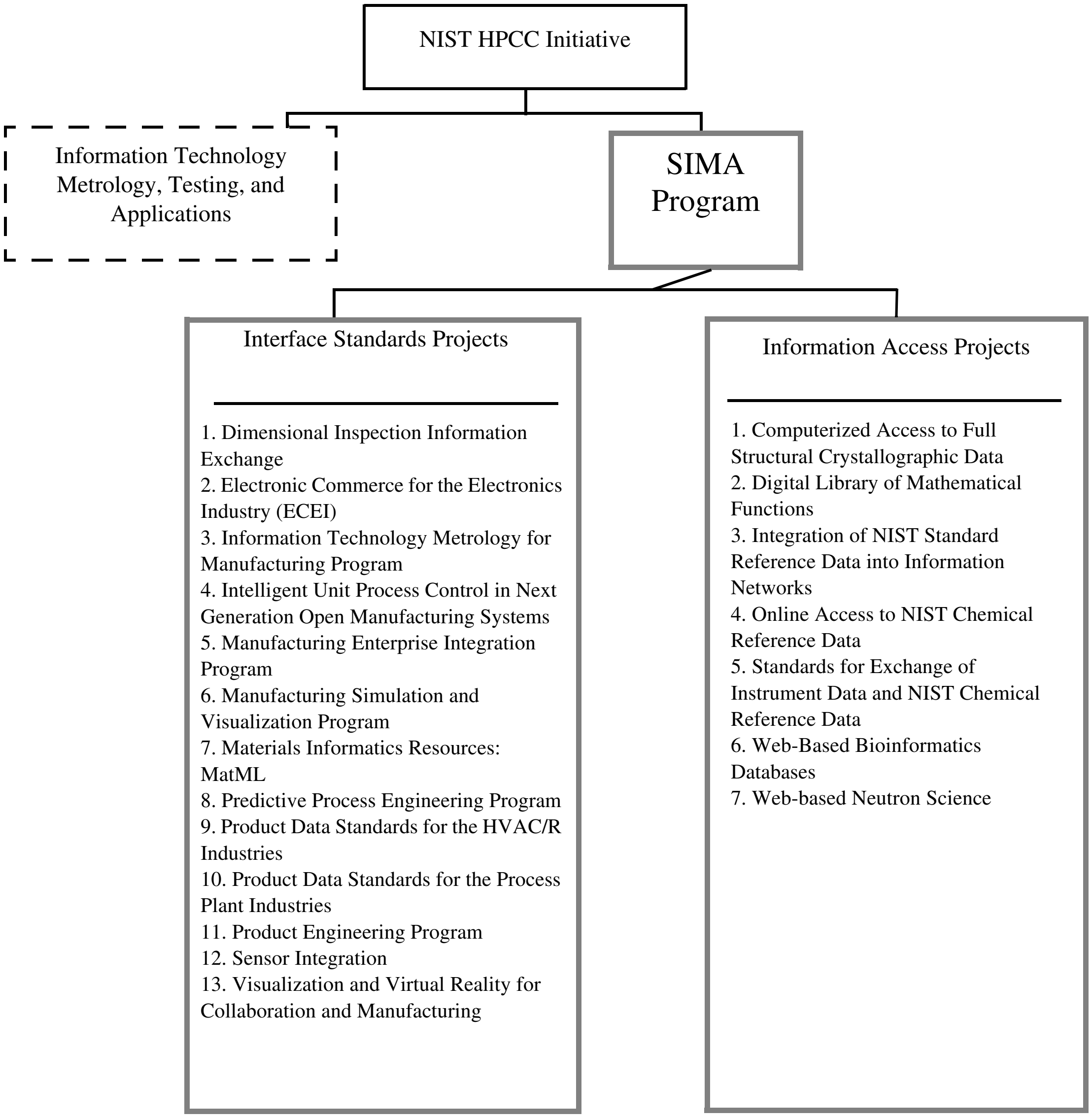

Figure 1. Organization of NIST's CIC Efforts

The SIMA Program was one of two CIC initiative efforts underway at NIST in FY2000 (see Figure 4). The SIMA Program is directed by a manager in the Manufacturing Systems Integration Division (MSID) of NIST's Manufacturing Engineering Laboratory (MEL). Individual SIMA projects are led by NIST research staff. The projects are organized into the technology areas briefly described below.

Program Technology Areas

To align the resources of the program with the needs defined by industry, the SIMA Program organizes projects into two program areas: (1) Interface Standards, and (2) Information Access. Activities within each area satisfy a unique NIST role in support of CIC goals and address the major technology and standards issues outlined in the IITA program report [7]. The focus of these technology areas are as follows.

Interface Standards (IS)

These SIMA projects continue work leading to the definition and creation of standards facilitating the exchange of manufacturing data within and across all levels of the product realization process. Objectives include the establishment of:

- Rigorous methods for defining and testing interoperability solutions.

- Standards specifying information to be exchanged as well as the interface mechanisms necessary to do so.

- Tests validating potential standards solutions and implementations.

Information Access (IA)

SIMA-supported efforts in this area are providing greatly broadened access to large amounts of authoritative scientific engineering data in NIST databases by initiating effective Internet access to those databases through user-friendly interfaces and sophisticated search techniques.

Participating NIST Organizational Units

All of NIST's intramural, technical organizational units participate in the SIMA Program. The following descriptions briefly summarize the mission of each participating NIST organization[1].

Building and Fire Research Laboratory (BFRL)

BFRL works to enhance the competitiveness of U.S. industry and public safety through performance prediction and measurement technologies and technical advances that improve the lifecycle quality of constructed facilities.

Chemical Science and Technology Laboratory (CSTL)

As the Nation's Reference Laboratory, CSTL performs cutting edge research in measurement science. The Laboratory develops and maintains measurement methods, standards, and reference data; and develops models for chemical, biochemical, and physical properties and processes.

Information Technology Laboratory (ITL)

ITL develops, demonstrates, and supplies high quality information technology, metrology, and standards that enable U.S. industry to develop usable, reliable, interoperable products. In doing so, the ITL serves as a neutral agent to accelerate acceptance and use of information technology that will promote economic competitiveness and the public good. ITL provides leadership and collaborative research to NIST programs in the areas of mathematics, statistics, and information technology use and services to enable NIST to maintain its status as a world class institution.

1. More information about NIST Laboratories can be found at http://www.nist.gov/labs2.html.

Electronic and Electrical Engineering Laboratory (EEEL)

EEEL promotes U.S. economic growth through improved international competitiveness, by providing measurement capability of high economic impact focused primarily on the critical needs of the U.S. electronics and electrical-equipment industries.

Manufacturing Engineering Laboratory (MEL)

MEL works to improve the competitiveness of U.S. manufacturing by working with industry to develop and apply infrastructural technology, measurements, and standards for manufacturing.

Material Science and Engineering Laboratory (MSEL)

MSEL works to stimulate the more effective production and use of materials by working with materials suppliers and users to assure the development and implementation of the measurements and standards infrastructure for materials.

Physics Laboratory (PL)

PL supports U.S. industry by providing measurement services and research for electronic, optical, and radiation technology.

Technology Services (TS)

TS provides a wide variety of services and programs to help U.S. industry improve its international competitiveness. TS supplies NIST reference materials, data, and calibrations to help industry maintain production quality control. TS also provides information and assistance concerning national and international voluntary and regulatory product standards and certification systems.

Appendix B: Collaborators

Consortia, National Programs, Professional and Trade Associations			
Name	Location	Description	Collaborating Project(s)
Aluminum Association, Inc.	Providence, RI	A trade association for producers of primary aluminum, recyclers, and semi-fabricated aluminum products.	Materials Informatics Resources: MatML (p. 25)
APICS	Vienna, VA	Provides educational opportunities to meet the needs of professionals in all areas of resource management including inventory, materials, information systems, accounting/finance, and supply chain.	Manufacturing Enterprise Integration Program (p. 21)
ASM International	Materials Park, OH	A society for materials engineers and scientists.	Materials Informatics Resources: MatML (p. 25)
Association Connecting Electronics Industries (IPC)	Northbrook, IL	Trade association for companies in the electronic interconnection industry.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
Association for Manufacturing Technology	McLean, VA	Association dedicated to supporting and enhancing the activities of American manufacturers.	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
Automotive Industry Action Group (AIAG)	Southfield, MI	A large automotive trade association addressing industry issues in supply, manufacturing, engineering, quality, and finance.	Information Technology Metrology for Manufacturing Program (p. 17)
Committee for Data on Science and Technology (CODATA)	Paris, France	A committee of the International Council for Science working to improve the quality, reliability, management and accessibility of data of importance to all fields of science and technology.	Integration of NIST Standard Reference Data into Information Networks (p. 38)
CommerceNet	Palo Alto, CA	An international, not-for-profit organization meeting the evolving needs of companies doing electronic commerce.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)

Consortia, National Programs, Professional and Trade Associations			
Name	Location	Description	Collaborating Project(s)
Consortium for Advanced Manufacturing, Inc. (CAM-I)	Bedford, TX	A not-for-profit, cooperative membership organization to support research and development in areas of strategic importance to manufacturing industries.	Predictive Process Engineering Program (p. 26)
Construction Industry Institute	Austin, TX	Seeks to improve the safety, quality, schedule, and cost effectiveness of the capital investment process through research and implementation.	Product Data Standards for the Process Plant Industries (p. 29)
Council on Ionizing Radiation Measurement And Standards (CIRMS)	Duluth, GA	A not-for-profit organization that provides national leadership, focus, action, and information dissemination across radiation protection disciplines on a wide range of ionizing radiation measurements and standards topics.	Integration of NIST Standard Reference Data into Information Networks (p. 38)
Enhanced Machine Controller (EMC) Consortium	Gaithersburg, MD	Provides initial open-architecture control system and development environment hardware and software configuration, base controller template, Java-based operator tools and communications mechanism for Joint Architecture project implementation testbeds.	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
funSTEP	Paterna, Spain	Promotes software interoperability within the furniture industry.	Product Engineering Program (p. 31)
Intelligent Manufacturing Systems (IMS) MISSION Project	Tokyo, Japan	The primary objective of MISSION is a bridge from today's tools and regionally-oriented factory design processes into those needed for extended enterprises and/or virtual enterprise networks.	Manufacturing Simulation and Visualization Program (p. 23)
International Alliance for Interoperability (IAI)	Reston, VA	IAI's mission is to define, publish and promote specifications for Industry Foundation Classes (IFC) as a basis for project information sharing in the building industry.	Product Data Standards for the HVAC/R Industries (p. 28)
MARITECH	North Charleston, SC	Initiative to manage and focus national shipbuilding research and development funding on technologies that will reduce the cost of warships to the U.S. Navy and establish U.S. international competitiveness.	Product Data Standards for the Process Plant Industries (p. 29)

Consortia, National Programs, Professional and Trade Associations			
Name	Location	Description	Collaborating Project(s)
Metrology Automation Association	Ann Arbor, MI	Consortium of suppliers, integrators, end users and technology developers of metrology automation, such as coordinate measurement machines.	Dimensional Inspection Information Exchange (p. 13) Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
National Electronics Manufacturing Initiative	Herndon, VA	Consortium dedicated to facilitating long-term North American leadership in volume electronics manufacturing.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
National Institute of Building Sciences (NIBS)	Washington, DC	Non-governmental, not-for-profit organization established by Congress to serve public interest by promoting a rational regulatory environment for the building community by facilitating the introduction of new and innovative technology and disseminating nationally recognized technical information.	Product Data Standards for the HVAC/R Industries (p. 28)
Next Generation Inspection System Program	Ann Arbor, MI	NGIS is a program of the National Center for Manufacturing Sciences, Production Equipment and Systems Special Interest Group. The objective is to develop next-generation inspection capabilities on coordinate measuring machines and machine tools.	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
North American OpenMath Initiative	Vancouver, Canada	Promotes development of a single standard for storing, transmitting, and manipulating mathematical information in online scientific documents and systems.	Digital Library of Mathematical Functions (p. 36)
Open Applications Group	n/a	The mission of the Open Applications Group is to promote the easy and cost-effective integration of key business application software components for enterprise and supply chain functions for end-user organizations.	Manufacturing Enterprise Integration Program (p. 21)
OpenMath Consortium	Helsinki, Finland	Promotes development of OpenMath, an emerging standard for representing mathematical objects with their semantics.	Digital Library of Mathematical Functions (p. 36)
Open Modular Architecture Control (OMAC)	Oak Ridge, TN	OMAC seeks to develop an Open Architecture, Application Programming Interface (API) for machine controllers.	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)

Consortia, National Programs, Professional and Trade Associations			
Name	Location	Description	Collaborating Project(s)
PDES, Inc.	Charleston, SC	The PDES, Inc. consortium's objective is to accelerate the development and implementation of STEP. The consortium includes the South Carolina Research Authority, Boeing, Ford, General Motors, Hughes, Lockheed Martin, Northrop Grumman, and other participants.	Information Technology Metrology for Manufacturing Program (p. 17)
Petrotechnical Open Software Corporation (POSC)	Houston, TX	A not-for-profit corporation dedicated to facilitating integrated business processes and computing technology for the exploration and production segment of the international petroleum industry.	Product Data Standards for the Process Plant Industries (p. 29)
PIEBASE (Process Industry Executive for achieving Business Advantage using Standards for data Exchange)	London, UK	PIEBASE is a global umbrella that coordinates development and implementation of data exchange and data-sharing standards for the process plant industry consortia and member companies.	Product Data Standards for the Process Plant Industries (p. 29)
PlantSTEP, Inc.	Wilmington, DE	PlantSTEP, Inc. is a consortium working to support the development of information exchange standards to advance the capabilities of process plant and construction industries. Members include DuPont, Merck, Black & Veach, Bechtel, Intergraph, Computervision, and CAD Centre.	Product Data Standards for the Process Plant Industries (p. 29)
Process Data eXchange Institute of AIChE (pdXi)	New York, NY	pdXi is an industry trade group working to develop and maintain open approaches to electronic data exchange and management of process engineering data. Members include DuPont, Exxon, and Simulation Sciences, Union Carbide, and others.	Product Data Standards for the Process Plant Industries (p. 29)
Process Industry Practices	Austin, TX	Coalition of process industry owners and engineering/construction contractors who serve the industry.	Product Data Standards for the Process Plant Industries (p. 29)
Process Interchange Format Group	Manoa, HI	Informal industry and academic consortium.	Predictive Process Engineering Program (p. 26)
Research Collaboratory for Structural Bioinformatics	n/a	Not-for-profit consortium dedicated to improving understanding of the function of biological systems through the study of the 3-D structure of biological macromolecules.	Web-Based Bioinformatics Databases (p. 43)
RosettaNet	Los Angeles, CA	Consortium dedicated to development of industry-wide electronic business operability standards.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)

Consortia, National Programs, Professional and Trade Associations			
Name	Location	Description	Collaborating Project(s)
SEMATECH	Austin, TX	SEMATECH's objective is to sponsor and conduct research aimed at assuring leadership in semiconductor manufacturing technology for the U.S. semiconductor industry. The consortium includes Advanced Micro Devices, Digital Equipment Corporation, Hewlett-Packard, Intel, IBM, Lucent Technologies, Motorola, National Semiconductor Corporation, Rockwell International, and Texas Instruments.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
Silicon Integration Initiative, Inc. (Si2)	Austin, TX	An international, not-for-profit consortium whose mission is to facilitate and promote the adoption of open electronic design automation technologies which improve designer productivity. Si2's membership includes over 40 companies comprised of electronic design automation designers and suppliers of high performance semi-custom silicon in North America, Europe, and Asia.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
Software Engineering Institute (SEI)	Pittsburgh, PA	DOD-funded R&D center tasked to provide leadership in advancing the state of the practice of software engineering to improve the quality of systems that depend on software.	Manufacturing Enterprise Integration Program (p. 21)
Supply Chain Council	Pittsburgh, PA	A cross-industry consortium formed to establish a framework to enable manufacturers and their supply-chain vendors to build a stronger supply chain and reap the competitive rewards of improved supply-chain management.	Manufacturing Enterprise Integration Program (p. 21)
Surface Mount Equipment Manufacturers Association (SMEMA)	Highland Park, IL	A not-for-profit organization of companies manufacturing equipment or producing software for surface mount board production.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
Virtual Assembly Technology Consortium	Pullman, WA	Consortium to bring together industry, government agencies, and universities to jointly address research, technology development, technology deployment, and standards issues related to the use of virtual reality, digital prototyping, modeling and simulation, and visualization techniques to plan, evaluate, and verify assembly processes for mechanical systems.	Product Engineering Program (p. 31)
Virtual Socket Interface (VSI) Alliance	Los Gatos, CA	The VSI Alliance is chartered to define, develop, authorize, test, and promote open standard specifications relating to data formats, test methodologies, and interfaces. These standards are to facilitate the mix and match and the reuse of blocks of electronic circuit functions from different sources in the design and development of system-level ICs.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)

Consortia, National Programs, Professional and Trade Associations			
Name	Location	Description	Collaborating Project(s)
Web3D Consortium	San Ramon, CA	A nonprofit corporation with the mission of fostering and evangelizing all three-dimensional technologies on the Internet.	Visualization and Virtual Reality for Collaboration and Manufacturing (p. 34)
Workflow Management Coalition	Winchester, UK	Not-for-profit international organization of workflow vendors, users, analysts and university/research groups seeking to promote and develop the use of workflow through the establishment of standards for software terminology, interoperability and connectivity between workflow products.	Predictive Process Engineering Program (p. 26)

Individual Companies			
Name	Location	Description	Collaborating Project(s)
Advanced Micro Devices, Inc.	Austin, TX	Supplier of integrated circuits for the computer and communications markets.	Manufacturing Enterprise Integration Program (p. 21)
Advanced Technology and Research Corporation	Burtonsville, MD	Consultants specializing in research and development of intelligent control systems, automation, robotics, simulation, engineering analysis, and computer science.	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
Advanced Technology Institute	Charleston, SC	Not-for-profit technology management firm.	Product Engineering Program (p. 31)
Aeptec Microsystems	Rockville, MD	Producer of wireless communications infrastructure, user-centric applications, and intelligent wireless devices.	Sensor Integration (p. 33)
Agile Software	San Jose, CA	Producer of software that enables companies to collaborate over the Internet by interactively exchanging information about the manufacture and supply of products and components.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
Agilent Technologies	Palo Alto, CA	Provider of enabling technologies to high-growth markets within the communications, electronics, life sciences and healthcare industries.	Sensor Integration (p. 33)
ALSTOM Power	London, UK	Producer of power-generation equipment and systems.	Materials Informatics Resources: MatML (p. 25)

Individual Companies			
Name	Location	Description	Collaborating Project(s)
AMP, Inc.	Harris-burg, PA	Manufacturer of electronic connectors.	Manufacturing Simulation and Visualization Program (p. 23)
Atomic Weapons Establish-ment	Reading, UK	British contractor dedicated to the research and develop-ment of the UK's defence capability, the decommission-ing of nuclear weaponry, and the monitoring of the Nuclear Test Ban Treaty.	Materials Infor-matics Resources: MatML (p. 25)
Automata Design, Inc.	Herndon, VA	Vendor of software simulating circuit board design and production processes.	Electronic Com-merce for the Electronics Industry (ECEI) (p. 15)
AutoSimulation, Inc.	Bountiful, UT	Vendor of simulation and scheduling software.	Manufacturing Simulation and Visualization Program (p. 23)
Bechtel	San Fran-cisco, CA	Provider of services to develop, engineer, construct, and manage capital projects and facilities worldwide.	Product Data Standards for the Process Plant Industries (p. 29)
B.F. Goodrich Corporation	Cleveland, OH	Aerospace and performance products manufacturer.	Manufacturing Simulation and Visualization Program (p. 23)
Black and Decker	Towson, MD	Manufacturer of portable power tools and household appliances.	Manufacturing Simulation and Visualization Program (p. 23) Product Engi-neering Program (p. 31)
Black & Veatch	Kansas City, MO	An engineering construction company.	Product Data Standards for the Process Plant Industries (p. 29)
blaxxun interactive	San Fran-cisco, CA	Develops and markets products for Internet multimedia communication.	Visualization and Virtual Reality for Col-laboration and Manufacturing (p. 34)

Individual Companies			
Name	Location	Description	Collaborating Project(s)
Boeing	Seattle, WA	Aerospace manufacturer.	Dimensional Inspection Information Exchange (p. 13) Information Technology Metrology for Manufacturing Program (p. 17) Materials Informatics Resources: MatML (p. 25) Sensor Integration (p. 33)
Borg-Warner Automotive	Chicago, IL	Designer and producer of key technology for engines, transmissions, and four-wheel drive systems.	Manufacturing Enterprise Integration Program (p. 21)
Bosonics	Boulder, CO	Federal R&D contractor that develops optoelectronic systems and cost simulation software into commercial products.	Predictive Process Engineering Program (p. 26)
Browne & Sharpe	North Kingstown, RI	Manufacturer of coordinate measuring machines for dimensional inspection and software systems to support dimensional inspection.	Dimensional Inspection Information Exchange (p. 13)
Brüel & Kjær	Nærum, Denmark	Producer of sound and vibration measurement equipment.	Sensor Integration (p. 33)
Centor Software Corp.	Irvine, CA	A provider of business-to-business interaction management solutions for collaborative commerce.	Materials Informatics Resources: MatML (p. 25)
Creon Software, GmbH	Linz-Kasbach am Rhein, Germany	Develops and sells quality-assurance applications for the pharmaceutical chemical, cosmetic, and food industries	Standards for Exchange of Instrument Data and NIST Chemical Reference Data (p. 42)
Cummins, Inc.	Columbus IN	World's largest producer of diesel engines above 200 horsepower.	Product Engineering Program (p. 31)

Individual Companies			
Name	Location	Description	Collaborating Project(s)
DaimlerChrysler	Auburn Hills, MI	Motor vehicle manufacturer.	Dimensional Inspection Information Exchange (p. 13)
Delmia	Troy, MI	Vendor of 3D graphics-based factory simulation, telerobotic, and virtual reality software.	Manufacturing Simulation and Visualization Program (p. 23)
Dow Chemical Company	Midland, MI	The Dow Chemical Company provides chemicals, plastics, energy, agricultural products, consumer goods and environmental services.	Online Access to NIST Chemical Reference Data (p. 40) Product Data Standards for the Process Plant Industries (p. 29)
Dupont	Wilmington, DE	An energy and chemistry-based company.	Product Data Standards for the Process Plant Industries (p. 29)
Endevco	San Juan Capistrano, CA	Supplier of dynamic instrumentation for vibration, shock, inertial motion and dynamic pressure measurements.	Sensor Integration (p. 33)
Engineering Animation, Inc.	Ames, IA	Vendor of simulation software and services.	Manufacturing Simulation and Visualization Program (p. 23)
Environmental Research Institute of Michigan (ERIM)	Ann Arbor, MI	A not-for profit organization dedicated to advancement of information technologies, such as the Internet and collaborative software, to enhance the efficiency and global competitiveness of US industry.	Information Technology Metrology for Manufacturing Program (p. 17)
EOG	Hunt Valley, MD	An electronics manufacturing services provider.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
ESM Software, Inc.	Hamilton, OH	A developer and marketer of software related to materials science and thermochemistry.	Materials Informatics Resources: MatML (p. 25)

Individual Companies			
Name	Location	Description	Collaborating Project(s)
Fachinformationszentrum Karlsruhe Gesellschaft für wissenschaftlich-technische Information mbH	Karlsruhe, Germany	A non-profit organization set up to provide information and information services for academic and industrial research & development, as well as for business and administration.	Computerized Access to Full Structural Crystallographic Data (p. 35)
Ford Motor Company	Dearborn, MI	Large automotive manufacturer.	Materials Informatics Resources: MatML (p. 25) Predictive Process Engineering Program (p. 26)
FTL Systems, Inc.	Rochester, MN	Developer and marketer of parallel optimizing compilers for shared memory multiprocessors, message-based parallel processors, and networked computer systems.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
Gaussian, Inc.	Carnegie, PA	Producer of software designed to model a broad range of molecular systems under a variety of conditions. The software performs its computations starting from the basic laws of quantum mechanics.	Online Access to NIST Chemical Reference Data (p. 40)
H. B. Zachry	San Antonio, TX	Large construction and project development company.	Product Data Standards for the Process Plant Industries (p. 29)
HeliSys Corporation	Carson, CA	Producer of layered material technology for rapid prototyping, modeling, pattern making, production tooling, and manufacturing.	Product Engineering Program (p. 31)
Honeywell	Morristown, NJ	Supplier of automation and control systems, components, software, products and services for homes, industry, and aerospace.	Manufacturing Enterprise Integration Program (p. 21) Product Engineering Program (p. 31)
Ingersoll Milling Machine Co.	Rockford, OH	Designer and producer of specialized machine tools used primarily in aerospace and automotive manufacturing.	Predictive Process Engineering Program (p. 26)
Intelligent Automation, Inc.	Rockville, MD	R&D and consulting firm specializing in Artificial Intelligence applications.	Manufacturing Enterprise Integration Program (p. 21)

Individual Companies			
Name	Location	Description	Collaborating Project(s)
International Business Machine Corp. (IBM)	White Plains, NY	Large information technology corporation.	Product Engineering Program (p. 31)
Kistler Instrument Corp.	Amherst, NY	Producer of instruments for measuring pressure, force, acceleration and strain.	Sensor Integration (p. 33)
Knowledge Based Systems, Inc.	College Station, TX	Vendor of software products for process modeling and analysis.	Manufacturing Simulation and Visualization Program (p. 23) Predictive Process Engineering Program (p. 26)
Knowledge Revolution	San Mateo, CA	Producer of functional motion simulation software for engineering, visualization, and education.	Visualization and Virtual Reality for Collaboration and Manufacturing (p. 34)
Knowledge Technologies International, Inc.	Burlington, MA	An independent organization handling development, marketing, sales and consulting services related to providing Knowledge-Based solutions to global manufacturing businesses.	Predictive Process Engineering Program (p. 26)
LK, Metrology Systems, Inc.	Brighton, MI	Manufacturer of coordinate measuring machines and integrated software and hardware solutions for measurement.	Dimensional Inspection Information Exchange (p. 13)
Lockheed Martin Tactical Aircraft Systems	Fort Worth, TX	Manufacturer of tactical combat aircraft.	Predictive Process Engineering Program (p. 26)
MathSoft, Inc.	Cambridge, MA	A provider of math, science, and engineering software.	Digital Library of Mathematical Functions (p. 36)
Merck & Co., Inc.	Somersett, NJ	A research-driven pharmaceutical products and services company.	Product Data Standards for the Process Plant Industries (p. 29)
Micro Analysis and Design	Boulder, CO	Developer and vendor of simulation and process modeling software.	Manufacturing Simulation and Visualization Program (p. 23)

Individual Companies			
Name	Location	Description	Collaborating Project(s)
Motion Factory	Fremont, CA	Vendor of human modeling simulation systems.	Manufacturing Simulation and Visualization Program (p. 23)
MSC Software, Inc.	Los Angeles, CA	A provider of mechanical computer-aided engineering software solutions.	Materials Informatics Resources: MatML (p. 25)
Netfish Technologies	Santa Clara, CA	Specialist in business process integration, both inside and outside enterprises.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
Nyamekye Research and Consulting	Rolla, MO	Research and consulting firm.	Manufacturing Simulation and Visualization Program (p. 23)
PACCAR, Inc.	Bellevue, WA	Manufacturer of on- and off-road trucks.	Product Engineering Program (p. 31)
Pathway Technologies, Inc.	Blue Bell, PA	Provider of R&D, design and engineering services, and software development.	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
PCB Group/The Modal Shop	Cincinnati, OH	Provider of structural and acoustic sensing systems.	Sensor Integration (p. 33)
ProModel Corporation	Orem, UT	Producer of simulation products used in a wide variety of settings, including manufacturing, healthcare and service industries.	Manufacturing Simulation and Visualization Program (p. 23)
Reaction Design, Inc.	San Diego, CA	Provides software simulation and modeling tools to help process engineers create more efficient and environmentally friendly manufacturing processes.	Online Access to NIST Chemical Reference Data (p. 40)
Real Time Innovations, Inc.	Sunnyvale, CA	Vendor of real-time software development tools.	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
Shaw Group	Baton Rouge, LA	World's largest supplier of fabricated piping systems and services.	Product Data Standards for the Process Plant Industries (p. 29)

Individual Companies			
Name	Location	Description	Collaborating Project(s)
SRI International	Menlo Park, CA	Not-for-profit research institute that seeks to promote and foster the application of science in the development of commerce, trade, and industry and in the improvement of the peace and prosperity of society.	Product Engineering Program (p. 31)
Sun Microsystems Laboratories (SunLabs)	Palo Alto, CA	Develops, demonstrates, and introduces new advanced technology and technical methodologies for Sun Microsystems, Inc. and its subsidiary corporations. Maintains an awareness of, and contact with, outside technical activities in academia, government, and industry.	Manufacturing Enterprise Integration Program (p. 21)
Systems Modeling Corporation	Pittsburgh, PA	Vendor of scheduling and simulation software.	Manufacturing Simulation and Visualization Program (p. 23)
TeamWave Software, Ltd.	Calgary, Alberta, Canada	Vendor of software products that support distributed collaborations.	Manufacturing Enterprise Integration Program (p. 21)
Tecnomatix Technologies, Ltd.	San Jose, CA	Developer and vendor of simulation and process modeling software.	Dimensional Inspection Information Exchange (p. 13) Manufacturing Simulation and Visualization Program (p. 23)
TechnoSoft, Inc.	Cincinnati, OH	Software vendor.	Predictive Process Engineering Program (p. 26)
Viewlogic Systems Incorporated	Marlborough, MA	Vendor of electronic product design and engineering software.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
William Andrew Publishing, Inc.	Norwich, NY	A scientific-technical publisher in the area of materials science. Also provides organization and management of disparate and unstructured information.	Materials Informatics Resources: MatML (p. 25)
Wilcoxon	Gaithersburg, MD	Producer of vibration instrumentation.	Sensor Integration (p. 33)

Government Agencies			
Name	Location	Description	Collaborating Project(s)
Air Force Research Laboratory	Wright-Patterson AFB, OH	Charged to lead the discovery, development, and timely transition of affordable, integrated technologies to maintain the U.S. Air Force's leading position.	Manufacturing Simulation and Visualization Program (p. 23)
Argonne National Laboratory	Argonne, IL	Large research laboratory operated by the Department of Energy, and the first U.S. national laboratory.	Web-based Neutron Science (p. 45)
Defense Advanced Research Projects Agency (DARPA)	Arlington, VA	This Defense Department agency's primary mission is to develop imaginative, innovative and often high-risk research ideas offering a significant technological impact that will go well beyond the normal evolutionary developmental approaches; and, to pursue these ideas from the demonstration of technical feasibility through the development of prototype systems.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15) Predictive Process Engineering Program (p. 26) Product Engineering Program (p. 31)
Defense Modeling and Simulation Office	McLean, VA	The lead agency for modeling and simulation activities within the U.S. Department of Defense.	Manufacturing Simulation and Visualization Program (p. 23)
Department of Energy	Washington, DC	A science and technology agency whose research supports the nation's energy security, national security, and environmental quality.	Web-Based Bioinformatics Databases (p. 43)
French National Institute for Research in Computer Science and Control (INRIA)	Paris, France	A scientific and technological institute operating under the dual authority of the Ministry of Research and the Ministry of Industry.	Digital Library of Mathematical Functions (p. 36)
Lawrence Berkeley National Laboratory	Berkeley, CA	A Department of Energy national research laboratory.	Materials Informatics Resources: MatML (p. 25) Product Data Standards for the HVAC/R Industries (p. 28)

Government Agencies			
Name	Location	Description	Collaborating Project(s)
National Aeronautics and Space Administration (NASA)	Washington, DC	NASA's mission is to: -Explore, use, and enable the development of space for human enterprise -Advance scientific knowledge and understanding of the Earth, the solar system, and the universe and use the environment of space for research -Research, develop, verify, and transfer advanced aeronautics, space, and related technologies.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15) Information Technology Metrology for Manufacturing Program (p. 17) Integration of NIST Standard Reference Data into Information Networks (p. 38)
National Institutes of Health	Bethesda, MD	The Federal focal point for biomedical research in the U.S. The NIH mission is to uncover new knowledge that will lead to better health for everyone.	Web-Based Bioinformatics Databases (p. 43)
National Research Institute for Metals, Japan	Tsukuba, Japan	National research agency devoted to devoted to metals and metallic materials.	Materials Informatics Resources: MatML (p. 25)
National Science Foundation	Arlington, VA	An independent U.S. government agency responsible for promoting science and engineering.	Digital Library of Mathematical Functions (p. 36) Web-Based Bioinformatics Databases (p. 43)
Navy Industry Digital Exchange Standards Committee (NIDDESC)	Arlington, VA	NIDDESC seeks to identify the actions, costs and timetables for completing U.S. content specifications, developing an international exchange specification and developing a test suite for all the anticipated functional areas involved in the exchange of a ship product model.	Product Data Standards for the Process Plant Industries (p. 29)
Office of Naval Research	Arlington, VA	ONR coordinates, executes, and promotes the science and technology programs of the United States Navy and Marine Corps through universities, government laboratories, and nonprofit and for-profit organizations.	Product Engineering Program (p. 31)

Government Agencies			
Name	Location	Description	Collaborating Project(s)
Oak Ridge National Laboratories	Oak Ridge, TN	Conducts basic and applied research and development to create scientific knowledge and technological solutions that strengthen the nation's leadership in key areas of science; increase the availability of clean, abundant energy; restore and protect the environment; and contribute to national security.	Integration of NIST Standard Reference Data into Information Networks (p. 38) Manufacturing Enterprise Integration Program (p. 21) Predictive Process Engineering Program (p. 26) Sensor Integration (p. 33)
U.S. Army Corps of Engineers Construction Engineering Research Laboratory (USACERL)	Champaign, IL	Part of the U.S. Army Engineer Research and Development Center, CERL directs research toward increasing the Army's ability to more efficiently construct, operate, and maintain its installations and ensure environmental quality and safety at a reduced life-cycle cost.	Product Data Standards for the HVAC/R Industries (p. 28)

Academic Institutions			
Name	Location	Department	Collaborating Project(s)
American University of Sharjah	Sharjah, UAE	College of Arts and Sciences	Digital Library of Mathematical Functions (p. 36)
Arizona State University	Tempe, AZ	Department of Industrial & Manufacturing Systems Engineering	Manufacturing Simulation and Visualization Program (p. 23)
Arizona State University	Tempe, AZ	Department of Mechanical & Aerospace Engineering	Product Engineering Program (p. 31)
Beloit College	Beloit, WI	Department of Mathematics and Computer Science	Digital Library of Mathematical Functions (p. 36)
California Institute of Technology	Pasadena, CA	Project MATHEMATICS	Digital Library of Mathematical Functions (p. 36)

Academic Institutions			
Name	Location	Department	Collaborating Project(s)
Carnegie Mellon University	Pittsburgh, PA	Department of Electrical and Computer Engineering	Product Engineering Program (p. 31)
Carnegie Mellon University	Pittsburgh, PA	Robotics Institute	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
Catholic University	Washington, DC	Department of Mechanical Engineering	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
City University of Hong Kong	Hong Kong, China	Faculty of Science and Engineering	Digital Library of Mathematical Functions (p. 36)
Colorado School of Mines	Golden, CO	Division of Metallurgical and Material Engineering	Materials Informatics Resources: MatML (p. 25)
CWI, the National Research Institute for Mathematics and Computer Science in the Netherlands	Amsterdam, The Netherlands	Probability, Networks, and Algoritms Cluster and Modeling, Simulation, and Analysis Cluster	Digital Library of Mathematical Functions (p. 36)
Dalhousie University	Halifax, Canada	Mathematics and Statistics	Digital Library of Mathematical Functions (p. 36)
Delft University of Technology	Delft, The Netherlands	Department of Technical Mathematics and Informatics	Digital Library of Mathematical Functions (p. 36)
Drexel University	Philadelphia, PA	Department of Electrical and Computer Engineering	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
Drexel University	Philadelphia, PA	Department of Mathematics and Computer Science	Digital Library of Mathematical Functions (p. 36)

Academic Institutions			
Name	Location	Department	Collaborating Project(s)
Fachhochschule Wiesbaden	Weis-baden, Germany	Computer Science Department	Standards for Exchange of Instrument Data and NIST Chemical Reference Data (p. 42)
Florida International University	Miami, FL	Industrial and Systems Engineering	Manufacturing Simulation and Visualization Program (p. 23)
Free University of Amsterdam	Amster-dam, The Nether-lands	Statistics Research Group	Digital Library of Mathematical Functions (p. 36)
George Washington University	Washing-ton, DC	Department of Physics	Digital Library of Mathematical Functions (p. 36)
Georgia Institute of Technology (Georgia Tech)	Atlanta, Georgia	Manufacturing Research Center	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
Georgia Institute of Technology (Georgia Tech)	Atlanta, Georgia	School of Mechanical Engineering	Predictive Process Engineering Program (p. 26)
Harvard University	Cam-bridge, MA	Harvard Smithsonian Center for Astrophysics	Integration of NIST Standard Reference Data into Information Networks (p. 38)
Indian Institute of Technology	Kanpur, India	Mechanical Engineering Department	Product Engineering Program (p. 31)
INRIA, the French National Institute for Research in Computer Science and Control	Paris, France	n/a	Digital Library of Mathematical Functions (p. 36)
Iowa State University	Ames, Iowa	Department of Materials Science and Engineering	Materials Informatics Resources: MatML (p. 25)

Academic Institutions			
Name	Location	Department	Collaborating Project(s)
Iowa State University	Ames, Iowa	Department of Mathematics	Digital Library of Mathematical Functions (p. 36)
Johannes Kepler University	Linz, Austria	Institute for Symbolic Computation	Digital Library of Mathematical Functions (p. 36)
Macalester College	St. Paul, MN	Department of Mathematics and Computer Science	Digital Library of Mathematical Functions (p. 36)
Mannheim University of Applied Sciences	Mannheim, Germany	n/a	Product Data Standards for the HVAC/R Industries (p. 28)
Masssachusetts Institute of Technology	Cambridge, MA	Department of Material Science and Engineering	Materials Informatics Resources: MatML (p. 25)
Masssachusetts Institute of Technology	Cambridge, MA	Department of Mathematics	Digital Library of Mathematical Functions (p. 36)
Musashi University	Tokyo, Japan	Department of Management	Manufacturing Simulation and Visualization Program (p. 23)
Pennsylvania State University	State College, PA	Department of Industrial and Manufacturing Engineering	Manufacturing Simulation and Visualization Program (p. 23) Predictive Process Engineering Program (p. 26)
Pennsylvania State University	State College, PA	Department of Mathematics	Digital Library of Mathematical Functions (p. 36)
Pennsylvania State University	State College, PA	Information Systems Department	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)

Academic Institutions			
Name	Location	Department	Collaborating Project(s)
Purdue University	Lafayette, IN	Computer Science Department	Digital Library of Mathematical Functions (p. 36)
Rutgers University	New Brunswick, NJ	Department of Chemistry	Web-Based Bioinformatics Databases (p. 43)
San Diego State University	San Diego, CA	Mathematical and Computer Sciences Department	Digital Library of Mathematical Functions (p. 36)
Stanford University	Stanford, CA	Center for Design Research	Manufacturing Enterprise Integration Program (p. 21)
Stanford University	Stanford, CA	Center for Integrated Facilities Engineering	Product Data Standards for the Process Plant Industries (p. 29)
Stanford University	Stanford, CA	Department of Statistics	Digital Library of Mathematical Functions (p. 36)
Stanford University	Stanford, CA	School of Engineering	Product Engineering Program (p. 31)
Syracuse University	Syracuse, NY	Department of Mechanical, Aerospace, and Manufacturing Engineering	Product Engineering Program (p. 31)
Université des Sciences et Technologies de Lille	Lille, France	Laboratoire d'Analyse Numérique et d'Optimisation	Digital Library of Mathematical Functions (p. 36)
University College London	London, UK	Department of Physics and Astronomy	Digital Library of Mathematical Functions (p. 36)
University of Abertay Dundee	Dundee, UK	Department of Mathematics	Digital Library of Mathematical Functions (p. 36)
University of Arizona	Tucson, AZ	Systems and Industrial Engineering Department	Manufacturing Simulation and Visualization Program (p. 23)

Academic Institutions			
Name	Location	Department	Collaborating Project(s)
University of Bristol	Bristol, UK	Department of Physics	Digital Library of Mathematical Functions (p. 36)
University of California	San Diego, CA	San Diego Supercomputer Center	Web-Based Bioinformatics Databases (p. 43)
University of California	Santa Barbara, CA	Department of Mathematics	Digital Library of Mathematical Functions (p. 36)
University of Cincinnati	Cincinnati, OH	Department of Electrical and Computer Engineering and Computer Science	Manufacturing Enterprise Integration Program (p. 21)
University of Delaware	Newark, DE	Center for Composite Materials	Materials Informatics Resources: MatML (p. 25)
University of Delaware	Newark, DE	Department of Mechanical Engineering	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
University of Edinburgh	Edinburgh, UK	Department of Mathematics and Statistics	Digital Library of Mathematical Functions (p. 36)
University of Essen	Essen, Germany	Mathematics and Computer Science	Digital Library of Mathematical Functions (p. 36)
University of Illinois	Chicago, IL	Department of Mechanical Engineering	Manufacturing Simulation and Visualization Program (p. 23)
University of Iowa	Iowa City, IA	Department of Industrial Engineering	Manufacturing Simulation and Visualization Program (p. 23)
University of Kent	Canterbury, UK	Institute of Mathematics and Statistics	Digital Library of Mathematical Functions (p. 36)

Academic Institutions			
Name	Location	Department	Collaborating Project(s)
University of Leeds	Leeds, UK	Department of Applied Mathematics	Digital Library of Mathematical Functions (p. 36)
University of Lille (Science and Technology)	Lille, France	Numerical Optimization and Analysis Laboratory	Digital Library of Mathematical Functions (p. 36)
University of Maryland	Baltimore, MD	Department of Chemistry	Online Access to NIST Chemical Reference Data (p. 40)
University of Maryland	Baltimore, MD	Department of Computer Science and Electrical Engineering	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
University of Maryland	College Park, MD	Department of Computer Science	Manufacturing Simulation and Visualization Program (p. 23) Predictive Process Engineering Program (p. 26)
University of Maryland	College Park, MD	Department of Electrical Engineering	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)
University of Maryland	College Park, MD	Department of Mechanical Engineering	Manufacturing Simulation and Visualization Program (p. 23) Predictive Process Engineering Program (p. 26) Product Engineering Program (p. 31)
University of Maryland	College Park, MD	Institute for Physical Science and Technology	Digital Library of Mathematical Functions (p. 36)

Academic Institutions			
Name	Location	Department	Collaborating Project(s)
University of Maryland	College Park, MD	Institute of Systems Research	Manufacturing Enterprise Integration Program (p. 21)
University of Melbourne	Parkville, Victoria, Australia	School of Physics	Integration of NIST Standard Reference Data into Information Networks (p. 38)
University of Michigan	Ann Arbor, MI	School of Information Collaboratory for Research in Electronic Work (CREW)	Manufacturing Enterprise Integration Program (p. 21)
University of Michigan	Ann Arbor, MI	College of Engineering	Product Engineering Program (p. 31)
University of Mississippi	Jackson, MS	Medical Center	Web-Based Bioinformatics Databases (p. 43)
University of Nebraska	Lincoln, NE	Department of Physics and Astronomy	Integration of NIST Standard Reference Data into Information Networks (p. 38)
University of New Brunswick	Saint John, NB, Canada	Department of Physical Sciences	Integration of NIST Standard Reference Data into Information Networks (p. 38)
University of North Carolina Charlotte	Charlotte, NC	Department of Mechanical Engineering and Engineering Science	Dimensional Inspection Information Exchange (p. 13)
University of St Andrews	St Andrews, UK	School of Mathematics and Statistics	Digital Library of Mathematical Functions (p. 36)
University of Saskatchewan	Saskatoon, Saskatchewan, Canada	Department of Computer Science	Manufacturing Enterprise Integration Program (p. 21)

Academic Institutions			
Name	Location	Department	Collaborating Project(s)
University of South Carolina	Columbia, SC	College of Engineering and Information Technology	Predictive Process Engineering Program (p. 26)
University of Southhampton	Southhampton, UK	Faculty of Mathematical Studies	Digital Library of Mathematical Functions (p. 36)
University of Tennessee	Knoxville, TN	Department of Chemistry	Online Access to NIST Chemical Reference Data (p. 40)
University of Toronto	Toronto, Canada	Enterprise Integration Laboratory	Predictive Process Engineering Program (p. 26)
University of Virginia	Charlottesville, VA	Department of Electrical Engineering	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
University of Washington	Seattle, WA	Department of Chemistry	Digital Library of Mathematical Functions (p. 36)
University of Wisconsin-Madison	Madison, WI	Department of Biostatics and Medical Informatics	Web-Based Bioinformatics Databases (p. 43)
University of Wisconsin-Madison	Madison, WI	Department of Mathematics	Digital Library of Mathematical Functions (p. 36)
University of Wisconsin-Milwaukee	Milwaukee, WI	Department of Engineering & Mathematical Sciences	Digital Library of Mathematical Functions (p. 36)
Virginia Polytechnic University	Blacksburg, VA	Department of Industrial and Systems Engineering	Manufacturing Simulation and Visualization Program (p. 23)
Virtual School of Molecular Sciences	Nottingham, UK	n/a	Materials Informatics Resources: MatML (p. 25)

Academic Institutions			
Name	Location	Department	Collaborating Project(s)
Washington State University	Pullman, WA	School of Mechanical and Materials Engineering	Product Engineering Program (p. 31)
Washington University St. Louis	St. Louis, MO	School of Arts and Sciences	Digital Library of Mathematical Functions (p. 36)

Standards Committees			
Committee	Organization	Description	Collaborating Project(s)
ASME Y14.5	American Society of Mechanical Engineers	Dimensioning and Tolerancing.	Product Engineering Program (p. 31)
ASTM/SC E28.16	American Society for Testing and Materials	Mechanical Testing/Rapid Prototyped Parts.	Product Engineering Program (p. 31)
ASTM/SC E01.25	American Society for Testing and Materials	Analytical Chemistry for Metals, Ores and Related Materials.	Standards for Exchange of Instrument Data and NIST Chemical Reference Data (p. 42)
ASTM/SC E49.08	American Society for Testing and Materials	Analytical Data Interchange Protocols.	Standards for Exchange of Instrument Data and NIST Chemical Reference Data (p. 42)
ASTM/SC E49.50	American Society for Testing and Materials	Chemical Data Interchange.	Standards for Exchange of Instrument Data and NIST Chemical Reference Data (p. 42)
	Consortium for Advanced Manufacturing, Inc. (CAM-I)	Dimensional Measuring Interface Standard	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19)

Standards Committees			
Committee	Organization	Description	Collaborating Project(s)
ASC X12	Data Interchange Standards Association	Electronic Data Interchange	Manufacturing Enterprise Integration Program (p. 21)
	Foundation for Intelligent Physical Agents (FIPA)	Promotes the development of specifications of generic agent technologies that maximize interoperability within and across agent-based applications.	Manufacturing Enterprise Integration Program (p. 21)
Conformance and Validation Testing Implementor Forum	IGES/PDES	ANSI-accredited national standards body with industry, government, and academic representation. Dedicated to the development and implementation of world-wide standards for the digital representation and communication of product data.	Information Technology Metrology for Manufacturing Program (p. 17)
DASC	Institute of Electrical and Electronics Engineers (IEEE)	DASC seeks to promote the development of standards in the Design Automation industry.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
DATC	Institute of Electrical and Electronics Engineers (IEEE)	Professional society for advancing the theory and practice of electrical, electronics and computer engineering and computer science.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
TC-9	Institute of Electrical and Electronics Engineers (IEEE)	Sensor Technology	Sensor Integration (p. 33)
IEC/TC3/SC3D/WG2	International Electrotechnical Commission (IEC)	The role of IEC/TC3/SC3D is to prepare standards regarding methods and rules associated with the handling of information in computer-sensible form. WG2 concentrates on classification of components and definition of technical data element types.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
IEC/TC93/WG1	International Electrotechnical Commission (IEC)	The role of IEC/TC93/WG1 is to propose to TC 93 an overall strategy and practical working approach for the harmonization and interoperability of electrotechnical data description standards.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
IEC/TC93/WG3	International Electrotechnical Commission (IEC)	The role of IEC/TC93/WG3 is to develop an IEC Standard based on the EDIF Standard from the EIA (Electronic Industries Association) in the U.S. The coverage of this standard includes an exchange format for describing the connectivity of components in electronic and electrotechnical netlists and PC boards.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
IEC/TC93/WG5	International Electrotechnical Commission (IEC)	The role of IEC/TC93/WG5 is to investigate test, validation, conformance and qualification methodologies for international standards for electrical and electronic product data exchange.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)

Standards Committees			
Committee	Organization	Description	Collaborating Project(s)
IEC/TC93/WG6	International Electrotechnical Commission (IEC)	The role of IEC/TC93/WG6 is to define standards and infrastructure necessary to support the exchange of component information at the international level.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
Area Committee: Automation	National Committee for Clinical Laboratory Standards	Subcommittee: System Status and Error and Exception Handling	Standards for Exchange of Instrument Data and NIST Chemical Reference Data (p. 42)
Area Committee: Automation	National Committee for Clinical Laboratory Standards	Subcommittee: Communications with Automated Systems	Standards for Exchange of Instrument Data and NIST Chemical Reference Data (p. 42)
JTC1/SC24	International Organization for Standardization (ISO)	Joint Technical Committee: Information Technology Subcommittee: Computer Graphics and Image Processing	Visualization and Virtual Reality for Collaboration and Manufacturing (p. 34)
TC184/SC4	International Organization for Standardization (ISO)	Technical Committee: Industrial Automation Systems and Integration Subcommittee: Industrial Data SC4 develops standards which provide capabilities to describe and manage product data throughout the life of the product.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15) Information Technology Metrology for Manufacturing Program (p. 17) Manufacturing Enterprise Integration Program (p. 21) Predictive Process Engineering Program (p. 26) Product Engineering Program (p. 31)

Standards Committees			
Committee	Organization	Description	Collaborating Project(s)
TC184/SC4/ Quality Committee	International Organization for Standardization (ISO)	Responsible for developing STEP methods and assessing the compliance of draft STEP parts with prescribed methods.	Information Technology Metrology for Manufacturing Program (p. 17)
TC184/SC4/ WG3/ Ad Hoc Committee on Parametrics	International Organization for Standardization (ISO)	The role of the Parametrics Committee is to determine the need for parametric representations in STEP and related standards, and propose how techniques and models may be changed to meet those needs.	Intelligent Unit Process Control in Next Generation Open Manufacturing Systems (p. 19) Product Engineering Program (p. 31)
TC184/SC4/ WG3/T11	International Organization for Standardization (ISO)	Technical Committee: Industrial Automation Systems and Integration Subcommittee: Industrial Data Working Group: Product Modeling Team: Manufacturing Technology	Information Technology Metrology for Manufacturing Program (p. 17)
TC184/SC4/ WG3/T20	International Organization for Standardization (ISO)	Technical Committee: Industrial Automation Systems and Integration Subcommittee: Industrial Data Working Group: Product Modeling Team: Process Plant Industries	Product Data Standards for the Process Plant Industries (p. 29)
TC184/SC4/ WG8	International Organization for Standardization (ISO)	Technical Committee: Industrial Automation Systems and Integration Subcommittee: Industrial Data Working Group: Industrial Manufacturing Management Data	Manufacturing Enterprise Integration Program (p. 21) Manufacturing Simulation and Visualization Program (p. 23)
TC184/SC4/ WG11	International Organization for Standardization (ISO)	Technical Committee: Industrial Automation Systems and Integration Subcommittee: Industrial Data Working Group: EXPRESS Language, Conformance, Testing, and Implementation Specifications	Information Technology Metrology for Manufacturing Program (p. 17)
TC184/SC4/ WG12	International Organization for Standardization (ISO)	Technical Committee: Industrial Automation Systems and Integration Subcommittee: Industrial Data Working Group: Common resources	Product Engineering Program (p. 31)

Standards Committees			
Committee	Organization	Description	Collaborating Project(s)
TC184/SC5/	International Organization for Standardization (ISO)	Technical Committee: Industrial Automation Systems and Integration Subcommittee: Architecture, Communications, and Integration Frameworks	Manufacturing Enterprise Integration Program (p. 21) Predictive Process Engineering Program (p. 26)
TC184/SC5/ WG1	International Organization for Standardization (ISO)	Technical Committee: Industrial Automation Systems and Integration Subcommittee: Architecture, Communications, and Integration Frameworks Working Group: Modeling and architecture	Predictive Process Engineering Program (p. 26)
TC184/SC5/ WG4	International Organization for Standardization (ISO)	Technical Committee: Industrial Automation Systems and Integration Subcommittee: Architecture, Communications, and Integration Framework Working Group: Manufacturing programming environments	Predictive Process Engineering Program (p. 26)
TC213/WG13	International Organization for Standardization (ISO)	Technical Committee: Dimensional and Geometrical Product Specifications and Verification Working Group: Statistical tolerancing of mechanical parts	Product Engineering Program (p. 31)
JTC1/SC32	International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC)	Joint Technical Committee: Information Technology Subcommittee: Data Management and Interchange	Manufacturing Enterprise Integration Program (p. 21)
JTC1/SC34	International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC)	Joint Technical Committee: Information Technology Subcommittee: Document Description and Processing Languages	Manufacturing Enterprise Integration Program (p. 21)
STEP Steering Committee	International Society for Measurement and Control (ISA)	Develops the ISA STEP implementation plan and promotes the value of participation in the development of STEP APs.	Product Data Standards for the Process Plant Industries (p. 29)
Area Committee on Automation	NCCLS	Global standards-developing and educational organization that promotes the development and use of voluntary consensus standards and guidelines within the healthcare community.	Standards for Exchange of Instrument Data and NIST Chemical Reference Data (p. 42)
Electronic Commerce Working Group	Object Management Group	Consortium dedicated to the development of technology and standards for distributed object systems.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)

Standards Committees			
Committee	Organization	Description	Collaborating Project(s)
Manufacturing Domain task Force	Object Management Group	Consortium dedicated to the development of technology and standards for distributed object systems.	Manufacturing Enterprise Integration Program (p. 21) Manufacturing Simulation and Visualization Program (p. 23) Product Engineering Program (p. 31)
Simulation Special Interest Group	Object Management Group	Consortium dedicated to the development of technology and standards for distributed object systems.	Manufacturing Enterprise Integration Program (p. 21) Manufacturing Simulation and Visualization Program (p. 23)
Human Modeling Technology Standards Committee	Society of Automotive Engineers	Organization for engineers involved in designing, building, maintaining, and operating self-propelled vehicles for use on land or sea, in air or space.	Visualization and Virtual Reality for Collaboration and Manufacturing (p. 34)
Electronic Data Interchange for Administration, Commerce and Transport (EDIFACT) Working Group	United Nations	Coordinates formation of internationally agreed standards, directories, and guidelines for the electronic interchange of structured data	Manufacturing Enterprise Integration Program (p. 21)
Electrical Applications Committee	US/PRO	Provides the management functions for the IGES/PDES Organization (IPO) and its related activities, including the U.S. Technical Advisory Group (TAG) to ISO TC184/SC4.	Electronic Commerce for the Electronics Industry (ECEI) (p. 15)
	Workflow Management Coalition	Develops standards for software terminology, interoperability and connectivity between workflow products.	Predictive Process Engineering Program (p. 26)

Appendix C: FY99-00 Project Publications

Electronic Commerce for the Electronics Industry (ECEI) (p. 15)

[1] Goldstein, B., Cartwright, J., "Opening Up to Standardization", Circuits Assembly, Vol. 10, Number 6, June 1999.

[2] Goldstein, B., Cartwright, J., Friedman, J., Minchella, J., "Virtual Factory Project Tackles Integration", Future EMS International, Vol. 2, September 1999.

[3] Goldstein, B., Rhodes, T., "Integrating Manufacturing Across Electronics Supply Chain Partners: the NIST Internet Commerce for Manufacturing Project," Engineering Development International, October 2000.

[4] McCaleb, M., "A Conceptual Data Model of Datum Standards", Journal of Research of the National Institute of Standards and Technology, Vol. 104, 349 (1999).

[5] Parks, C., "Internet Commerce for Manufacturing Product Data", NISTIR 6320, NIST, Gaithersburg, MD, April 1999.

[6] Parks, C., Nell, J., "Internet Commerce for Manufacturing Data Staging", NISTIR 6578, NIST, Gaithersburg, MD, October 2000.

Manufacturing Enterprise Integration Program (p. 21)

[7] Barkmeyer, E., Nell, J., Parks, C., "Internet Commerce for Manufacturing Activity Model", NISTIR 6516, NIST, Gaithersburg, MD, May 2000.

[8] Ivezic, N., Barbacci, M., Libes, D., Potok, T., Robert, J., "An Analysis of a Supply Chain Management Agent Architecture", Proceedings of The Fourth International Conference on MultiAgent Systems, Boston, MA, July 2000.

[9] Ivezic, N., Barbacci, M., Libes, D., Potok, T., Robert, J., "An Architecture Analysis of Agent-based Systems", Proceedings of Engineering Societies in the Agents' World (ESAW 00), Berlin, Germany, August 2000.

[10] Ivezic, N., Barbacci, M., Libes, D., Potok, T., Robert, J., "An Architecture and COTS Analysis of Agent Systems", Proceedings of The First Goddard Workshop on Formal Approaches to Agent-based Systems, Greenbelt, MD, April 2000.

[11] Ivezic, N., Fong, E., Peng, Y., Rhodes, T., "B2B E-Commerce Infrastructure using Agents and Standards", Proceedings of the 4th International Conference on Design of Information Infrastructure Systems for Manufacturing (DIISM) 2000, Melbourne, Australia, November 2000.

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Appendix D: Program Products Newly Available in FY99 - 00

Software/Services

AnthroGloss - 3D Visual Anthropometric Landmark Glossary
A three-dimensional, manipulable visual glossary depicting human anatomical reference points.
Available: http://ovrt.nist.gov/projects/vrml/h-anim/landmarkInfo.html

EXPRESSO Version 2.3
A software tool to validate STEP schemas and verify STEP translator conformance.
Available: http://www.nist.gov/expresso

Tools for Planning Neutron Small-Angle Scattering and Reflectrometry and Powder Diffraction Experiments
Tools for planning small-angle neutron scattering (SANS) and neutron reflectivity (NR) experiments are on line.
Available: http://webster.ncnr.nist.gov/resources/
Analogous tools for powder diffraction experiments are now on line.
Available: http://webster.ncnr.nist.gov/programs/crystallography/

Tools for Analysis of Small-Angle Neutron Scattering (SANS) Data
Macros for more than a dozen models of scattering functions used to analyze SANS data have been written according to a uniform protocol and are now available for downloading, along with documentation.
Available: http://webster.ncnr.nist.gov/programs/sans/

Standard Reference Databases[2]

Atomic Spectral Line Broadening Bibliographic Database
This database contains approximately 800 recent references, all collected after the most recent published bibliography (NIST Special Publication 366, Suppl. 4, 1993). These papers contain numerical data, general information, comments, and review articles and are part of the collection of the Data Center on Atomic Line Shapes and Shifts at NIST.
Available: http://physics.nist.gov/linebrbib

Atomic Transition Probability Bibliographic Database, Version 6.0
The database contains numerical data, comments, and review articles on atomic transition probabilities (oscillator strengths, line strengths, or radiative lifetimes).
Available: http://physics.nist.gov/fvalbib

Atomic Weights and Isotopic Compositions, Version 2.1
The atomic weights are available for elements 1 through 111, and isotopic compositions or abundances are given when appropriate. The atomic weights data were published by T. B. Coplen in *Atomic Weights of the Elements 1995,* and the isotopic compositions data were published by K. J. R. Rosman and P. D. P. Taylor in *Isotopic Compositions of the Elements 1997.* One should note that the isotopic compositions data are not based on *Atomic Weights of the Elements 1995* but on *Atomic Weights of the Elements 1997.*
Available: http://physics.nist.gov/comp

Digital Library of Mathematical Functions
Prototype site from a project which will eventually provide a comprehensive, ongoing and authoritative body of information on the notation, properties, computation and applications of the higher mathematical functions, and to

2. More information on Standard Reference Data products can be found at http://www.nist.gov/srd/.

present this data free of charge on the World Wide Web in the form of an interactive Digital Library of Mathematical Functions (DLMF).
Available: http://dlmf.nist.gov/

Electron-Impact Ionization Cross Section Database
This database contains primarily total ionization cross sections of molecules by electron impact. It also includes cross sections for a small number of atoms and energy distributions of ejected electrons for H, He, and H_2. The cross sections were calculated using the Binary-Encounter-Bethe (BEB) model, which combines the Mott cross section with the high-incident energy behavior of the Bethe cross section. Selected experimental data are included.
Available: http://physics.nist.gov/ionxsec

Elemental Data Index
The Elemental Data Index provides access to the holdings of NIST Physics Laboratory online data organized by element. It is intended to simplify the process of retrieving online scientific data for a specific element. Data accessible through this index include: atomic spectroscopic data, electron-impact ionization cross sections, x-ray and gamma ray absorption data, radiation dosimetry data, radionuclide half-life measurements, isotopic compositions and atomic weights, and atomic reference data for electronic structure calculations. Other Physics Laboratory databases were modified to allow access to data through the EDI.
Available: http://physics.nist.gov/edi

Glossary of Terms for Phase Equilibria Diagrams
Multi-media and cross-referenced glossary.
Available: http://www.ceramics.nist.gov/webbook/glossary/ped/glossary.htm

Java Virtual Environment Device Interfaces (JVEDI)
Provides source code for server/client JVEDI for control and monitoring of Lego robots, a video camera, and a Flock of Birds device.
Available: http://ovrt.nist.gov/jvedi/

NIST Atomic Spectra Database v.2.0
Version 2.0 features a completely new engine and vastly expanded data that integrate atomic energy level information with transition probability information.
The Atomic Spectra Database (ASD) contains data for radiative transitions and energy levels in atoms and atomic ions. Data are included for observed transitions of 99 elements and energy levels of 52 elements. ASD contains data on about 900 spectra from about 1 Å (Ångströms) to 200 µm (micrometers), with about 70,000 energy levels and 91,000 lines, 40,000 of which have transition probabilities listed. The most current NIST-evaluated data associated with each transition are integrated under a single listing.
Energy level data are included for most spectra of H-Kr (Z=1-36), Mo (Z=42), plus up to the first five spectra of the lanthanide rare earths (Z=57-71). Classified lines with transition probabilities are included for most spectra of H-Ni (Z=1-28), including new extensive transition probabilities for C, N, and O; output for these can be ordered by either multiplet (for a given spectrum) or wavelength. Also, prominent lines (unclassified) with wavelengths and relative intensities are included for up to the first five spectra of H-Es (Z=1-99). Some transition probabilities are listed for selected lines of Cu-Es (Z=29-99). Comprehensive wavelength lists of observed lines with relative intensities are incorporated for all spectra of Mg, Al, S, Sc, plus Be I, O II, and Ne I.
Available: http://physics.nist.gov/asd

Searchable Bibliography on the Constants
This bibliographic database contains citations for the most important theoretical and experimental publications relevant to the fundamental constants and closely related precision measurements published since the mid 1980s, but also includes many older papers of particular interest, some of which date back to the early 1900s. It is periodically

updated through the addition of papers from the current literature and made more comprehensive through the addition of papers published earlier.
Available: http://physics.nist.gov/constantsbib

Stopping-Power and Range Tables for Electrons, Protons, and Helium Ions
Three radiation dosimetry databases (ESTAR, PSTAR, and ASTAR) calculate stopping powers, ranges and related quantities, for electrons, protons and helium ions. The underlying methods were developed by a members of a report committee sponsored by the International Commission on Radiation Units and Measurements (ICRU).
With a default option, ESTAR generates stopping powers and ranges for electrons which are the same as those tabulated in ICRU Report 37 for 72 materials at a standard grid of 81 kinetic energies between 10 keV and 1000 MeV. ESTAR can also calculate similar tables for any other element, compound or mixture. Furthermore, it can calculate stopping powers at any set of kinetic energies between 1 keV and 10 GeV.
With a default option, PSTAR and ASTAR generate the stopping powers and ranges for protons and helium ions tabulated in ICRU Report 49 for 74 materials at a standard grid of 133 kinetic energies between 1 keV and 10 GeV for protons, and 122 kinetic energies between 1 keV and 1 GeV for helium ions. These databases can also calculate similar results at any other energy grid between these limits.
Available: http://physics.nist.gov/star