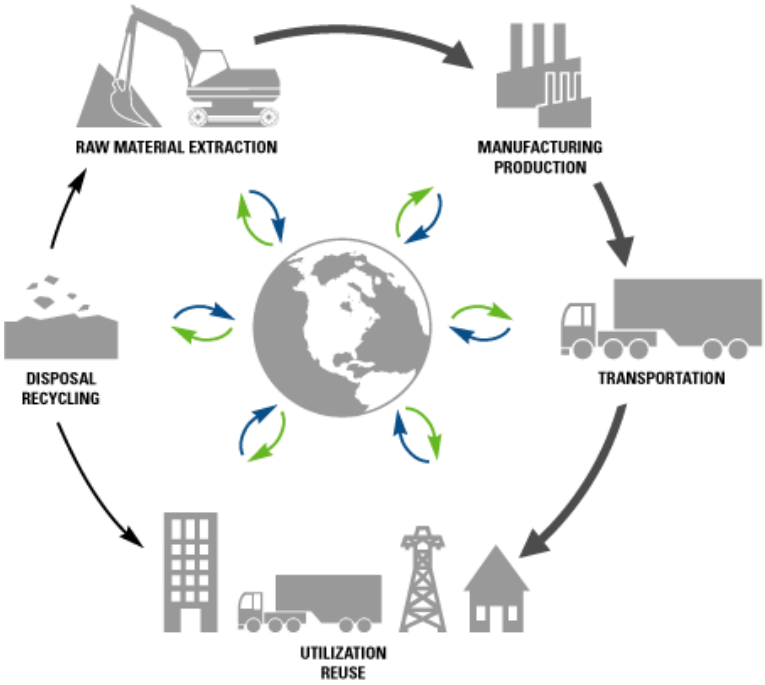
Manufacturing Systems Integration Programs

Sustainable and Lifecycle Information-based Manufacturing

Annual FTEs: 9 NIST FTEs

5 Guest Researcher FTEs

14 Total FTEs



Challenge:

Industry increasingly depends on Product Lifecycle Management (PLM)[12] systems to integrate information throughout all phases of a product's lifecycle. Well-defined standards are needed to provide both syntactic and semantic interoperability among computer systems and people. PLM systems are evolving from the exchange of product data, to the exchange of product information and knowledge throughout an enterprise; they are providing more value by adding product functionality and process information to product geometry. During the past three years, the program has worked on significant extensions to product and process data standards and PLM information models. The accomplishments are briefly sketched below.

Key Accomplishments:

- **Formalizing product and process models.** A formal description of the product beyond the representation of form (geometry and materials) is required to manage information throughout the product's lifecycle. We have developed several rigorous models that facilitate concurrent product development[13] and are amenable to automated reasoning, consistency maintenance, and semantic interoperability. This work has produced standards [ISO 10303-109 (Assembly), ISO-18629 (PSL), OMG's SysML] and product/process models in use in the aerospace and automotive industries [Airbus, Boeing, and GM].
- **STEP transition.** STEP[14] and related ISO TC 184/SC4 Industrial Data standards have been in use for two decades and provide a rich source of consensus-based domain-specific information exchange models. To take advantage of evolving Web technologies, we have developed methods and tools to integrate STEP, OMG, and W3C standards, and a process for migrating STEP data models to these more widely implemented modeling and implementation technologies. This methodology will allow the STEP, OMG, and INCOSE communities to reuse proven high-quality models.

12 PLM is the process of managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal.

13 Concurrent activities associated with a product's design, planning, manufacturing, analysis, maintenance, and disposal.

14 STEP – Standard for the Exchange of Product model data, the informal acronym for ISO 10303, an ISO standard for the computer-interpretable representation and exchange of industrial product data.

- **Standards landscape for product lifecycle management**. PLM support requires a set of complementary and interoperable standards. In 2007, we developed a typology of standards for the exchange of product, process, operations, and supply chain information. Under a commission by the U.S. Army, we undertook a major study in 2006 to identify standards and gaps relevant to standardization, interoperability, and exchange among systems of the Army and its OEMs. The U.S. Army, OASIS, PDES Inc, IMS, and Eurostep are using this work in their deliberations on standards, patent laws, and system implementation.
- **Toward long term data and knowledge retention.** Digital models and systems built today need to be extensible and reusable by subsequent generations. Design repositories and product lifecycle management systems assume that the data will always be readable, which is not the case. We conducted several workshops to determine archival requirements for digital engineering information. This has led to an invitation by the National Archives to work with the U.S. Navy to create specific experiments for archiving product and process information.

Future Direction and Plans:

We need to prepare for a sustainable future where products are 100% recyclable, complete disassembly and sustainable disposal of a product at its end of life is routine, and manufacturing itself has a zero net impact on the environment. In support of this trend, the program looks forward to extending its work by addressing several challenges including: 1) analysis of existing and needed standards for sustainable manufacturing; 2) creation of lifecycle information models for interoperability among systems and tools that support sustainable manufacturing; and 3) validation and testing of information models for sustainable design and manufacturing.

Awards and Recognition

Board Memberships

Staff	Board Membership
Fenves, Steven	• Advisory Board, Faculty of Civil Engineering, Technion, the Israel Institute of Technology. • Advisory Board, Construction Engineering Research Laboratory, U.S. Army Corps of Engineers. • Editorial Board, Journal of Engineering with Computers (Founding Editor). • Editorial Board, Journal of Artificial Intelligence for Engineering Design, Analysis, and Manufacturing. • Editorial Board, International Journal of Computer Applications in Technology.
Frechette, Simon	• System Integration Board, PDES, Inc.
Lyons, Kevin	• Alternate, Interagency Working Group on Manufacturing R&D while at the National Science Foundation (NSF)
Sriram, Ram	• Advisory Board of the Journal of Concurrent Engineering: Research and Applications • Editorial Journal Review Board for "Research for Engineering Design," Springer Verlag • Advisory Board, Several International Conferences • Scientific Officer, National Center for Biomedical Ontologies
Subrahmanian, Eswaran	• Editorial Board, International Journal of Product Life Cycle Management, 2004-to present. • Editorial Board, Journal of Design Research, 2002-to present. • Industry Innovation Board (Science Team, Dutch Paper and Board), Netherlands, 2005.
Ray, Steve	• PDES, Inc. Executive Board • USPRO Executive Board

Leadership

Staff	Leadership
Barnard Feeney, Allison	• NIST voting member on the U.S. TAG to ISO TC 184/SC4, Industrial Automation
Bock, Conrad	• Working Group Lead for activity and action models at the Object Management Group • Working Group Lead for functional modeling in the Systems Engineering Modeling Language Submission Team at the Object Management Group • Lead for semantics of the Business Process Definition Metamodel at the Object Management Group • Lead for formal semantics of the Unified Modeling Language
Fenves, Steven	• Chair, Editorial Task Committee for the Committee on Specifications, American Institute of Steel Construction, Inc.
Lyons, Kevin	• Served a two-year detail at the National Science Foundation. Under his direction, the Nanomanufacturing Program exhibited sustained growth and added an additional Center focused on Nanomanufacturing • Co-Chair and Co-Editor for Interagency Working Group (IWG) workshop and report on Instrumentation, Metrology, and Standards for Nanomanufacturing, October 2006 • Sponsored and participated in a World Technology Evaluation Center (WTEC) study on Carbon Nanotube Production R&D at NSF. The study was initiated with a U.S. baseline workshop and concluded with travel to Japan, Korea, and China with public briefing in November 2006 • Lead NIST advisor volunteer for the FIRST (For Inspiration and Recognition of Science and Technology) robotics student group at Magruder High School, Montgomery County, MD. The regional competition was held in Annapolis, MD, March, 2007 • Invited by the Advanced Technology Program (ATP) Office to assist them during the proposal review cycle (June 2007 for 2 months).
Sriram, Ram	• Technical Co-Chair of the Imaging as a Biomarker workshop (Sept. 14-15, 2006) • Guest Co-Editor of a special issue of the ASME Journal of Computing and Information Science in Engineering, 2006 • Chair, NIST Library Advisory Board

Staff	Leadership
Sudarsan, Rachuri	• U.S. Regional Editor for the International Journal of Product Development • Associate Editor for the new International Journal of Product Lifecycle Management (IJPLM) published by the Inderscience Publishers • Conference Co-Chair for Open Standards for Manufacturing and Healthcare Informatics • Special Issue Co-Editor for ASME Journal of Computing and Information Science in Engineering on Engineering Informatics • Invited talk on "The role of standards in PLM domain" in Intellegent Manufacturing Systems Network of Excellence (IMS-NoE) SIG 1 (Special Interest Group on PLM) workshop in Lyon • Workshop Co-Chair for French-U.S. Workshop, "ICT and Standards for Supply Chains and PLM" • Member, Scientific Committee for the 16th International Conference on Engineering Design ICED 07 held in Paris France, on 28-31 August 2007 • Program Committee for the International conference on Software Knowledge Information Management and Applications (SKIMA) 2006 and 2008. • Invited lecture at PLM Summit, North America 2007 on the topic of quality issues in PLM.
Subrahmanian, Eswaran	• Program Committee Member, ACM Conference on ICT for Development, Bangalore, India, Dec. 2007 • Program Committee Member, Special Track on ICT for Development, W3C Conference, 2007 • Program Committee Member, ACM Conference on ICT for Development, Berkeley California, May 2006 • Co-chairman, Open ICT Ecosystems: Open standards for Manufacturing and health care Informatics, National Institute for Standards and technology, March 2006 • Co-Chairman, Indo-U.S. Workshop on Design Engineering, 5-7, Jan, 2006 • Program Committee, PLM06 – Product Life Cycle Management Conference, Bangalore India, 2006

Staff	Leadership
Subrahmanian, Eswaran (continued)	• Program Committee, IEEE-ACM Conference on ICT and Sustainable Development, Berkley, March 2006 • Nominating member, Japan Science Prize. 1999-to date • Founding member, Center for Science Technology and Policy, Bangalore, India, 2005 • Visiting Professor (Summer) 2007 in the Faculty of Technology Policy and Management at TU Delft Netherlands • Visiting Professor, University of Lumiere-Lyon2, Lyon, June 14- July 14, 2005 • Co-Editor, Special Issue on "Annotation and Engineering Design," Research In Engineering Design, Expected fall of 2008 • Co-Editor, Special Issue on "Engineering Informatics", JCISE. Issue to appear in March 2008

Excellence

Staff	Excellence Recognized
Barnard-Feeney, Allison	• ISO TC184-SC4 Award for Leadership in the Development of SC4 Standards, October 2006 • PDES, Inc. Bryan K. Martin Technical Excellence Award, March 2006
Bock, Conrad	• Published article, "UML 2 Activity and Action Models," translated to German by a major German consulting firm for the magazine OBJEKTspektrum. • International Council on Systems Engineering Outstanding Service Award for contribution to the development of the Systems Modeling Language. • Department of Commerce Bronze Medal for outstanding technical leadership incorporating process modeling in the Unified Modeling Language and the Systems Modeling Language
Feng, Shaw	• Invited editor for a special issue on Modeling and Optimization of Supplier-based Manufacturing and Management using Software Agents, International Journal of Manufacturing Technology and Management magazine
Fenves, Steven	• Awarded Lifetime Achievement Award from the American Institute of Steel Construction for outstanding service to the structural steel design, construction, and academic community • Honored with a special session at the 17th Analysis and Computation Specialty Conference of ASCE in Pittsburgh, Pennsylvania
Frechette, Simon Barnard-Feeney, Allison Lubell, Josh	• Awarded the 2005 Silver Medal Award for Exceptional Service for sustained leadership in the development and deployment of the STEP Application Protocol AP203 Edition 2, a new standard for computer-aided design interoperability

Staff	Excellence Recognized
Lyons, Kevin	• Presented at a public briefing of World Technology Evaluation Center (WTEC) study on Carbon Nanotubes held at the National Science Foundation on November 2-3, 2006 • Presented at 2006 NSF Grantees Conference (Dec 2006) "NIST: The U.S. Nanometrology Resource for Nanotechnology and Nanomanufacturing" • Requested by the ManTech Electronics sub-panel to present and update on Nanomanufacturing technologies, specifically those critical to the DoD, at their Winter meeting (Jan 2007) in Orlando • Principal author and editor (1 of 5) of "Manufacturing at the Nanoscale" report sponsored by the National Science and Technology Council Committee on Technology, Subcommittee on Nanoscale Science, Engineering, and Technology and the National Science Foundation • Invited panelist for 'Challenges in Micro and Nanomanufacturing' Panel Discussion held at the ASME Manufacturing Science and Engineering Conference at Georgia Institute of Technology in October 15-18 2007 • Invited Guest Editor for special nanomanufacturing issue of Journal of Nanoparticle Research to be published in Spring/Summer 2008
Sriram, Ram	• Key Note Speaker, Concurrent Engineering 2005, July 29th, 2005. • Invited Panel Chair, PLM 2005, Lyon France, July 11-15th, 2005. • Founder's Guest Editorial, 20th Anniversary Issue, AI in Engineering Journal. • Keynote Speaker, Korean Society of CAD/CAM Engineers Annual Meeting, January 2007 • Elected as the Fellow of the American Society of Mechanical Engineers (December 2006) • Keynote Speaker, TMCE, Turkey, April 2008
Subrahmanian, Eswaran	• Steven J. Fenves Award for Systems Engineering, Carnegie Mellon University, 2005 • Best Paper Award ASME Design Theory and Methodology Conference, September 2007 • Invitational workshop on Design Problem formulation, Concept Selection and design education, IIT Bombay, India, Jan 8, 2007. (with Yoram Reich, Tel Aviv Univ.)

Staff	Excellence Recognized
Sudarsan, Rachuri	• Gave invitational seminars at Indian Institute of Science (IISc) and Indian Institute of Management (IIM), and Indian Institute of Technology, India • Invited to invitational-only Product Lifecycle Management workshop held at Georgia Institute of Technology • Received a certificate of appreciation by ASME for contribution as panel member for the special session on Product Lifecycle Management held at ASME Congress
Ray, Steve	• Invited Keynote at Product Lifecycle Management '06 in Bangalore, India, July 2006, entitled "The Next Generation of Standards – A Science-Based Discipline of Information Management for Manufactured Products" • Invited "Viewpoint" interview, "International Journal of Product Lifecycle Management," Volume 2, No 3, 2007.

Projects

Sustainable and Lifecycle Information-based Manufacturing

Globalization, both of markets and of partners, is the major trend in product engineering and manufacturing today. Market globalization means that the companies will produce and sell their products in different parts of the world. Globalization of partners is the distribution of supply chain members all over the world. These trends have created extended, network-centric product engineering and manufacturing enterprises. Network-centric enterprises have become tremendously complex due to the increased number of stakeholders and the growing variety of products and production methods, all of which have led to an explosion in the amount of information sharing that must take place. It is critical to the success of companies and their suppliers that this sharing is done correctly, efficiently, and inexpensively.

A key strategy for a manufacturer seeking competitive advantage is to ensure all stakeholders rely on sharing a common product description throughout the product's lifecycle. Detailed product information cannot be kept isolated within any single entity of the extended networked enterprise but must be shared in a collaborative and secure manner across the global enterprise and its extended value chain. The overall challenge of this program is to support the creation, exchange, archiving, and management of information about product, process, people, and services within and across the networked and extended enterprise and throughout the product lifecycle.

Envisioning a lifecycle support system requires a move from product data exchange to product information and knowledge exchange across different disciplines and domains. To realize a lifecycle support system we will need both syntactic and semantic interoperability through well-defined open standards. The following projects address the challenges of lifecycle management support.

Sustainable and Lifecycle Information-based Manufacturing

STEP Evolution and Transition

(Status: complete in 2009)

Challenge/Problem Addressed:

Evolving industry needs and new technology require existing STEP standards to be extended and made compliant with emerging OMG (Object Management Group) and W3C (World Wide Web Consortium) standards. Accordingly, tools and methods are needed to allow reuse of existing manufacturing data standards within an evolving standards infrastructure, and to help manufacturers ensure that established and widely-implemented engineering and product data standards can be retooled to work with more popular implementation technologies, such as the W3C set of integration technologies.

Objective(s):

- Develop new STEP capabilities to meet evolving industry needs
- Enable the successful integration of STEP, OMG, and W3C standards
- Demonstrate a process for migrating STEP data models to more widely implemented modeling and implementation technology

Accomplishments:

- Led the project to create an OMG technical specification (Ontology Definition Metamodel – ODM) of a bidirectional mapping between EXPRESS Edition 2 and UML Version 2
- Led the project to create a UML models for inspection process planning, as extensions to STEP
- Led the project to create AP203[15] Edition 2 for CAD data, which supports GD&T specification
- Led the project to create a STEP Parametrics specification (ISO 10303-109)
- Led the project to create a STEP Construction history specification (ISO 10303-111)

Extensions to STEP allow better interoperability between traditional CAD systems to improve the efficiency of the product development cycle. The ODM technical specification will promote wider use of the STEP model, and will transfer the intellectual capital invested in the STEP standard to a new generation of technologies.

Planned Future Accomplishments:

- Develop supporting tools and methods to permit the successful integration of STEP, OMG, and W3C standards including an OMG technical specification of a bidirectional mapping between EXPRESS Edition 2 and UML Version 2.
- Demonstrate a process for migrating high-value STEP data models to more widely implemented modeling and implementation technology.
- Develop and validate an approach for transforming a STEP Application Protocol (AP) into an OWL Ontology that contains all the concepts and relationships of a STEP AP.

Customers and Collaborators:

- PDES, Inc.
- ISO TC 184/SC4
- Object Management Group (OMG)
- World Wide Web Consortium (W3C)
- EuroSTEP, Inc.

15 An application protocol (AP) is one type of standard developed within ISO 10303, and covers a particular function(s) within an industry domain

Sustainable and Lifecycle Information-based Manufacturing

Formalization of Product and Process Models

(Status: complete in 2011)

Challenge:

Lack of formal models (syntactically and semantically consistent representations) of product life cycle information makes it difficult to standardize and validate support systems for product life cycle management. Formal representations of information are needed to support the full range of the product lifecycle beyond the representation of form (geometry and material), and the standardization and validation of the OMG reference model for managing product lifecycle information

Objective(s):

- Extend the formal representation developed to date by synthesizing prior work on product, assembly and systems models, leading to comprehensive and rigorous models that facilitate automated reasoning, maintenance of consistency, semantic interoperability, and concurrent product development.
- Integrate product and process models by developing design process models using PSL, SysML and related methodologies.
- Define a clear set of conformance classes and metrics based on well defined standards and required functionalities at various stages of PLM, thus defining precise levels of interoperability among various systems and stake holders.

Accomplishments:

- ISO standard for assembly models (ISO 10303-109)
- Led the development and ongoing efforts for the Process Specification Language (PSL) family of standards (ISO 18629). This standard has been used within several other standards (OMG's UML action semantics, W3C's Semantic Web Services Language) because of the rigor it provides for representing process.
- Led the development of the OMG Systems Modeling Language (SysML) standard
- Research reports and journal papers on: Open Assembly Model; Integrated product and process models that extend ontology languages; Systems Modeling Language; ontology-based process representation; evaluation of reasoning systems
- Project underway with Boeing on ontology-based manufacturing processes.

Planned Future Accomplishments:

- Develop mechanisms for systematically evaluating, comparing, selecting and/or harmonizing a full suite of prospective PLM-related standards of overlapping scope.
- Define a clear set of conformance classes[16] and metrics based on some well defined standards, and required set of functionalities at various stages of PLM and define precise levels of interoperability among various systems and stake holders.

16 Conformance classes partition the standard's specifications to a particular range of requirements and states all the criteria must be satisfied to claim conformance.

- Identify existing and potentially needed standards in the area of failure reporting, system reliability and safety.
- Integrate existing product and process models by developing ontological representations using PSL, SysML, and related methodologies.
- Develop model-based validation and testing techniques

Customers and Collaborators:

- George Washington University (GWU)
- Syracuse University
- University of Maryland
- Carnegie Mellon University (CMU)
- University of Toronto
- University of San Jose
- Ford
- U.S. Army
- Lockheed Martin
- Boeing
- General Motors
- OMG
- ISO TC 184/SC4

Sustainable and Lifecycle Information-based Manufacturing

Standards Landscape for Lifecycle Product Management

(Status: complete in 2008)

Challenge:

Ad hoc and independent evolution of standards covering different aspects of the product lifecycle call for an understanding of the current standards coverage and gaps. Mechanisms are needed for systematically evaluating, comparing, selecting and/or harmonizing product standards of overlapping scope so as to identify a set of complementary and interoperable standards for PLM support.

Objective(s):

- Develop a typology of standards for the exchange of product, process, operations, and supply chain information.
- Conduct detailed study of standards and existing gaps or overlaps to precisely identify standards needed for lifecycle product data standardization, interoperability, and exchange among manufacturing enterprise systems as well as their clients and supply chains.

Accomplishments:

- An international workshop at NIST on open standards for manufacturing, focusing on social, economic, legal and technical perspectives, co-organized with IBM and Oracle. The U.S. Army, OASIS, PDES Inc, IMS, and Eurostep are using the reports in their deliberations on standards, patent laws, and system implementation.
- An investigative study in collaboration with Army Materiel Command personnel to assess the level of current pilot or pro-

duction use of various military, national, or international standards during the lifecycle support of any given weapon system component or part. The investigative report for the U.S. Army entitled "Analysis of Standards for Lifecycle Management of Systems for U.S. Army – a preliminary investigation" has had more than 50,000 hits on the MSID website since its publication in August 2006.

- Journal papers. The impact from these publications include: A journal paper on PLM in a networked economy and standards typology became required reading at John Deere standards division; various degrees of adoption by Standards Development Organizations (SDOs) of the concepts, analyses and recommendations presented in our reports and papers; and PLM information model journal papers ranked No. 1 and No. 3 for the most downloaded papers in Journal of CAD, July-Sept. 2007.

Customers and Collaborators:

- GWU
- Syracuse University
- CMU
- U.S. Army
- National Science Foundation
- IBM
- Oracle
- Ford
- Various other Federal agencies.

Sustainable and Lifecycle Information-based Manufacturing

Toward Long Term Data And Knowledge Retention

(Status: complete in 2010)

Challenge/Problem Addressed:

Lack of an infrastructure for archiving digital representation of manufactured artifacts impedes the ability to retrieve and use prior engineering knowledge. The nature of product and process information must be characterized to allow the development of methodologies for sustaining long-term usability of engineering information, and the definition of metrics for digital preservation of engineering information from Computer-Aided Design (CAD), Computer-Aided Engineering, Computer-Aided Manufacturing, Product Lifecycle Management (PLM) and related computer aided tools.

Objective(s):

- Gather requirements by providing a forum for information and archival specialists, domain knowledge experts from manufacturing, product engineering and other stakeholders to discuss issues such as knowledge representation, archival methods and policies, and the use of data standards to promote long term retention of manufacturing knowledge.
- Create criteria and a classification system for long term preservation of engineering information to serve as the basis for evaluating the quality of archiving practices.

Accomplishments:

- Two workshop reports, which resulted in an invitation by National Archives for NIST to work with the U.S. Navy to create specific experiments for product and process information archiving.
- An initial taxonomy of engineering information usage scenarios – presented at Digital Curation Conference, and invited for submission to the International Journal of Digital Curation. Increased awareness of digital preservation needs and of promising technologies to solve preservation problems in product design, engineering, and manufacturing.

Planned Future Accomplishments:

- Characterize engineering information in support of long-term access to lifecycle information
- Develop a digital format repository for output of CAD, PLM, and CAE systems to create a legal deposit similar to global digital format registry developed by the Library of Congress
- Implement and evaluate an archival test bed based on OAIS (Open Archival Information System) reference model, using a U.S. Navy digital ship design example

Customers and Collaborators:

- ITL
- U.S. Archives
- University of Bath
- University of Lyon
- GWU
- CMU

Sustainable and Lifecycle Information-based Manufacturing

(Status: complete in 2011)

Challenge/Problem Addressed:

Changing social demands with respect to environmentally sustainable products and manufacturing methods require the development of new information models, standards, metrics, and tools for sustainable design and manufacturing that support interoperability among tools and standards for design, analysis, lifecycle assessment and information management.

Objective(s):

- Analyze standards requirements for sustainable manufacturing
- Create lifecycle information models for interoperability among systems and tools that support sustainable manufacturing
- Validate and test information models for sustainable design and manufacturing

Accomplishments:

- None yet – project just begun

Planned Future Accomplishments:

- Perform case studies for existing sustainable manufacturing systems to generate information requirements for sustainability and characterize economic, ecological and societal interactions in a product's lifecycle.
- Develop information models and standards for products and manufacturing processes to support lifecycle management and sustainable manufacturing.
- Facilitate the creation of standards and metrics for sustainable manufacturing.
- Develop green accounting principles to trace the carbon footprint (weight) and energy use from the part level to the system level and for the full lifecycle, including assembly, disassembly, and recycling.
- Develop a testbed to validate the different aspects of the work conducted throughout this project. The testbed will apply metrics for the performance of specific applications or procedures for zero-impact manufacturing.

Customers and Collaborators:

- University of Arizona
- Other NIST laboratories
- IMS Project partners
- GWU
- CMU
- OMG
- ISO
- EPA
- DOE
- Automotive (GM, Ford, Toyota)
- Aerospace (Boeing) industries