NIST Activities in Model-Based Engineering

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

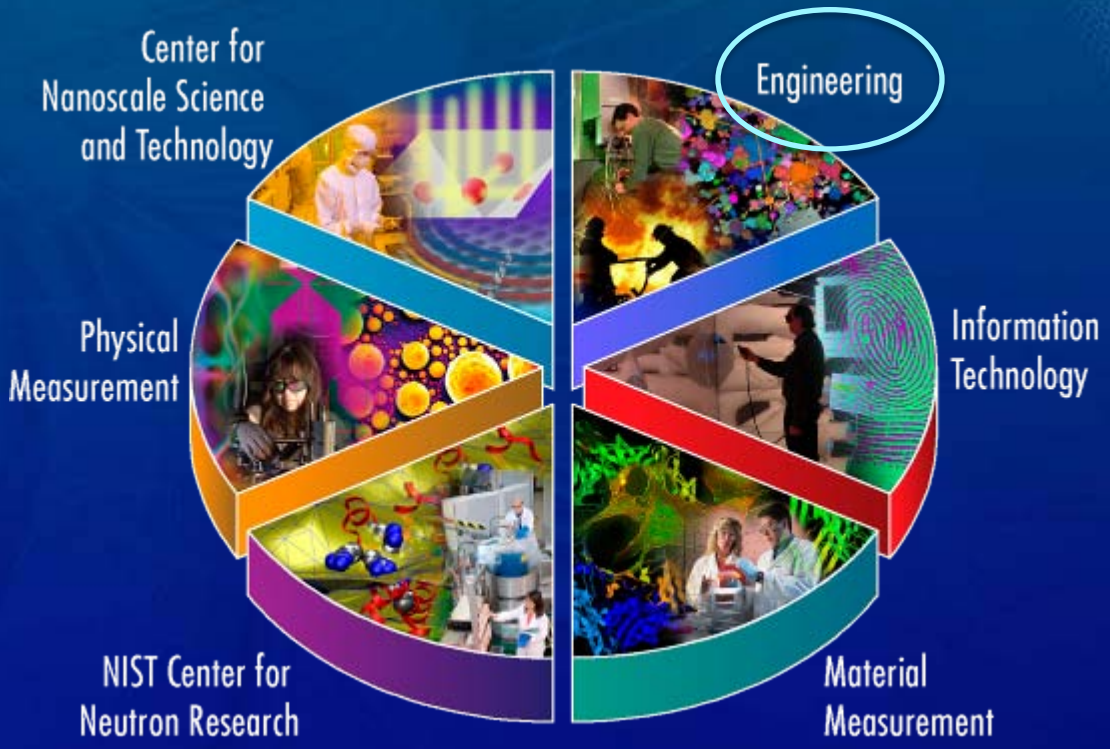
The NIST Laboratories

NIST's work enables

- Advancing manufacturing and services
- Helping ensure fair trade
- Improving public safety and security
- Improving quality of life

NIST works with

- Industry
- Academia
- Other agencies
- Government agencies
- Measurement laboratories
- Standards organizations



Engineering Laboratory Mission

To promote U.S. *innovation* and *industrial competitiveness* in areas of critical national priority **by anticipating and meeting the:**

- **measurement science and**
- **standards**

needs for technology-intensive manufacturing, construction, and cyber-physical systems in ways that enhance *economic prosperity* and improve the *quality of life.*

Engineering Laboratory Vision

To be *the* source for:

- creating **critical *solution-enabling* measurement science**, and
- critical technical contributions underpinning emerging **standards, codes, and regulations**

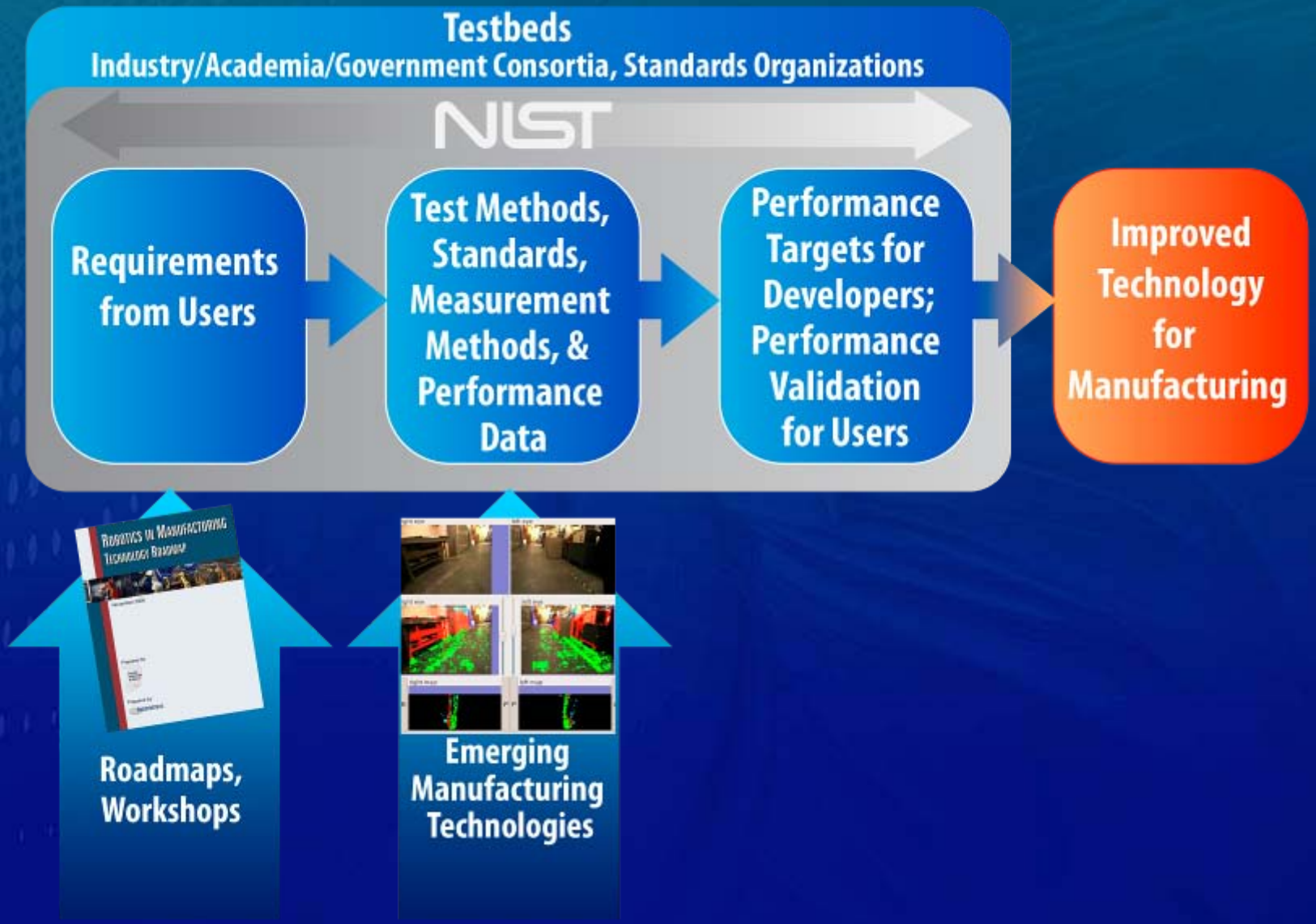
that are *used* by the U.S. manufacturing, construction, and infrastructure industries to strengthen leadership in domestic and international markets.

EL is the primary federal laboratory serving the manufacturing and construction industries

Engineering Laboratory Role in Manufacturing

- U.S. manufacturing is challenged by aggressive competition
- U.S. manufacturers rely on enhanced innovation, productivity, and quality to compete successfully
- EL helps manufacturers to compete more effectively by providing **measurement science** to help advance standards and technology

Driving Manufacturing Technology Innovation Through Measurements and Standards



EL Manufacturing Program Portfolio

Smart Manufacturing, Construction, and Cyber-Physical Systems Strategic Goal:

- Smart Manufacturing Processes and Equipment
- Next-Generation Robotics and Automation
- Smart Manufacturing and Construction Systems
- Systems Integration for Manufacturing and Construction Applications

Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure Strategic Goal:

- Sustainable Manufacturing
- Sustainable, High-Performance Infrastructure Materials
- Net-Zero Energy, High-Performance Buildings
- Embedded Intelligence in Buildings

SMART MANUFACTURING PROCESSES AND EQUIPMENT PROGRAM

Alkan Donmez

Smart Manufacturing Processes and Equipment Program

Objective: To develop and deploy advances in measurement science that will enable rapid and cost-effective production of innovative, complex products through advanced manufacturing processes and equipment

Measurements and standards enabling smart **(self aware, self diagnosed, adaptive and optimized)** processes and equipment

THRUST AREAS:

Metal-based additive manufacturing - addressing the needs to understand, identify, and reduce uncertainties in metal powder characteristics coupled with uncertainties in the AM process and equipment that lead to uncertainties in the final product

Smart machining - addressing the needs for rapidly turning new materials and designs into products by integrating modeling and simulation with real-time measurements to optimize processes and equipment

Micro- and nano-manufacturing - addressing the needs for improving the quality and yield of micro- and nano-scale products through new measurement methods for improved process control

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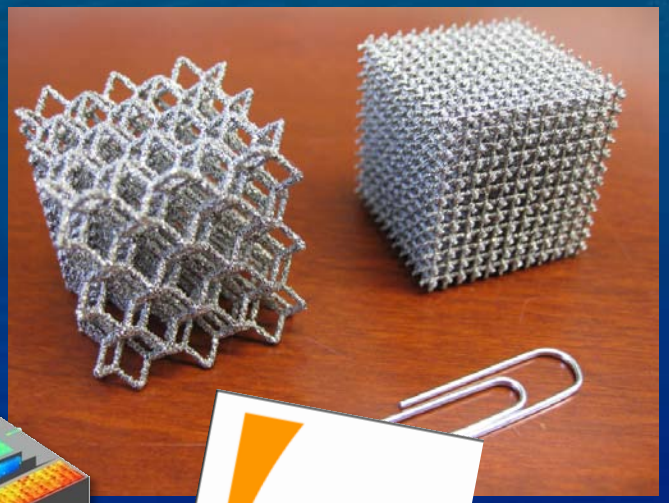
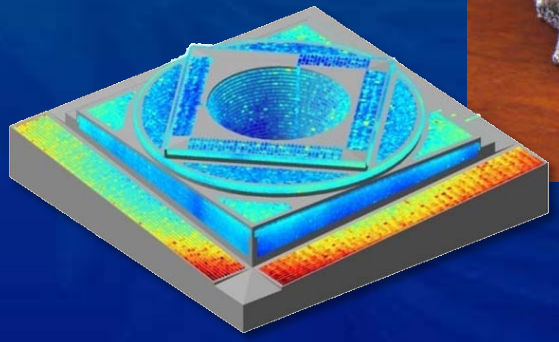
Metal-Based Additive Manufacturing

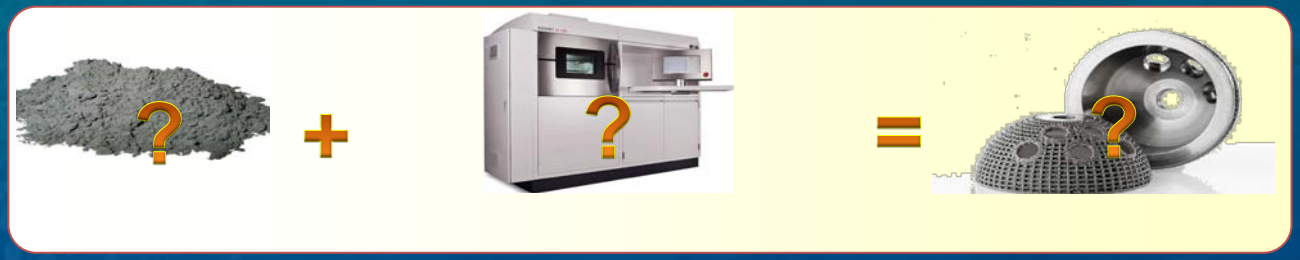
- **Rapid art-to-part capability** of fabricating complex structures – revolutionary potential
- **Key barriers** to the widespread adoption of metal-based additive processes:
  - part accuracy
  - surface finish
  - material properties
  - process certification
  - process speed
  - data formats
  - lack of standards





- **NIST role:**
  - Identified barriers and research needs
  - Evaluated research on machine/process performance
  - Helped form Standards Committee F42 on Additive Manufacturing Technologies (founded 2009)

Metal-Based Additive Manufacturing



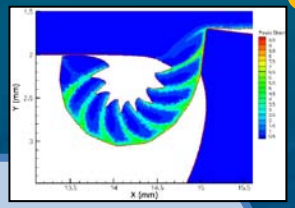
- Properties of both bulk metal materials and raw metal powder
  - Powder characterization
  - Mechanical testing (indentation and fracture testing for strength)
  - Non-destructive techniques (porosity, modulus)
- Determine the sensitivity of part material properties to variations in powder properties

- Design of new test artifact for ASTM standard
- Test methods for thermal measurements within the build chamber
- Test methods evaluating geometric errors of AM equipment
- Measurement systems and methods for in-situ monitoring and closed-loop process control
- Determine sensitivity of process parameters to final product properties

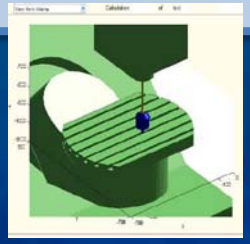
Smart Machining

Pre-Machining Measurement Science

In-Process Measurement Science

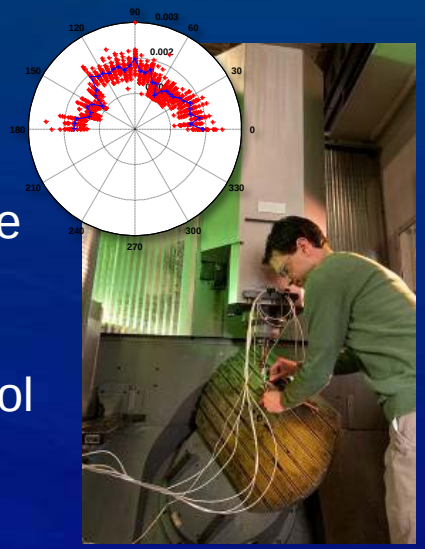


Modeling and Simulation

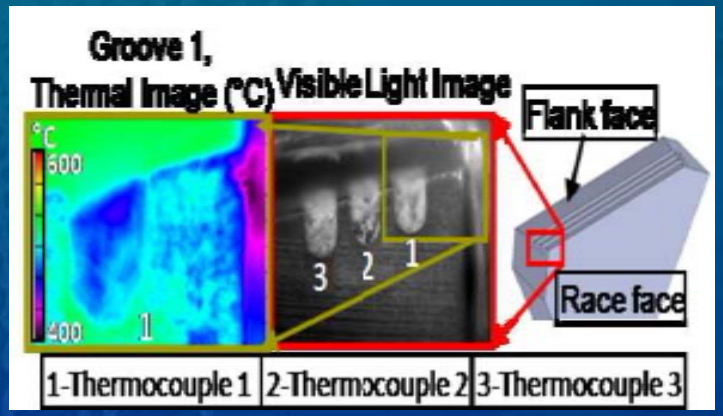


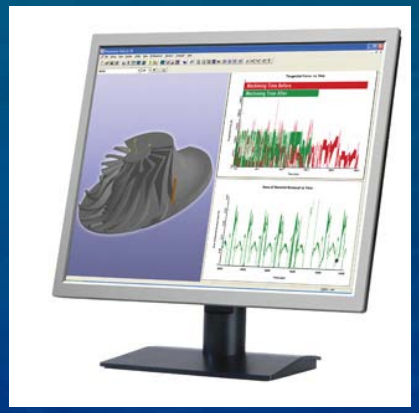
Optimization

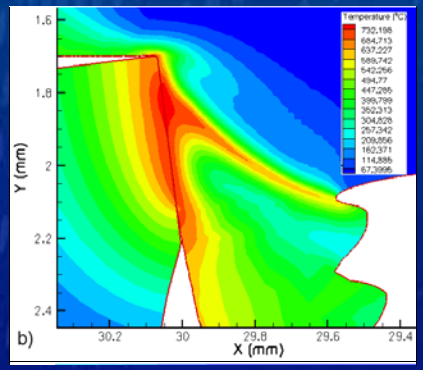
- Self aware machines
  - Standards for performance testing of complex motion
  - Standards for digital representation of machine performance
  - Machine performance under loaded conditions
- Optimized machines and processes (First part correct)
  - Integrate machine model with CAM/STEP-NC to optimize tool path
  - Measure tool dynamics
  - Trade offs between optimizing for speed, tolerance, tool wear
- Self diagnosed machines
  - In-situ measurements monitoring condition of machine
  - Machine adapts to changing condition, recommending maintenance



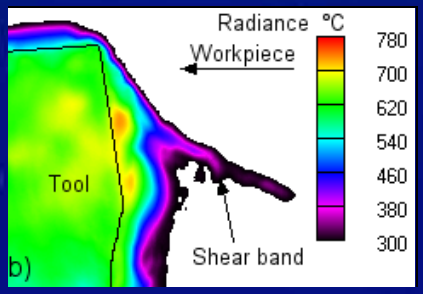
Connecting Fundamental to Applied to Practice: Bridging the Gap through a New Consortium

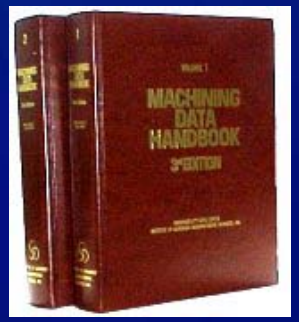






- NIST fundamental measurement methods applied to nonconventional materials
- Fundamental measurements combined with industrially practical methods (thermocouple)
- Combined measurements enable robust and practical model validation and verification
- Robust modeling streamlines and improves industrial process optimization
- Optimized product feature-specific process recipes disseminated through supply chain



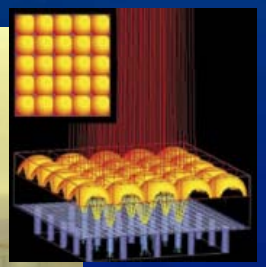


Closed-loop manufacturing of complex micro optics

Integrate commercially available measurement system(s) with the diamond turning machine

Develop & implement workpiece reference marks

Smart Manufacturing Processes and Equipment Program



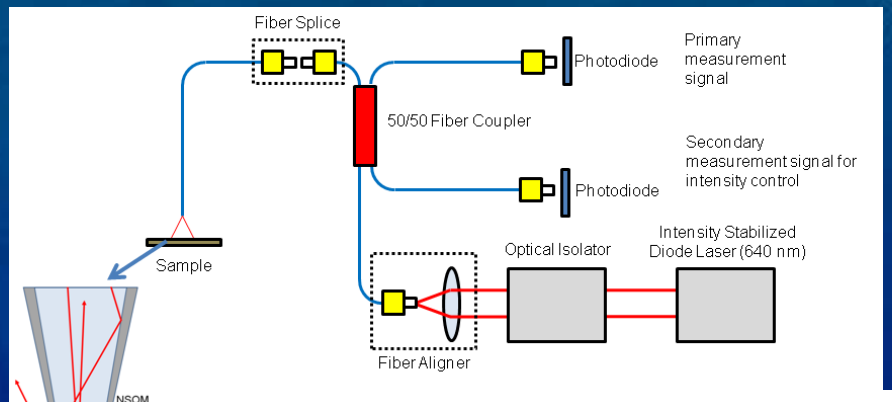
Develop test methods, measurement artifacts, & uncertainty budgets

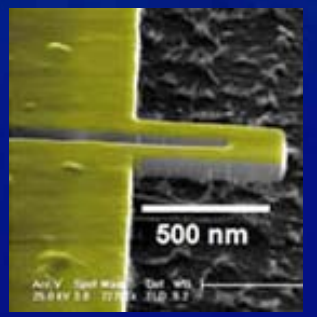
NEMS measurement science

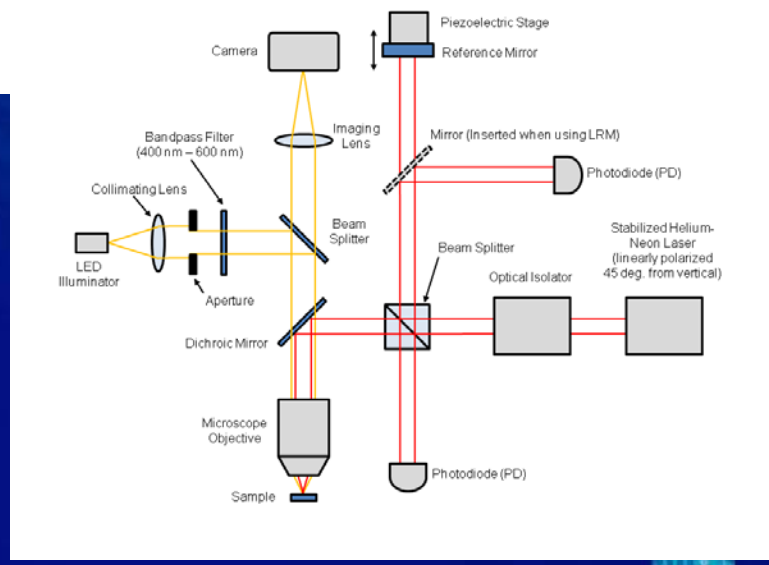
Development and improvement of measurement techniques to characterize the performance of NEMS devices to be used both for in-process measurement of nanomanufacturing processes and the measurement of nano-scale products

Research activities include:

- Improvement of Nanoscale Motion Microscope (NMM) and Near-field Scanning Optical Microscope (NSOM)
- Modal analysis at the nanoscale to understand variations in fabrication and failure mechanisms
- Automated measurements of multi-NEMS on a single chip as a step towards production line automation
- Interactions with MEMS/NEMS industry for a proposed Workshop







NEXT GENERATION ROBOTICS AND AUTOMATION PROGRAM

Mike Shneier

Next Generation Robotics and Automation Program

Objective: To develop and deploy advances in measurement science to safely increase the versatility, autonomy, and rapid re-tasking of intelligent robots and automation technologies for smart manufacturing and cyber-physical systems applications in the following thrust areas:

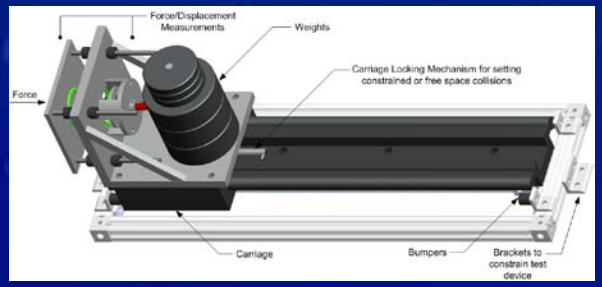
- **Sensing and Perception** – enabling next-generation robots that can safely collaborate with humans in unstructured environments and without costly fixturing, through development of ISO and ASTM standards
- **Manipulation** – enabling dexterous manipulation that is essential for agile manufacturing operations and a greater breadth of applications, including at the micro and nano scales, through RIA or ASTM standards for measuring performance
- **Mobility** – allowing manufacturing vehicles to operate safely and more effectively in the same workspace as humans, through development of industrial vehicle safety standards
- **Autonomy** – making possible agile and reconfigurable robots that are easily tasked to perform new manufacturing operations through standards and measurement tools for intelligent planning and modeling

Sensing and Perception

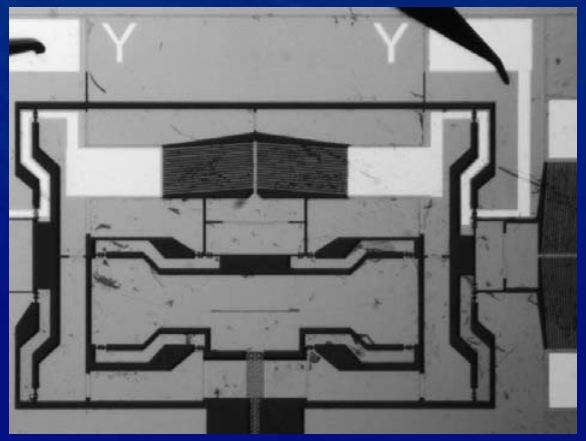
- Reduce the need for fixturing
- Enable adaptation to variations in parts
- Enable in-process inspection
- Extend robots to unstructured environments
- Develop performance measures for sensors used to monitor the work area and ensure safety of people, robots, and vehicles

Manipulation

- Develop performance measures for dexterous manipulation
- Develop dynamic force measurements and force-based control of manipulation
- Develop collaborative manipulation strategies for safe human-robot or robot-robot operations



- Develop measurement methods and sensors for micro- and nano-scale objects
- Enable scale-up from the micro- to the macro-scale



Mobility

- Develop standards for safety of manufacturing vehicles
- Develop methods to enable sensors on a vehicle to inter-operate and provide combined information
- Develop standards to enable vehicles from different manufacturers to work together

Autonomy

- Develop planning algorithms for manufacturing applications
- Develop standard ways of representing information that facilitate planning and can be easily ported to new applications
- Develop performance measures for the accuracy and completeness of planning systems
- Develop standard methods to validate simulation models to ensure that they accurately reflect the real world

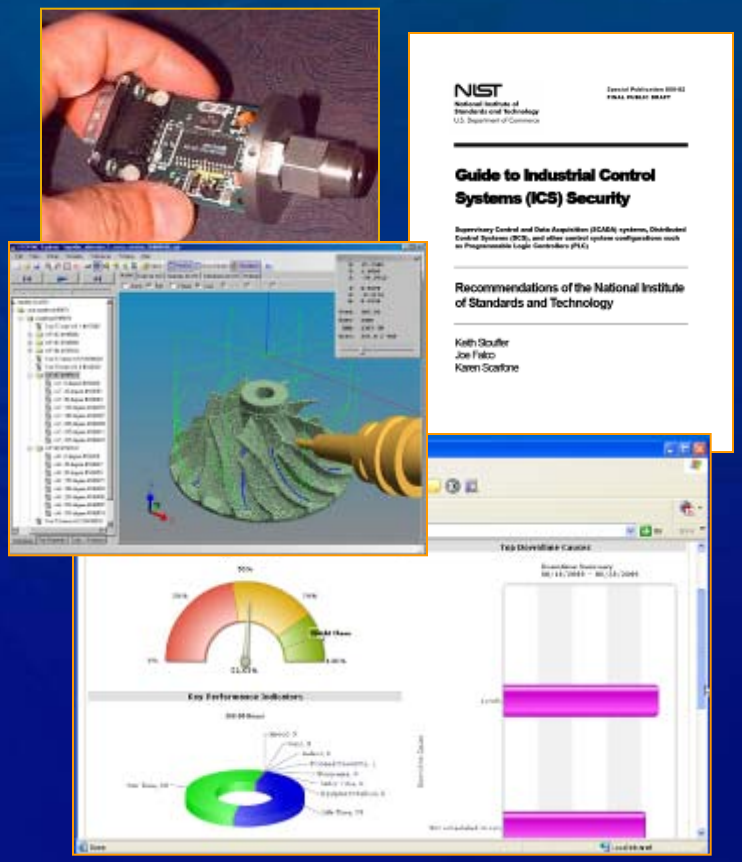
SMART MANUFACTURING SYSTEMS PROGRAM

Fred Proctor

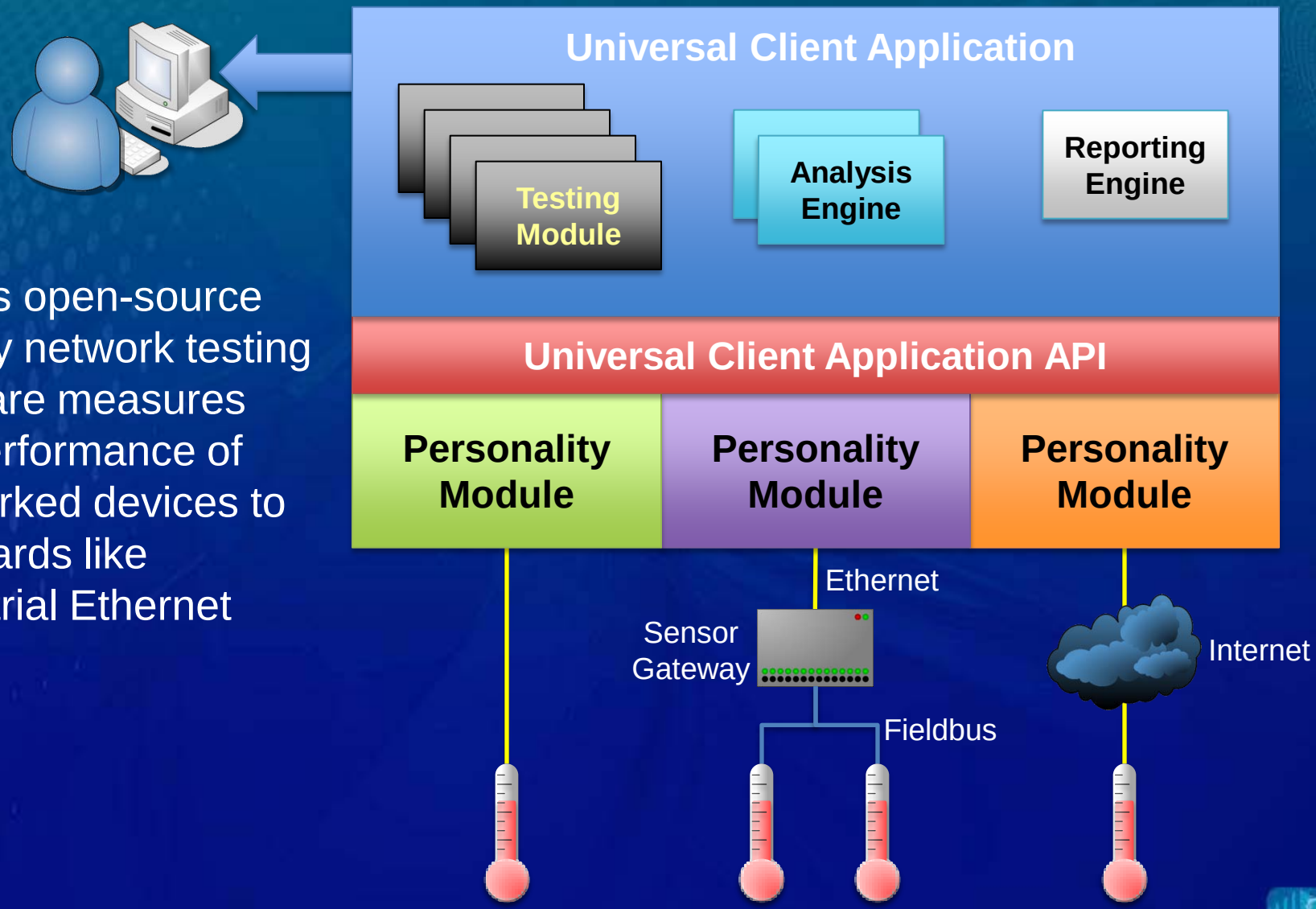
Smart Manufacturing Systems Program

Objective: To develop and deploy advances in measurement science to enable real-time monitoring, control, and performance optimization of smart manufacturing systems in the factory

- **Factory Networks** – enabling cost savings and ease of integration for factory networks of equipment and sensors by developing performance and conformance tests for data exchange and cybersecurity standards through IEEE and ISA
- **Information Modeling and Testing** – enabling seamless information exchange throughout production activities by developing validation and conformance tests for information exchange standards through ISO and the Dimensional Measurement Standards Consortium (DMSC)
- **Performance Measurement and Optimization** – enabling optimization of manufacturing across the shop floor by developing standards for measuring key performance indicators through the Association for Manufacturing Technology (AMT)



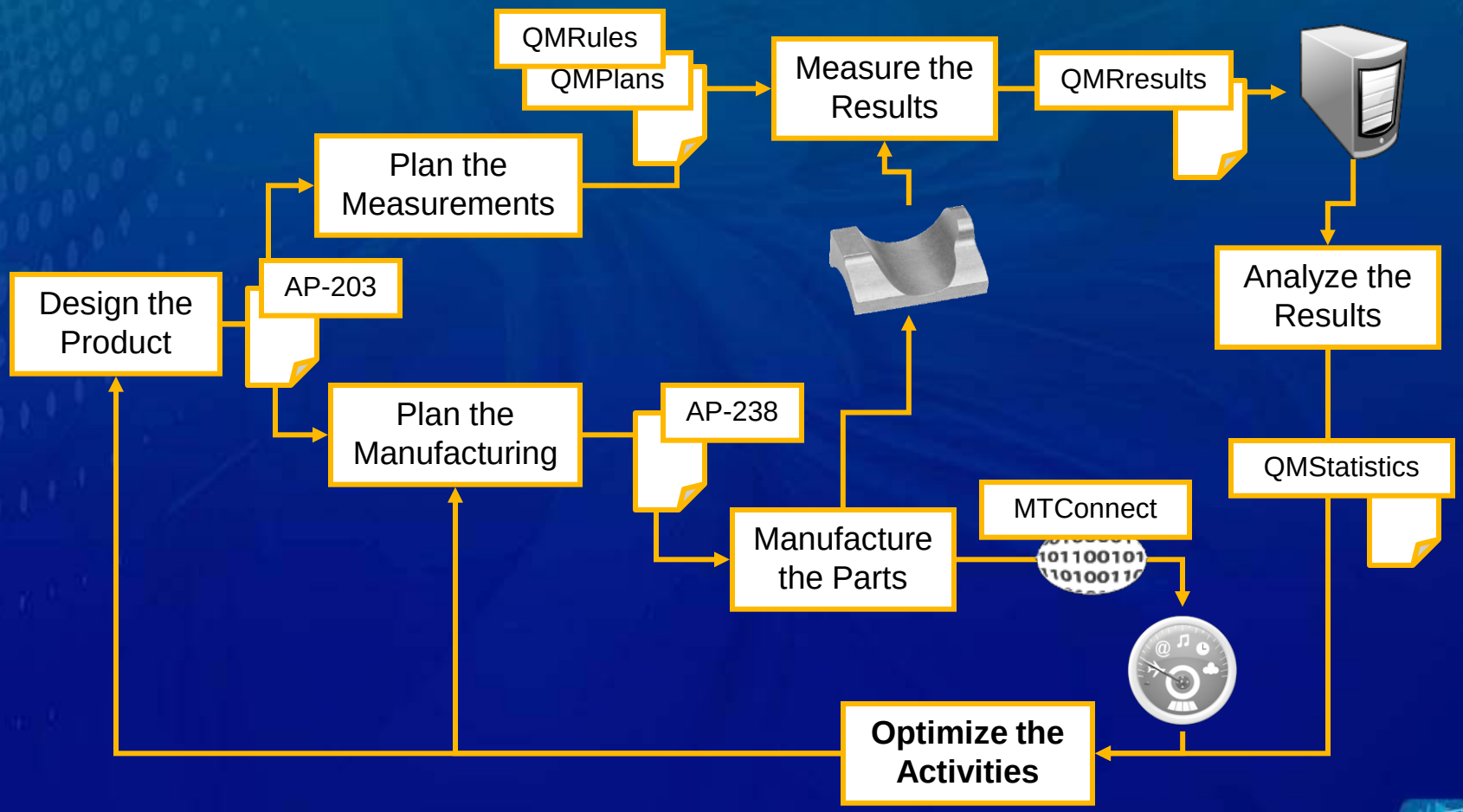
Factory Networks: Testing



NIST's open-source factory network testing software measures the performance of networked devices to standards like Industrial Ethernet

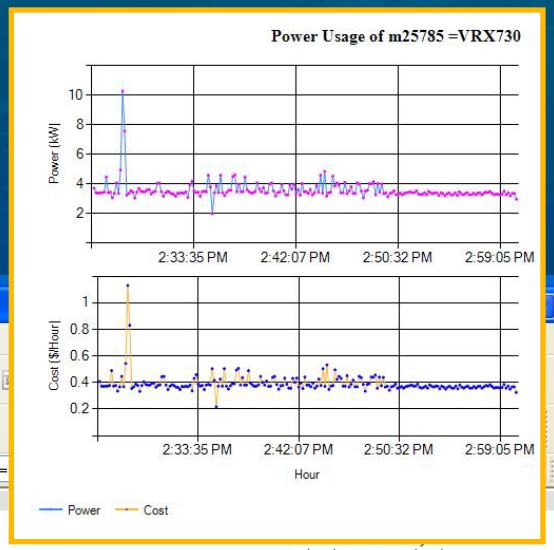
Information Modeling and Testing

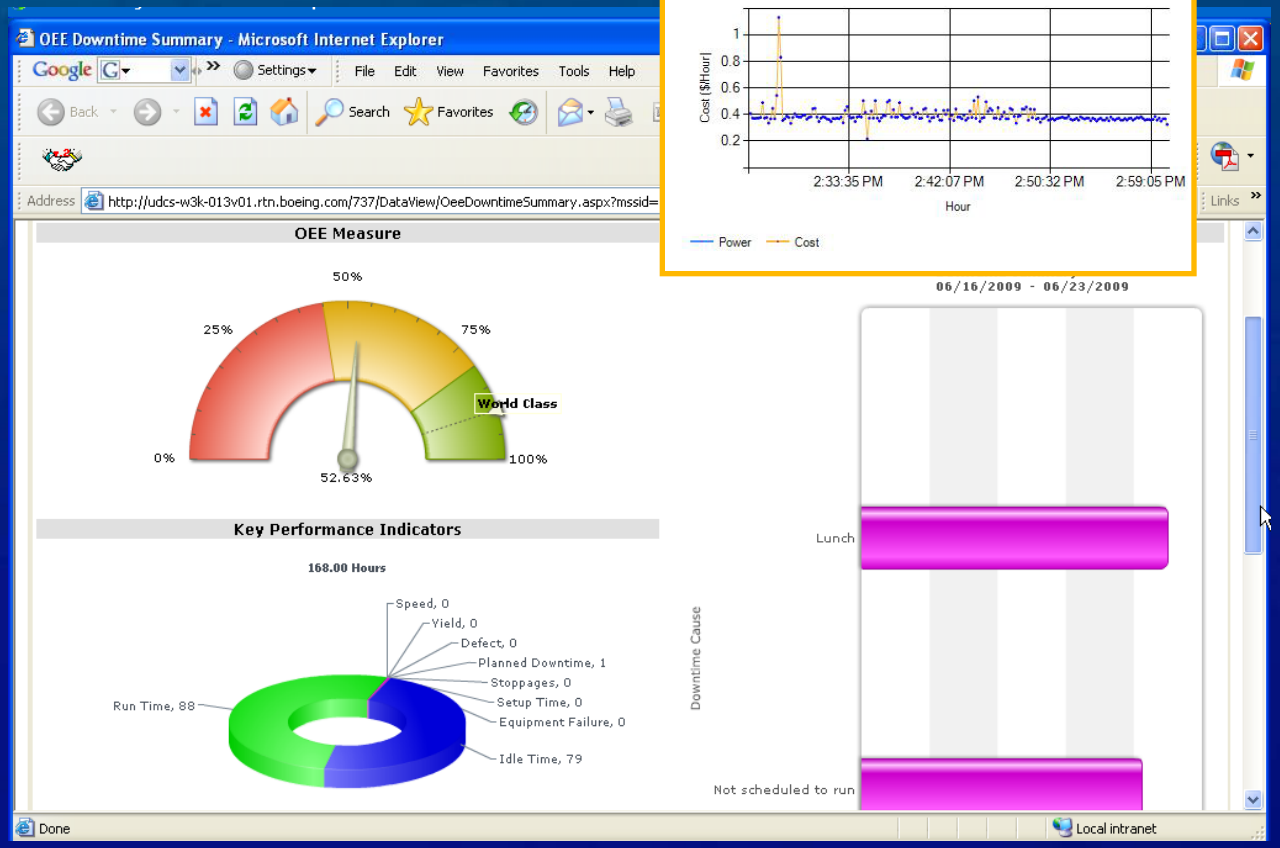
NIST helps validate standards for manufacturing information exchange, and measure performance and conformance



Performance Measurement and Optimization

Standards like MTConnect enable collection of real-time production information, driving "dashboard" applications that show key performance indicators





SYSTEMS INTEGRATION FOR MANUFACTURING APPLICATIONS PROGRAM

Simon Frechette

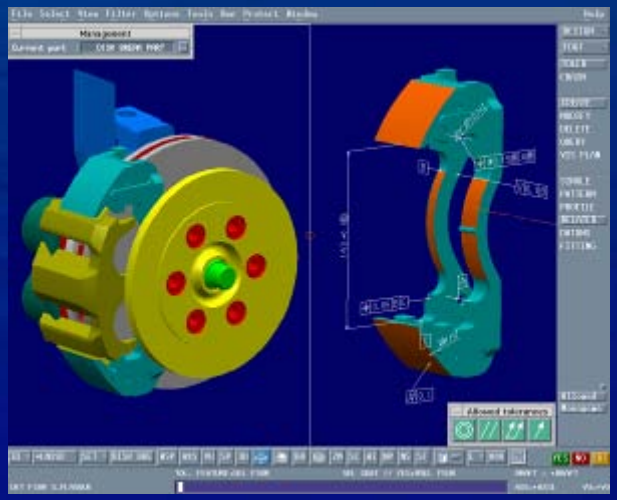
Systems Integration for Manufacturing Applications Program

Objective: To develop and deploy advances in measurement science for integration of engineering information systems used in complex manufacturing networks to improve product and process performance

- **Engineering Systems Integration** – Enabling systems engineering standards that will reduce cycle time from product development to manufacturing

- **Production Network Integration** – Enabling network integration standards to improve efficiency and agility, and support new manufacturing services model

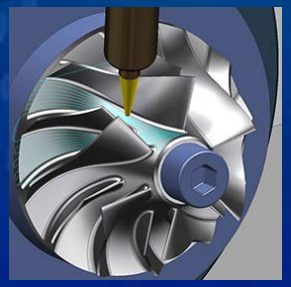
- **Production Network Data Quality** – Developing and testing standard methods for quantifying the quality of engineering and manufacturing data



SIMCA is the Gateway to Production Networks

Production Networks

SIMCA

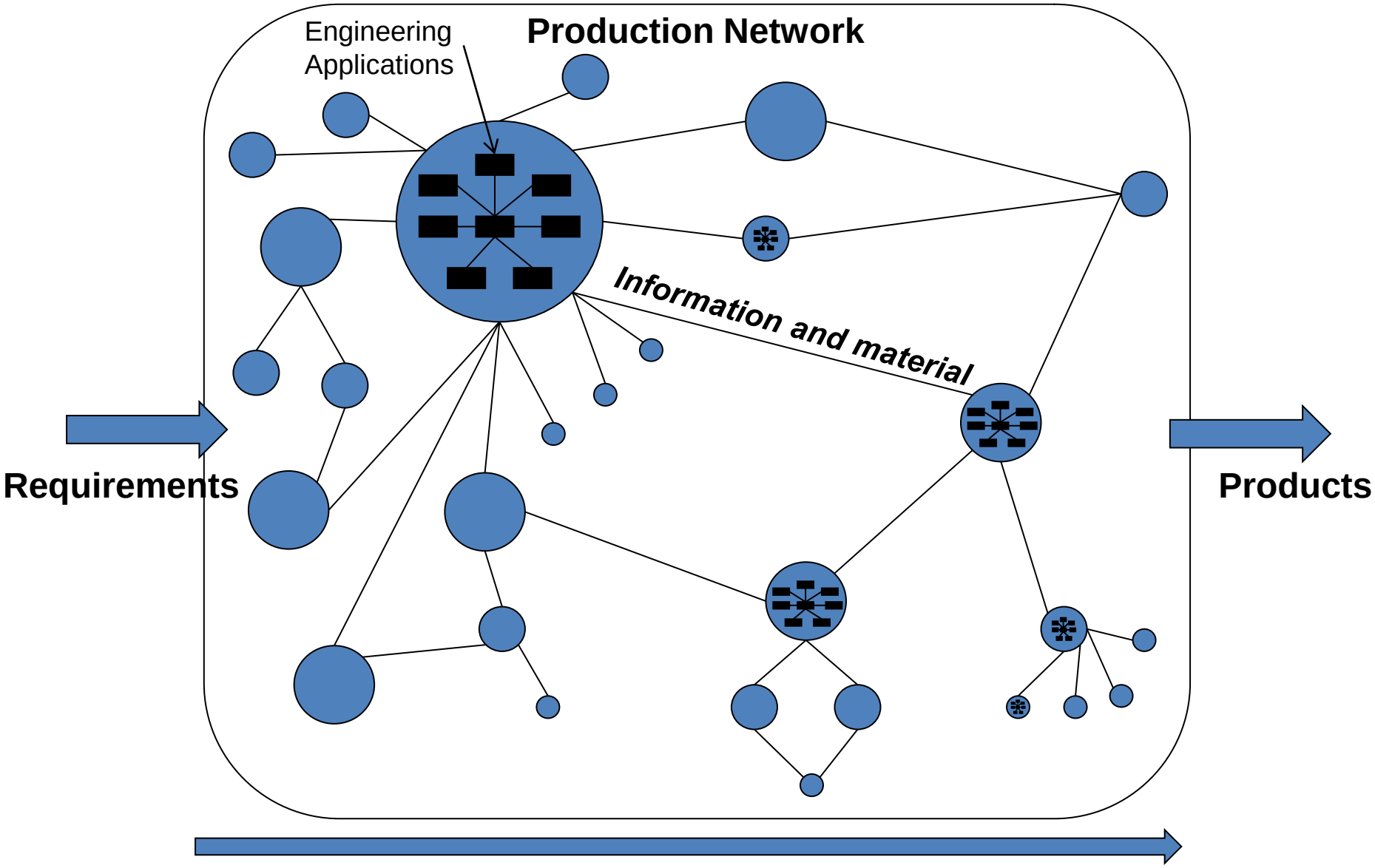


Smart Manufacturing Systems

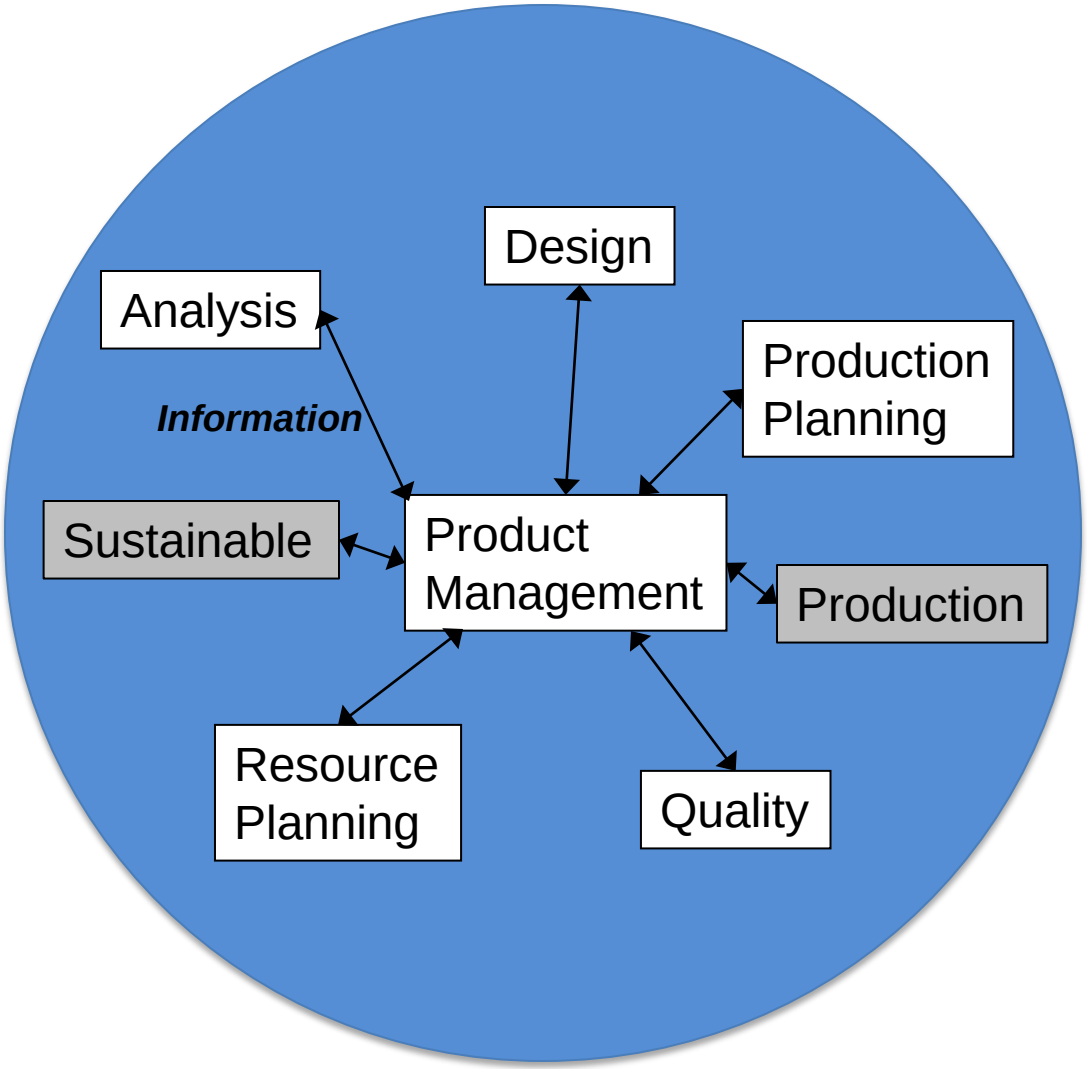
Next Generation Robotics and Automation Systems

Smart Manufacturing Processes and Equipment

A Network of Enterprises



Production Network Enterprises Each have a Unique Set of Engineering Applications

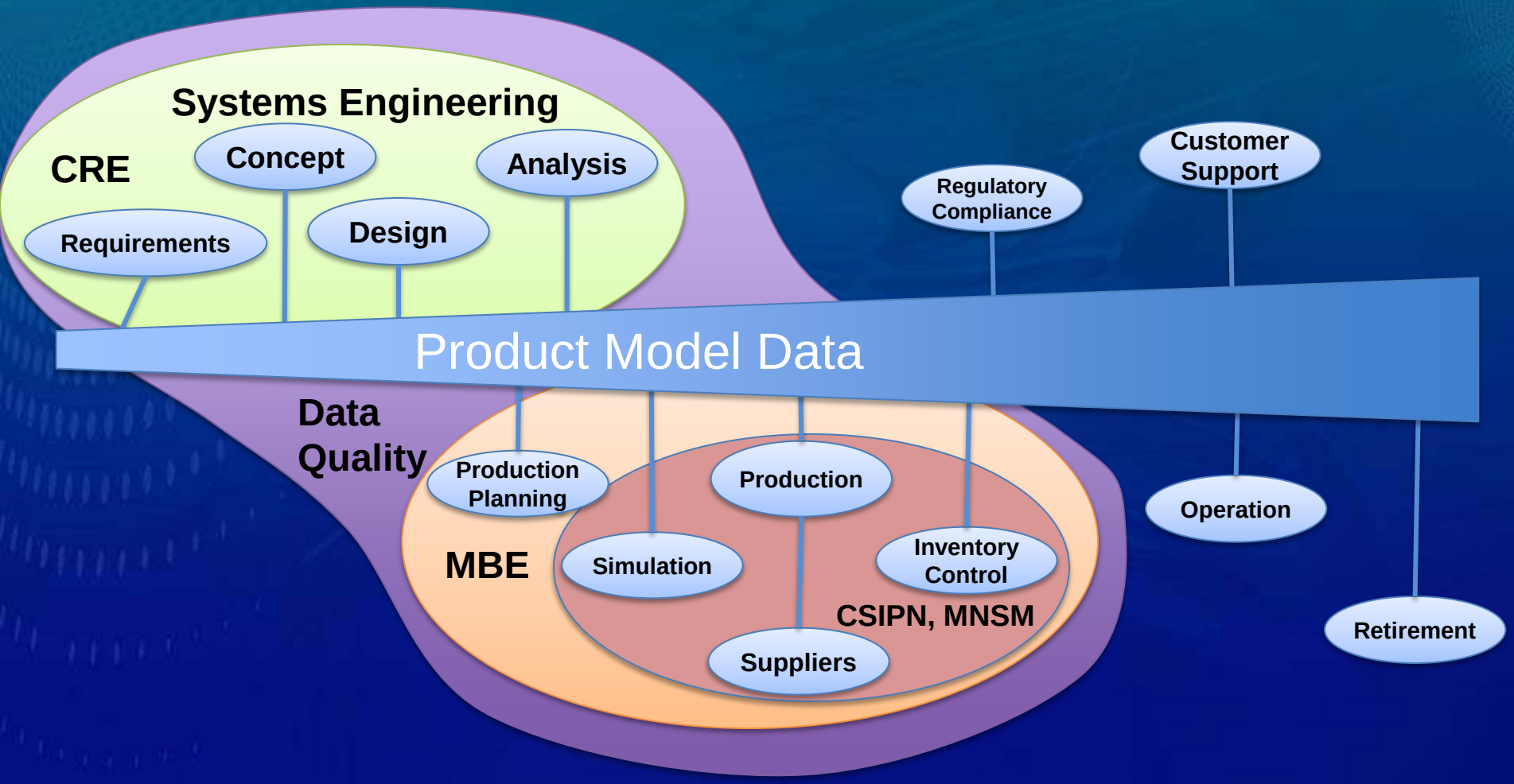


SIMCA Strategy

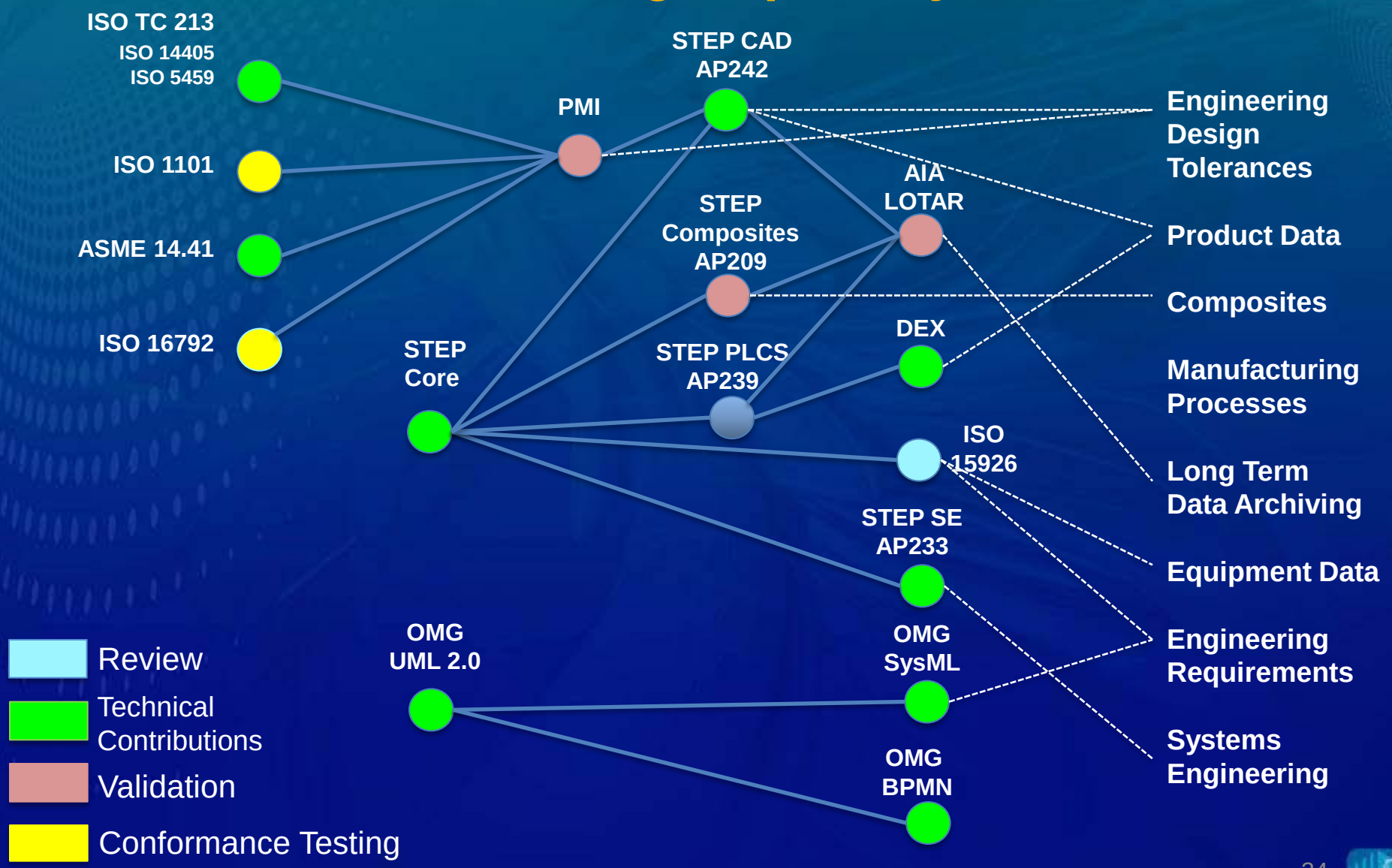
The SIMCA program addresses measurements and standards for

- model-based engineering (MBE)
- systems engineering (SE)
- production network integration
- engineering data quality

Seamless Access to Information Throughout the Product Lifecycle Greatly Improves Productivity

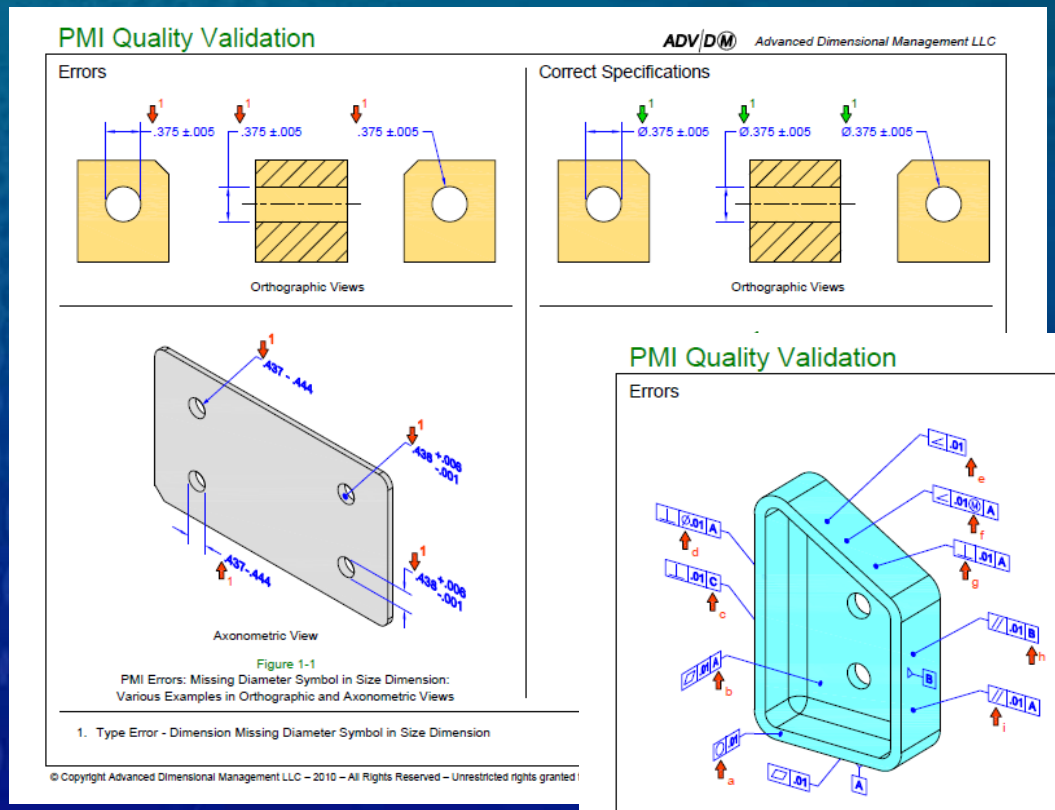


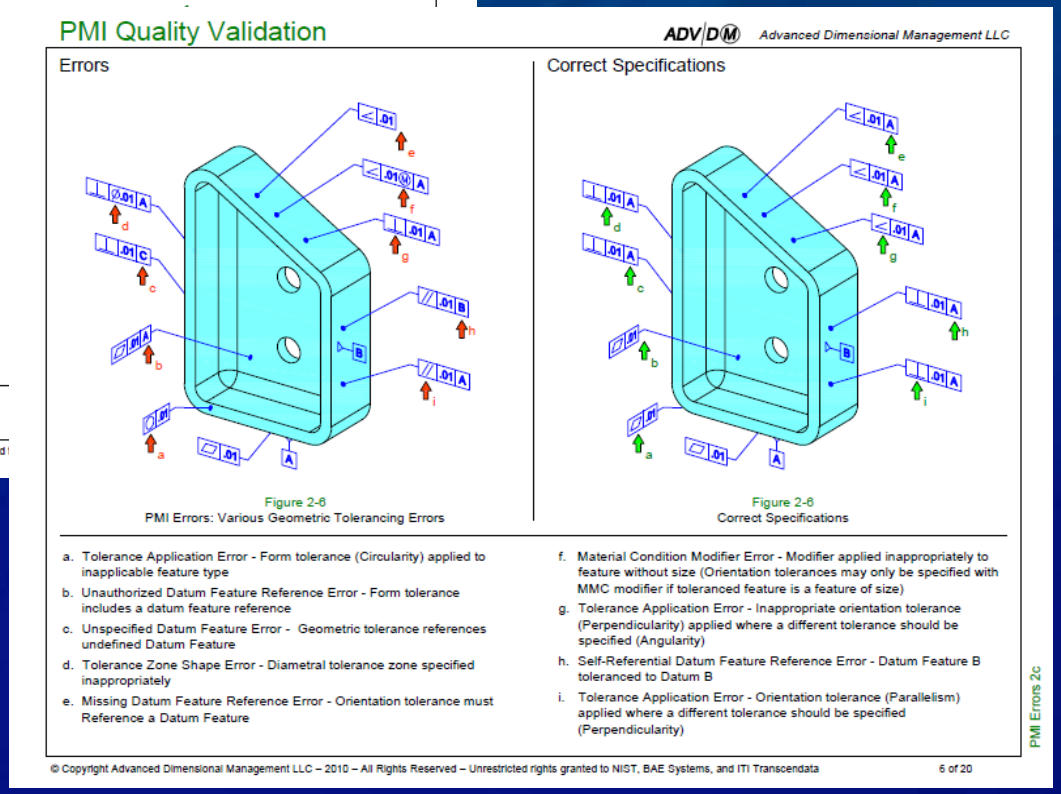
How do Standards Relate to Manufacturing Capability?



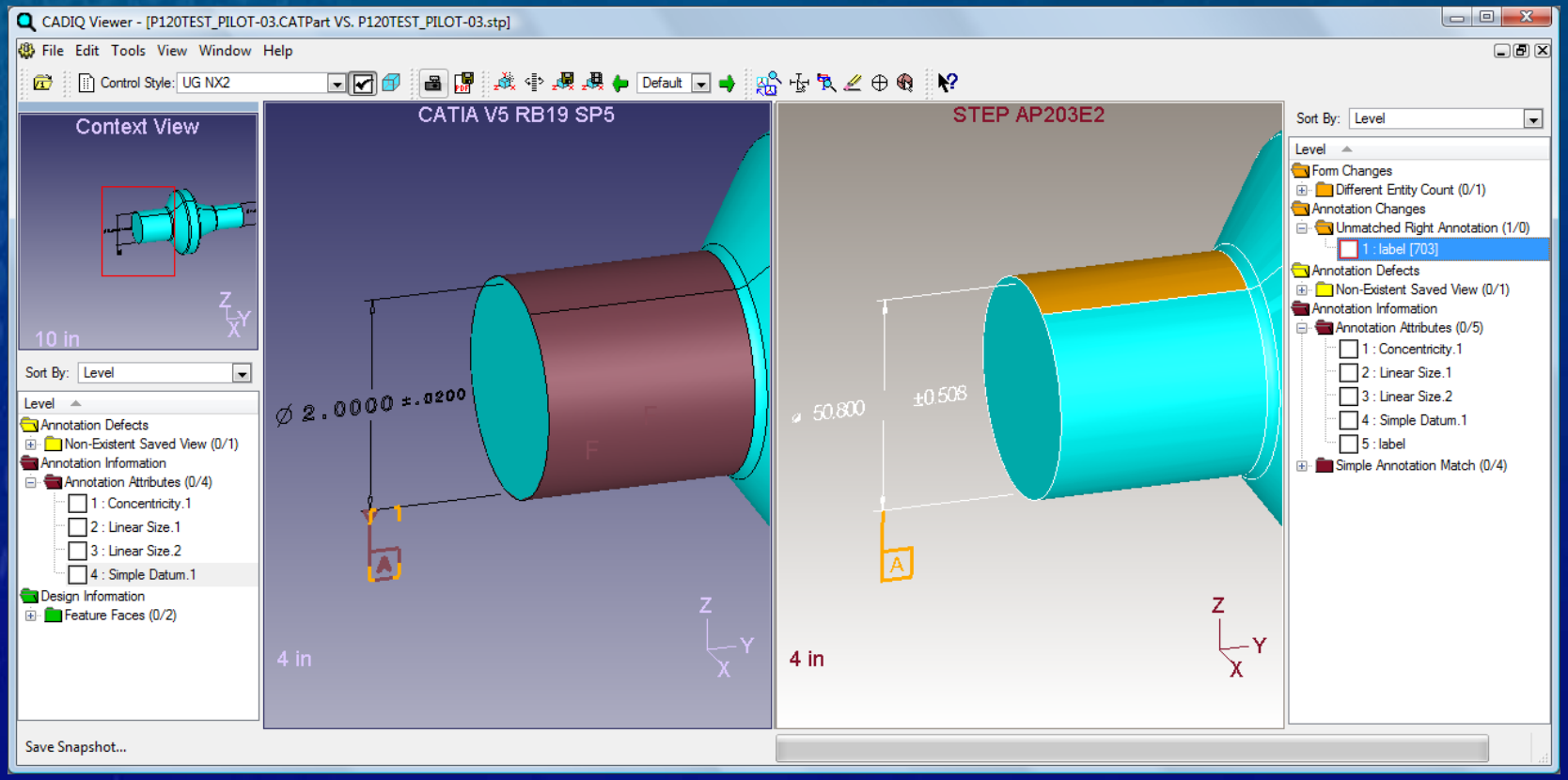
ISO PMI Standards Roadmap for CAD/CAM/PLM Software Vendors

Geometric & Dimensional Tolerance Conformance Tests are Needed to Validate New Software Tools and Integration Standards





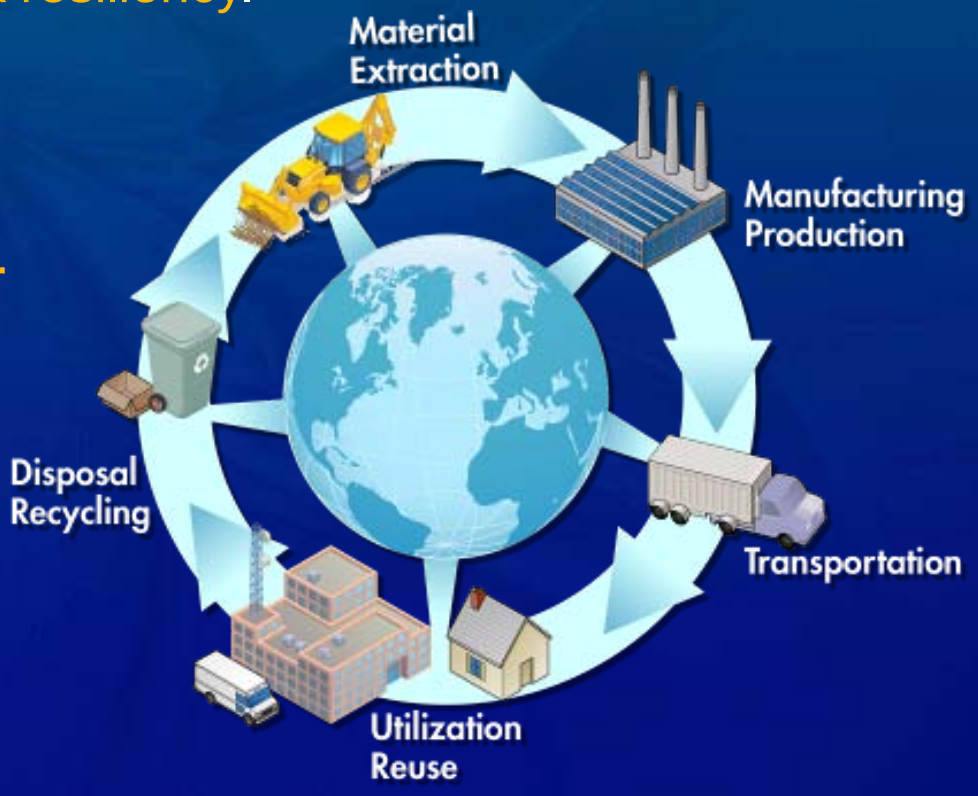
Data Quality Measurement



Sustainable Manufacturing Program

Objective: To develop and deploy advances in measurement science to achieve sustainability across manufacturing processes enabling resource efficiency and production network resiliency.

- **Sustainable Processes and Resources**
- **Integration Infrastructure for Sustainable Manufacturing**



Partnering Strategies with Industry

- Standards Engagement
- Planning Workshops
- Performance Metrics and Test Methods
- Unique Facilities and Testbeds
- Modeling and Testing Tools
- CRADAs and Consortia
- Competitions at NIST Test Arenas and other venues
- "Plugfests" at Tradeshows