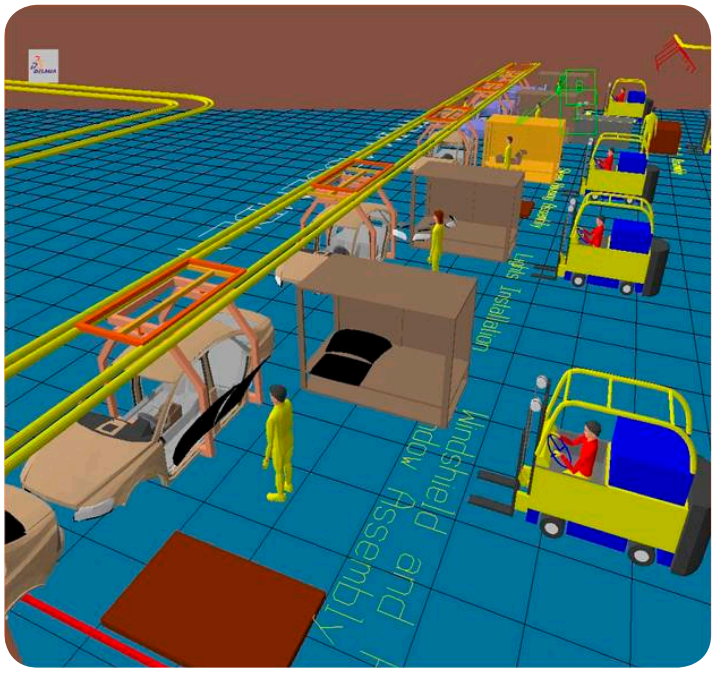
Manufacturing Systems Integration Program

Simulation-based Manufacturing Interoperability Standards and Testing

Annual FTEs: 6 NIST FTEs
5 Guest Researcher FTEs
11 Total **FTEs**

Challenge:

Manufacturing systems, often requiring large investments in capital equipment and supporting software, are costly and time-consuming to acquire, integrate, and operate. Simulation technology, which makes possible the construction of technically correct, dynamic models of organizations, systems, and processes, is a tool of proven effectiveness in reducing manufacturing costs and improving the efficiency of manufacturing system design, operation, and maintenance. Simulation models can be used to perform "what-if" analyses and make better-informed decisions. But because simulations take time as well as specialized expertise in both construction and analysis of results, they are not used as often or as effectively as they might be; manufacturing management makes decisions based on intuition or superficial analysis. Manufacturing simulations are often developed to address a narrow set of industrial issues, such as the purchase of new equipment or the improvement of an existing manufacturing process, with no thought given to reusability for other purposes.



Overview

Greater use of simulation technology and re-use of existing models can help U.S. industry improve its manufacturing systems and compete more effectively in world markets. The NIST Simulation Program focuses on simulation standards and testing issues that will enable the U.S. manufacturing industry to make more effective use of simulation technology. The Department of Homeland Security (DHS) has also recognized the value of NIST's expertise in simulation, and is giving the Program additional support to provide guidance on standards and testing for DHS modeling, simulation, and analysis applications.

There are three major components to the Program: Frameworks and Architectures; *Data Models and Standards; and Simulation Prototypes and Testing Systems*.

Frameworks and Architectures - NIST has developed distributed integration frameworks and architectures for both manufacturing and homeland security applications. The frameworks and architectures have set the direction for NIST's interface standardization, prototyping, and testing activities. As well as publishing journal articles, technical reports, and other papers, we were invited in 2007 to give the keynote at the Simulation Interoperability Standards Organization Conference (SISO) that addressed the NIST modeling and simulation architecture for incident management training.

Data Models and Standards - NIST has provided leadership and technical expertise to the Simulation Interoperability Standards Organization (SISO) to develop a Core Manufacturing Simulation Data (CMSD) model. The CMSD provides neutral data interfaces for integrating job shop software applications with manufacturing simulators. CMSD is now being extended to address flow shop[17] simulation, plant layout, and other data types. A number of major organizations – manufacturers, software vendors, research institutions and government agencies – have supported and participated in the validation of the specifications, and have provided technical contributions and reviews. Current validation efforts are being conducted with Volvo's truck engine plant, a division of the Ford Motor Company, and Chalmers University of Sweden. Unigraphics, Enterprise Dynamics, and Simul8 simulation systems are being used in the validation process.

Simulation Prototypes and Testing Systems - NIST scientists and engineers involved in the Simulation Program are using simulation technology to gain first hand experience with the problems faced by industrial users, to validate standards solutions, and to establish interoperability and other testing capabilities. A major focus is the development of a new, dynamic, simulation-based interoperability testing facility for manufacturing software applications.

NIST has developed a number of simulations to support simulation-based interoperability testing, including an automotive supply chain, a vehicle final assembly plant, and various shop floor operations. The interfaces that have so far been incorporated into these simulations include the SISO Core Manufacturing Simulation Data Model and the Open Application Group's (OAGIS) specification supporting Inventory Visibility. Future work will focus on integrating manufacturing software applications with a virtual machine shop to support validation and interoperability testing.

17 The flow structure of the process used to make or deliver a product or service impacts facility layout, resources, technology decisions, and work methods. When characterized by its flow structure, a process broadly can be classified either as a job shop or a flow shop. A job shop process uses general purpose resources and is highly flexible. A flow shop process uses specialized resources and the work follows a fixed path. Consequently, a flow shop is less flexible than a job shop. [http://www.netmba.com/operations/process/structure/]

Key Accomplishments and Impacts:

- Drafted Core Manufacturing Simulation Data (CMSD) specification, available through the standards development organization SISO – Simulation Interoperability Standards Organization.
- Validation of CMSD with Volvo and several simulation vendors.
- Completed exercise control system for homeland security training with various California agencies.

Future Directions and Plans:

The technical plan for this program is to develop manufacturing simulations that incorporate standard interfaces and instrumentation to support dynamic interoperability testing of manufacturing software applications for the automotive, aerospace, and other industries. Projects include:

1. **Standards Harmonization and Extensions:** Work with the Simulation Interoperability Standards Organization (SISO) to expand the Core Manufacturing Simulation Data Model (CMSD) to incorporate ISA 95, OAGIS IV&I, Oasis UN/CEFACT Components standards. Incorporate additional data types for plant layout, inventory, cost accounting, message transactions, equipment specifications, flow shop operations, supply chains, etc.
2. **Virtual Manufacturing System Enhancements**: Enhance current supply chain, manufacturing plant, and shop floor level simulations with functionality to support processing and interoperability testing for external inventory, process specification, bill of materials, cost accounting, product life cycle management data, etc.
3. **Testing Tool Integration:** Identify, select, and integrate appropriate testing tools developed by the Integration Standards Testing Tools project and others to instrument the Virtual Manufacturing Systems Environment, including integration infrastructures, communications channel monitors, system and module status displays, logging and reporting tools, message and file syntax checkers, system initialization, control utilities, rollback utilities, configuration management, and writing of software for testing tools and test case data sets.
4. **Testing Facility Operations:** Working with industry, research, and SDO partners to define neutral test cases, data sets; and testing policies, procedures, and checklists. Work with software vendors to set priorities and initiate interoperability testing operations for selected software products in key problem areas.

Awards and Recognition:

Board Memberships

Staff	Board Membership
Jain, Sanjay	• Editorial Board, International Journal of Industrial Engineering
Johansson, Bjorn	• Board member, Swedish Manufacturing Simulation Network • Board member, Special Interest Group Product Models • Chairman of the Board, Special Interest Group -Product Models, Sweden 2007
Leong, Swee	• SRC (Semiconductor Research Council) TAB (Technical Advisory Board) • Executive Committee of the Simulation Interoperability Standards Organization
McLean, Chuck	• Editorial Advisory Board of the International Journal of Production Planning & Control • Executive Board – Winter Simulation Conference • Editorial Board – Journal of Simulation • Editorial Board – Journal of Digital Enterprise Technology

Leadership

Staff	Leadership
Jain, Sanjay	Associate Editor, International Journal of Simulation and Process Modeling
Johansson, Bjorn	• Program Committee Secretary, Swedish Production Symposium, Gothenburg, Sweden 2007 • International Program Committee member for European Conference on Modeling and Simulation • International Program Committee member for Industrial Simulation Conference • International Program Committee member for European Simulation and Modelling Conference • International Program Committee member for Swedish Production symposium • International Program Committee member for International Middle Eastern Multiconference on Simulation and Modelling • International Program Committee member for International Conference on Flexible Automation and Intelligent Manufacturing
Lee, Tina	• Secretary, Product Development Group/Simulation Interoperability Standards Organization

Staff	Leadership
Leong, Swee	• Chair, Product Development Group/Simulation Interoperability Standards Organization. • Manager, Simulation Standards Consortium. • Co-Chair, Plenary Session Organizing Committee with theme entitled, "Modeling & Simulation in Manufacturing" at the Simulation Interoperability Standards Organization Fall Simulation Interoperability Workshop • Chair, Modeling & Simulation Standards in Manufacturing Panel discussion at the Simulation Interoperability Standards Organization Fall Simulation Interoperability Workshop
McLean, Chuck	• Secretary, Simulation Interoperability Standards Organization Crisis Management and Societal Security (CMSS) Forum • Standards Program Manager SimSummit Consortium
Riddick, Frank	• Vice-Chair, Product Development Group/Simulation Interoperability Standards Organization
Shao, Guodong	• Conference Committee and Track Chair of the Virtual Reality and Graphical Simulation for the Industrial Simulation Conference 2006 • Invited talk at Brooks Automations 13th Annual Worldwide Symposium on Simulation Prototype for Incident Management Training • Conference Program Committee and Track Chair of the Virtual Reality and Graphical Simulation for the Industrial Simulation Conference 2007

Excellence

Staff	Excellence Recognized
Jain, Sanjay	• Invited Guest Editor for a special issue on supply chain simulation and modeling of the International Journal of Simulation and Process Modeling • Invited Coordinator for Simulation Interoperability track in 2007, and Homeland Security and Emergency Response track in 2006 and 2005 Winter Simulation Conference
Johansson, Bjorn	• Invited Coordinator for Simulation based scheduling track in 2007 and Manufacturing track in 2008 Winter Simulation Conference • Invited Chair for a session on Sustainable Food Manufacturing at FOODSIM2008, Dublin, Ireland 2008
Leong, Swee	• Invited seminar at Beijing University Aeronautics & Astronautics entitled, "Modeling and Simulation in Manufacturing" in November 2007
McLean, Chuck & Jain, Sanjay	• More than 100,000 downloads of co-authored workshop report on "Modeling and Simulation for Emergency Response- Workshop Report, Standards, and Tools"
McLean, Chuck	• Invited Keynote Speaker – Simulation Interoperability Standards Consortium Fall Simulation Interoperability Workshop September 2007

Projects

Simulation-based Manufacturing Interoperability Standards and Testing

Frameworks and Architectures
(Status: complete in 2010)

Today simulation analysts typically code simulators and models from scratch and build custom data translators to import required data. As a result, developers and analysts around the world are rebuilding over and over again the same basic analytical, programming, and modeling processes. Although a simulation analyst may think that each modeling problem is unique, the component elements of many problems often have a good deal in common. Classification of different types of modeling problems according to uniform schemes or frameworks could identify and exploit such, commonalties. Frameworks make possible the establishment of modular architectures that can minimize redundant code development.

Architectures based on these frameworks divide larger systems into their component modules and identify the interfaces between those modules, allowing the assembly of more sophisticated systems from specialized modules that are independently developed by experts in each modeling area. Use of standard data input formats, as defined by commonly accepted architectures, would permit direct import of data with no need for translation.

Challenge:

Integration of simulators and other software applications and data-sharing among them are currently very difficult because no commonly accepted frameworks and architectures exist that define the simulation module functionality, boundaries, data requirements, and interfaces.

Objective(s):

- Specify frameworks and integration architectures that scope simulation module functions
- Identify interface requirements that can be used to guide future standardization efforts.

Accomplishments:

- Journal paper: An Architecture and Interfaces for Distributed Manufacturing Simulation
- Journal paper: An Architecture for Simulation-based Incident Management Training
- Report: A Data Exchange Strategy for Manufacturing Simulation of Shop Floor Systems
- Report: A Simulation and Gaming Architecture for Manufacturing Research, Testing, and Training
- Paper: A Framework for modular semiconductor simulation with experts from University of Cincinnati, OH

Planned Future Accomplishments:

- A software architecture for job shop manufacturing in the machined parts domain

Customers and Collaborators:

- Department of Homeland Security Science and Technology Directorate
- SimSummit Consortium

Simulation-based Manufacturing Interoperability Standards and Testing

Data Models and Standards
(Status: complete in 2010)

The primary reason for building manufacturing simulations is to provide support tools that aid decision-making in manufacturing processes. Simulations are typically a part of a case study that has been commissioned by manufacturing management to address a particular set of problems. The objectives of the case study determine the appropriate types of simulation models, input and output data. Translation of real world manufacturing problems into the language of manufacturing simulators requires a considerable degree of abstraction. Commercial manufacturing simulators are usually based on discrete event modeling paradigms (e.g., stations, queues, resources, processes) and do not have data interfaces that are consistent with commonly used manufacturing terminology or data structures (e.g., process plans, bill of materials, schedules). The analysis, acquisition, formatting, and translation of required data is often the most difficult part of the simulation analyst's job.

Standard data interfaces for manufacturing simulators simplify and significantly improve the inclusion of simulations in typical case studies. Standard interfaces help reduce the costs of model construction and data exchange between simulators and other software applications, and thus make simulation technology more affordable and accessible to a wide range of potential industrial users. Currently, many small manufacturers do not use simulation technology because of the difficulties of model development and data translation. These businesses typically do not have staff with the technical qualifications to develop custom simulations of their operations or custom translators to import their data from other software applications.

Challenge:

Commercially-developed simulators are typically constructed as general purpose modeling tools that require considerable efforts to input and process real world data, in part due to a lack of agreement on how to represent real world systems and data.

Objective:

- Define information models and standard interfaces for simulation modeling that make simulation technology more accessible and easy to use by conforming to real world information and permitting sharing of data between various software applications.

Accomplishments:

- Technical report: A Machine Shop Data Model
- Technical paper: A Neutral Data Interface Specification For Simulating Machine Shop Operations
- Unified Modeling Language (UML) models of job shop discrete parts manufacturing data structures
- Extensible Markup Language (XML) schemas for the job shop discrete parts manufacturing data structures
- Draft SISO standard: Core Manufacturing Simulation Data (CMSD) Model
- Emergency response simulation data model in the Unified Modeling Language (UML)

- Review of data and interface standards for incident management and emergency response simulation-based training
- Standards program leadership and plan for the SimSummit simulation industry consortium
- UML and XML shift staffing plan amendments to CMSD in cooperation with Volvo
- Analysis of Instrument Society of America (ISA) 95 ERP to MES standards compatibility with CMSD – issues noted included: detailed data formats and values not specified, lacks typing information on data, weak cross referencing scheme, no support for various simulation data types (layout, statistics, cost, inventory)
- Definition of an Radiological Dispersion Device (RDD) terrorist attack scenario and data sets for a collaborative homeland security simulation development effort

Planned Future Accomplishments:

- Draft SISO standard: Core Manufacturing Simulation Data (CMSD) Model machine shop environment
- Needs analysis for homeland security modeling simulation
- Taxonomy for homeland security modeling simulation

Customers and Collaborators:

- Volvo
- Chalmers University
- In Control
- Unigraphics
- Simul8
- Ford Motor Company
- Department of Homeland Security Science and Technology Directorate
- Wright-Patterson Air Force Base
- Doyle Center, Pittsburgh, PA
- Carnegie Mellon University
- Kurt J. Lesker
- Software Engineering Institute
- SISO

Simulation-based Manufacturing Interoperability Standards and Testing

Simulation Prototypes and Testing Systems

(Status: complete in 2011)

Manufacturing systems developed by different software vendors typically cannot work together. Development of custom integrations of manufacturing software incurs costs and delays that hurt U.S. productivity and competitiveness. As software applications continue to evolve interoperability is expected to remain a problem. Although NIST has developed static testing tools that, for example, check data formats, software applications must ultimately be tested in live operational systems. It is impractical to use real industrial systems to support dynamic interoperability testing and research due to: 1) access issues - manufacturing facilities are not open to outsiders, as proprietary data and processes may be compromised; 2) technical issues - operational systems are not instrumented to support testing; and 3) cost issues - productivity suffers when actual production systems are taken offline to allow testing.

No publicly available facility with open interfaces currently exists to support dynamic interoperability testing for a broad range of manufacturing interface standards and software applications. Prohibitive development costs and other priorities prevent most software vendors, research, and standards organizations from developing systems to support interoperability testing.

Software applications from the supply chain to the shop floor must be supported. New standards now being developed to address interoperability issues often overlap and conflict with each other. Adequate testing facilities are not available for evaluating the suitability and effectiveness of existing and candidate standards for application to specific manufacturing domain areas. New, dynamic, manufacturing domain-specific testing capabilities are needed to evaluate the suitability of standards for selected applications, identify and resolve conflicts between standards, and evaluate compliance of vendor implementations with standards. Non-proprietary systems and neutral test case data sets are needed to support fair and open competition.

Challenge:

Publicly available simulations do not exist to demonstrate simulation integration issues, validate potential standards solutions, or dynamically test the interoperability of simulation systems and other software applications.

Objective(s):

- Develop simulation prototypes and testing systems with open architectures and neutral interfaces that can be use to validate simulation interface standards requirements and evaluate the interoperability of software applications with evolving standards.

Accomplishments:

- Simulation of the TDI Corporation manufacturing supply chain for a smart bomb adapter kit using Rockwell Software's Arena simulator that demonstrated the viability of new product and surge production for the Doyle Center and the U.S. Air Force.
- Generic simulation of an automobile final assembly plant using Delmia's Quest to support manufacturing interoperability testing and evaluation of the SISO CMSD and the AIAG IV&I standards specifications.
- Generic simulation of an automobile supply chain using Rockwell Software's Arena simulator to support manufacturing interoperability testing and evaluation of the AIAG IV&I standards specifications
- Distributed integration of the automobile supply chain and final assembly plant to support manufacturing interoperability testing and the evaluation of the IEEE 1516 HLA and AIAG standards specifications
- Simulation of the Volvo automobile paint shop using In Control Enterprise Dynamics simulator to validate the SISO CMSD specifications
- Simulation of the Volvo truck plant using Unigraphics' Plant Simulation and In Control Enterprise Dynamics simulators to validate the SISO CMSD specifications.
- Prototype data editor for shop data model
- Prototype database of the generic machine shop data model
- A web-based simulation called the Exercise Control System to support distributed homeland security training exercises (traditionally table top paper exercises) using the Common Alerting Protocol (CAP), Emergency Data Exchange Language (EDXL), and HLA incident management symbology standards for various response and support organizations in the State of California
- Microsoft Excel template for developing incident management training scenarios using CAP and EDXL for the Exercise Control System
- Prototype translator to convert California State Golden Guardian Exercise emergency message traffic to the Emergency Data Exchange Language (EDXL) and Common Alerting Protocol Standard (CAP)
- Set of coordinated prototype emergency response simulations, built with external collaborators, including plume behavior, vehicle movement, traffic congestion, hospital emergency room, crowd, Metro rail, triage gaming, strategy gaming, databases, and distributed message exchange for a radiological terrorist attack scenario
- Prototype wildfire gaming simulation using the Unreal game engine and a cellular automata model for fire propagation
- Draft report: Study of new alternative systems for implementation of simulation user interfaces and displays
- Simulation prototype of Washington, DC emergency response exercise using Google Earth, Common Alerting Protocol (CAP) and DHS symbology standards

Planned Future Accomplishments:

- Machine shop virtual manufacturing environment.

Customers and Collaborators:

- Volvo
- Chalmers University
- In Control
- Unigraphics
- Simul8.
- Wright-Patterson Air Force Base
- Doyle Center, Pittsburgh, PA
- Dartmouth College
- University of Arizona
- Office of Naval Research
- George Washington University
- Brooks Automation (Autosimulations Division)
- Promodel Corporation
- TDI
- San Francisco MapLab
- Comcare Consortium
- San Jose Water Department

ACI (American Competitiveness Initiative) Activities

The Manufacturing Systems Integration Division received additional funding through the American Competitiveness Initiative under two distinct programs: Supply Chain Integration and Bioimaging. The bioimaging work, performed essentially in a consulting role, was awarded to MEL because of our recognized expertise in semantic integration. The supply chain integration funds augmented our existing supply chain program documented above.

Bioimaging

Introduction

MEL participates in the "Standards and Software Validation" thrust of the NIST Bioimaging ACI. MEL is supporting ITL in achieving the goal of this thrust, which is to improve the quality of image acquisition, analysis, and storage through effective standardization, improved software, and rigorous testing. MEL's tasks in this project are:

- Development of standardized representation schemes and archival techniques for a web-based data storage system that will permit semantic annotation, content-based search and retrieval, visual browsing, cross linking between pathological states and image features, all with appropriate levels of security
- Development of an ontology to represent the semantics of archived images that can be used as the basis for open standard implementations of archive systems.

Achievements

- A workshop was held at NIST in 2006 to determine the need to standardize imaging methods for data collection and data analysis in the context of drug or radiation therapy trials. The NIST meeting was a stakeholders meeting attended by 230+ scientists from academia, imaging and pharmaceutical companies, contract research and trade organizations, and representatives from imaging societies and agencies of the Federal Government.
- Worked on a project intended to support clinical decision making by using image analysis of diseased organs to highlight deviations from normal conditions and to suggest potential disease conditions. The intention is not to automate diagnosis. While providing general a framework for building clinical decision support systems through image analysis, the initial project focused on images captured through wireless endoscopy of the gastrointestinal (GI) system. A disease ontology for part of the system was developed and is currently being validated with experts.
- Cosponsored (with ITL, NIH, and Stanford University) a workshop on evaluating ontologies. This workshop report will develop a plan for addressing the following barriers for effective utilization of ontologies: lack of a systematic method for evaluating ontologies, inadequate techniques for verification and validation, lack of standard methods for comparing ontologies, and paucity of real world applications demonstrating effectiveness of ontologies.

Impacts

The bioimaging workshop report has generated considerable interest in the radiology community. The Radiological Society of North America is planning on implementing some of the recommendations of the workshop. The image analysis work has elicited interest in applying the methodology to large databases of medical images such as the NIH's RIDER (Reference Image Database to Evaluate Response) project.

Supply Chain Integration

Introduction

ACI funding to Supply Chain Integration allowed us to undertake additional supporting research on fundamental issues associated with automatic testing of information content that is exchanged between systems. This research supports the semantic integration projects described above. It is being done in collaboration with the Information Technology Laboratory at NIST, Stanford University, and, the University of Maryland. We conducted two major research activities: (1) development of testing methods, metrics, and conformance criteria for integrating supply chain standards, and (2) development of methods and tools for the automatic generation of conformance tests. Traditional systems testing focuses on the syntax of the data for exchange. Focusing on the semantics and information in the exchange will increase supply chain efficiencies by reducing miscommunication, misinterpretation, and inaccuracies.

Achievements for Activity (1)

- Developed and demonstrated an initial suite of content-level tests for the exchange of e-Kanban messages for the IV&I/ATHENA project, showing that the principal idea of a semantic and web services mediation tool can be put into practice.
- Developed a Naming and Design Rule (NDR) Authoring and Testing environment and demonstrated its capabilities for a number of OAG standard supply-chain messages. NDRs are key to interoperable XML schemas used by government and industry. Since each application sector has particular terminologies and practices, single NDR relates to all applications. A neutral authoring and testing system promotes a consistent exchange environment that supports all rule sets.
- Established a working relationship with the OASIS working group responsible for developing Test Assertion Guidelines. OASIS is a standards development consortium, which will drive worldwide adoption and deployment of our guidelines.
- Collaborated with the Korean B2B Interoperability Testbed (KORBIT) to conduct a proof-of-concept demonstration of Web Services conformance testing associated with the IV&I/ATHENA project. Partnering with KORBIT leverages our ACI funds as both KORBIT and NIST share the development of tools for global e-business testing and demonstrate results collaboratively.
- Worked with Stanford University and the University of Maryland to develop metrics for comparing the semantic content of two information objects. These applied metrics will assist supply chain partners in establishing a baseline common understanding between systems, a first step in effective information exchange and interoperability.

Achievements for Activity (2)

- Developed a tool to automatically translate between Resource Description Framework (RDF) Schema and eXtensible Markup Language (XML) Schema, and between RDF and XML data in support of the IV&I/ATHENA project. RDF Schema is a vocabulary for describing properties and classes of RDF resources, which provide simple semantics. XML Schema is a language for restricting the structure of XML syntax and resulting XML documents. Both RDF and XML Schemas are in use in the global supply chain. NIST's tool automatically translates between the two standards, allowing manufacturing enterprises to retain interoperability while negotiating with a broader spectrum of providers.Developed new algorithms to generate covering arrays as part of the Automated Combinatorial Testing for Software (ACTS) projects18. New algorithms and faster processors make large-scale testing practical; thus reducing testing cost, improving cost-benefit ratio for software assurance

18 This work was performed in the Information Technology Laboratory using part of the MEL ACI funding allocation.

- Collaborated with KORBIT to develop a universal framework for testing conformance to OAGi supply chain standards. This framework was used and demonstrated in the IV&I/ATHENA projects. Having a universal framework for consistent conformance testing increases the probability that products will be portable and interoperable.
- Initiated development of an expanded information mapping test to support the Materials Off-Shore Supply Chains project. The work advances information exchange between different information models and proof-of-concept tools, in collaboration with the automotive industry and other partners, and provides better data management across ocean freight supply chains.