NIST Technical Note 1753

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http://dx.doi.org/10.6028/NIST.TN.1753

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

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August 2012

U.S. Department of Commerce
Rebecca M. Blank, Acting Secretary

National Institute of Standards and Technology
Patrick D. Gallagher, Under Secretary of Commerce for Standards and Technology and Director

National Institute of Standards and Technology Technical Note XXXX
Natl. Inst. Stand. Technol. Tech. Note XXXX, NNN pages (Month and Year)
http://dx.doi.org/10.6028/NISTTN.XXXX
CODEN: NTNOEF

Abstract

This report summarizes the presentations, discussions and recommendations from the Model-Based Enterprise Summit held at the National Institute of Standards and Technology in December of 2011. The purpose of the Summit was to identify challenges, research, implementation issues, and lessons learned in manufacturing and quality assurance where a digital three-dimensional (3D) model of the product serves as the authoritative information source for all activities in the product's lifecycle. The report includes an overview of model-based engineering, technical challenges, summaries of the presentations given at the workshop, and conclusions that emerged from the presentations and discussions.

Acknowledgment

We wish to acknowledge the individuals who organized and participated in the Model Based Engineering / Technical Data Package Summit – particularly those who presented to the group as a whole, many of whom provided comments and suggestions on an earlier draft of this document. We would like to acknowledge Richard Neal, whose meeting notes were invaluable in writing the presentation summaries in this report, and Roy Whittenburg for his thorough review of this document.

Keywords

Model-based, manufacturing, quality, MBE, MBD, technical data package

1 Introduction

The National Institute of Standards and Technology (NIST) Engineering Laboratory and the Office of the Secretary of Defense (OSD) hosted the third annual Model-based Enterprise and Technical Data Package[1] (MBE/TDP) Summit from December 12 through December 15, 2011, at NIST. Over 150 participants from industry and government met to share the latest technological developments and best practices for model-based engineering (MBE) [2], and to continue work on a new version of the MIL-STD-31000 Technical Data Package (TDP) standard [1] to include requirements for 3D models. The Department of Defense (DoD) Engineering Drawing and Modeling Working Group is responsible for updating MIL-STD-31000 to support delivery of model-based technical data for defense systems. Table 1 lists the organizations that attended the Summit.

The Summit consisted of a series of technical presentations focusing on different aspects of model-based engineering. The summit included separate working group meetings devoted to revising MIL-STD-31000 and related DoD standards. This report is concerned with the technical presentations and technical discussions related to MBE. The results and materials from the MIL standards working group meetings are not included in this report.

Section 1 of the report provides a brief introduction. Section 2 describes the main concepts of MBE and its advantages for manufacturing. Section 3 highlights technical challenges to adopting MBE in manufacturing. Section 4 summarizes each of the technical presentations. Conclusions and recommendations are in Section 5. The appendix contains a table of acronyms used in the report, agenda, and all presentations approved for public distribution.[3]

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[1] The Technical Data Package (TDP) is the collection of all product data needed to manufacture and maintain the product.

[2] Model-based "Enterprise" and Model-based "Engineering" are often treated as interchangeable terms. For the purposes of this document, we define the terms as follows.

- Model-Based *Engineering* – an approach to product development, manufacturing, and lifecycle support that uses a digital model to drive all engineering activities.
- Model-Based *Enterprise* – an organization that uses model-based engineering.

[3] Those not included were not approved as of the publication of this Technical Note.

Table 1. Organizations participating in the Summit

ACIT	Action Engineering
Aerospace Industries Association (AIA)	Anark Corporation
South Carolina Research Authority (SCRA)	Autodesk, Inc.
Automation Alley	B&W Y-12, LLC National Security Complex
BAE Systems	Bell Helicopter Textron
Boeing Company	CT Core Technologies
Dassault Systemes	Decision / Analysis Partners
Defense Logistics Agency	GE Energy
Honeywell	ICF International
Imagecom, Inc.	ITI TranscenData
Jacobs Engineering	Jotne North America Inc.
L-3 Combat Propulsion Systems	LMI Government Consulting
Lockheed Martin Missiles & Fire Control	Lucrum Group
Metrosage LLC	Mitutoyo America Corporation
National Institute of Standards and Technology	Nextec Applications Inc.
Northrop Grumman Technical Services	OSD Manufacturing Technology
Peerless Technologies Corporation	Pratt & Whitney
PTC	Raytheon Company
RECON Services/Army	Renaissance Services, Inc.
Renishaw PLC	Rolls-Royce North America
Sandia National Laboratories	Siemens PLM Software Inc.
Spatial Integrated Systems, Inc.	TSR Optima
U.S. Air Force	U.S. Air Force Research Laboratory
U.S. Air Force Warner Robins Air Logistics Center (WR-ALC)	U.S. Army Armament Research, Development and Engineering Center (ARDEC)
U.S. Army Materiel Command Logistics Support Activity (USAMC LOGSA)	U.S. Army Research, Development and Engineering Command (RDECOM)
U.S. Army Research Laboratory	U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC)
U.S. Coast Guard	U.S. Marine Corps
U.S. Naval Air Systems Command (NAVAIR)	U.S. Naval Facilities Expeditionary Logistics Center (NFELC)
U.S. Naval Sea Systems Command (NAVSEA)	

2 Model-Based Engineering

Until recently, most engineering and manufacturing activities relied on hardcopy and/or digital documents (including 2D drawings) to convey engineering data and to drive manufacturing processes. With the advent of new manufacturing data format standards and more powerful engineering software, it is now possible to perform all engineering functions using data models. The model-based engineering (MBE) approach uses these models rather than documents as the data source for all engineering activities throughout the product life cycle. The core MBE tenet is that models are used to drive all aspects of the product lifecycle and that data is created once and reused by all downstream data consumers.

A model is a representation or idealization of the structure, behavior, operation, or other characteristics of a real-world system. A model is used to convey design information, simulate real world behavior, or specify a process. Engineers use models to convey product definition or otherwise define a product's form, fit and function. In MBE, models can be applicable to a wide range of domains (systems, software, electronics, mechanics, human behavior, logistics, and manufacturing). Models can be either computational or descriptive. Computational models are meant for computer interpretation and have a machine-readable format and syntax. Descriptive models are human interpretable and meant for human consumption (symbolic representation and presentation). Core to MBE is the integration of descriptive models with computational models. Computer aided design (CAD) models used in manufacturing are a good example. Early CAD models were meant only for human viewing. Today, CAD models can be directly interpreted by other engineering software applications. A variety of standard interchange formats now exist to enable application-to-application transfer of engineering data.

In the context of manufacturing, model data drives production and quality processes. A product model used in manufacturing is a container not only of the nominal geometry, but also of any additional information needed for production and support. This additional data, known as Product Manufacturing Information (PMI), may include geometric dimensions and tolerances (GD&T), material specifications, component lists, process specifications, and inspection requirements.

Two critical factors give MBE significant advantages over drawing-based or document-based engineering: 1) computer interpretability and 2) data associativity. The primary reason to use a data model in engineering and manufacturing is that a model can be processed directly by engineering software applications. In a document-based environment, humans must interpret the engineering documents and then enter the information into the specific user interface of each engineering application. Whether it is finite element analysis (FEA) or computer aided manufacturing (CAM), each application creates its own internal model. In the past, the only access to this model was through the application's user interface (keyboard and screen). With

MBE, the applications read and write the models directly. This results in fewer errors and a drastic reduction in processing time.

Data associativity is critical to model integrity. Data association within and between documents is very difficult to maintain. Tolerances, material specifications, surface finish, hardness, and other information must be associated with specific features in the model. In analysis models, for example, boundary conditions are associated with the point at which they act. In assembly models, components must be associated with and oriented toward mating components. Data associativity is critical for model interpretation by software applications and is built-in to the model representation formats and data exchange standards.

Quintana et al. [2] define a product's Model-Based Definition (MBD) as a dataset containing the model's precise 3D geometry and annotations. The annotations specify manufacturing and life cycle support data and may include notes and lists. The model comprises a complete definition of the product, without relying on supplemental documents such as 2D drawings. 2D drawings are not needed when annotations are associated with objects in the model and can be viewed with the model.

Not only do humans have to be able to understand the model, but software applications have to "understand" the model as well. Quintana outlines requirements for engineering models.

- CAD systems must be able to manipulate, import, and export 3D solid models.
- CAM software must be able to define and validate machine-readable instructions for making the model, and must document the process definition.
- Computer Aided Engineering (CAE) software must be able to validate and optimize the product definition.
- Product Lifecycle Management (PLM) software must be able to control access and manage change of the various models and documents associated with the product.
- Applications such as Enterprise Resource Planning and Manufacturing Execution Systems need to extract raw material and component information from product models.

The key to achieve interoperability across software applications is open standards, i.e., those developed by consensus either within a standards development organization or a consortium of stakeholders. No single software tool can perform all of the engineering tasks needed to design and manufacture a product. No single software product *can* do it all well. Users will mix and match software products according to their business objectives. Standards define an agreed-upon syntax and semantics of 3D modeling constructs and annotation so that users can understand one another's models. Standards for representing, exchanging, and determining the fidelity of PMI are of particular importance because PMI (includes GD&T annotations) is essential to manufacturing. Driven by industry, standards are adopted nationally and internationally, positively affecting interoperability across software applications.

Open standards are vital for MBE. Unlike industry standards, where the underlying technology is neither open nor democratically managed, no single company can exert an inordinate amount of control over the intellectual property in an open standard.[3] As a result, a company whose product model is based on open standards is less likely to find itself in a situation where it must rely on a competitor's software in order to "understand" the model or, even worse, support a product whose digital model was created using software and computer hardware that is no longer available. Avoiding the latter scenario is of particular concern for companies such as aerospace manufacturers whose products have lifecycles measured in decades – far longer than the typical lifetime of a CAD software application or computer operating system.

3 Benefits, Opportunities, and Challenges

MBE yields significant benefits to manufacturers and their customers. MBE has been shown to substantially improve productivity and reduce manufacturing costs. A study by the Aberdeen Group documented significant time and cost savings when model-based techniques are compared to conventional engineering practices.[4] Another study found MBE methods result in time savings of a factor of three for first-article product development and a factor of four for engineering change management.[5]

Model-based engineering increases the potential value of archived product data. As mentioned in Section 2, MBE enables Product Manufacturing Information (PMI) including Geometric Dimensions and Tolerances (GD&T), annotations, and notes to be integrated with the product's digital 3D representation. Incorporating PMI into the model eliminates the need for 2D drawings and other supporting documents. MBE can also improve the accuracy of GD&T annotations by enabling the association of GD&T semantics with features in a 3D model of a part. Software tools can detect inconsistencies between the GD&T and the part geometry. New PMI standards for dimensioning and tolerancing make this possible. As Bill Tandler states in his presentation (4.11.4), emerging standards and technologies have the potential to prevent useless and costly "decoration" of models.

Scott Lucero, OSD, states (4.7), MBE facilitates "cross-domain coupling," i.e., integration across a complex system spanning more than one engineering discipline. Cross-domain coupling results in benefits such as improved integration of modeling and simulation, which in turn can lower product development costs.

Recent technical and standards developments now make the vision of MBE possible for even the smallest manufacturers. Developments include the implementation of 3D PMI (e.g., GD&T) standards in CAD software, and the availability of low-cost software using new formats for viewing – and potentially exchanging – models. The result is a dramatic lowering of the cost of MBE, particularly for small businesses. For example, a 3D CAD model with GD&T annotations and other supporting information can now be exported to the 3D Portable Document Format (3D PDF).[6] A 3D PDF file can, in turn, be viewed with the Adobe Reader, free software that is a standard application on most computers.

As discussed in Section 2, an open standards-based approach provides many advantages to achieve interoperability between the applications creating and accessing model-based engineering data. Still needed are new standards for the syntax and semantics of PMI symbols, standards for the exchange of annotated 3D model data between systems, and standards for low-cost, efficient formats such as 3D PDF used for collaboration with partners and customers. Key to the success of standards is effective deployment and risk reduction. Test methods for validating that software applications correctly produce and interpret model data are an essential component of standards development.

Validation testing is a multi-faceted, multiple-stage process. Not only must CAD systems correctly implement dimensioning and tolerancing standards, but CAD systems must also be able to exchange data with other CAD systems using standard formats. In addition, translators must correctly export data to low-cost, collaborative formats. Finally, software for viewing and manipulating the formats must correctly interpret the model.

4 Workshop Presentation Summaries

This section contains subsections summarizing each technical presentation. Subsection titles are presentation titles. Italicized text following the subsection title identifies the presenter and organization represented. Summary text for the most part paraphrases the actual ideas communicated by the presenter. An exception is Bill Tandler's summary (4.11.4, second paragraph), where we describe a real-time demonstration.

The Summit included two special sessions, each containing a group of presentations sharing a common theme. The first, a session on quality control and quality assurance (4.11), was organized by John Horst of NIST's Intelligent Systems Division, Engineering Laboratory, who was responsible for choosing and inviting the speakers. The second special session, a series of CAD vendor demonstrations, was organized by Rich Eckenrode of RECON Services.

4.1 OSD MBE / TDP Summit Objectives

Paul Huang, US Army Research Laboratory

The Department of Defense (DoD) Engineering Drawing and Modeling Working Group (DEDMWG) provides technical coordination and policy guidance on weapon systems data for acquisition, product design, analysis, simulation, manufacturing, provisioning and other product lifecycle management functions. The DEDMWG works in concert with the Joint Defense Manufacturing Technology Panel and DoD's Advanced Manufacturing Enterprise subpanel. A major emphasis of the DEDMWG is to reduce costs by creating synergy across the community utilizing work that has been done and avoiding "reinventing the wheel" in moving toward a model-based enterprise. DEDMWG team members and collaborators include:

- OSD Manufacturing Technology (ManTech)
- Armed services (Army, Air Force, Navy/Marine Corps)
- Defense Logistics Agency
- Standards organizations such as the American Society of Mechanical Engineers (ASME) and the Aerospace Industries Association
- Government agencies including NIST, Department of Energy (DoE), and National Aeronautics and Space Administration (NASA)

The scope of the DEDMWG includes standardization of technical data information requirements for computer-aided design, engineering, manufacturing, data repository, data archival and retrieval tools, and related applications for total product lifecycle management. Current ManTech-funded activities where DEDMWG is playing a leadership role include definition and validation of certified 3D models, use of 3D models across supply chains, reuse of 3D technical data package (TDP) in technical publications, and revision of MIL-STD-31000. Key DEDMWG accomplishments to date include:

- Conversion of the MIL-DTL-31000C Detail Specification [7] to MIL-STD-31000
- Improving synergy between ASME Y14.41 Digital Product Definition Data Practice standard [8] and the Aerospace Industries Association's NAS3500 standard [9]
- Refinement of annotations and delivery of schemas and validation guidebook into MIL-STD-31000
- Over 60 subject matter experts participating in the revision to MIL-STD-31000

The MBE Summit supports the DEDMWG goals of encouraging cross-agency and industry/government partnerships and discouraging duplication of efforts. The purpose of the Summit for OSD is to communicate the state of the art, key research challenges, and to share lessons learned and best practices.

4.2 NIST Engineering Laboratory Manufacturing Programs Overview

Vijay Srinivasan, Alkan Donmez, Mike Shneier, Fred Proctor, and Simon Frechette
National Institute of Standards and Technology

The Engineering Laboratory manufacturing program vision is to be the source for measurement science and critical technical contributions underpinning standards used by the U.S. manufacturing industry. Consistent with this vision, the Engineering Laboratory conducts research to help advance standards and technology enabling U.S. manufacturers to compete more effectively. The Engineering Laboratory has five manufacturing research programs: Smart Manufacturing Processes and Equipment, Next Generation Robotics and Automation, Smart Manufacturing Controls, Systems Integration for Manufacturing and Construction Applications, and Sustainable Manufacturing.

The Smart Manufacturing Processes and Equipment Program's objective is to advance measurement science enabling rapid and cost-effective production of innovative, complex products through advanced manufacturing processes and equipment. There are three thrust areas in the program: metal-based additive manufacturing, smart machining, and micro- and nano-manufacturing. The metal-based additive manufacturing thrust addresses the need to understand, identify, and reduce uncertainties in metal powder characteristics coupled with uncertainties in the advanced manufacturing process and equipment that lead to uncertainties in the final product. The smart machining thrust addresses the need to integrate modeling and simulation with real-time measurements to optimize processes and equipment. The micro- and nano-manufacturing thrust addresses the need to improve the quality and yield of micro- and nano-scale products through new measurement methods for improved process control.

The Next Generation Robotics and Automation Program's objective is to advance measurement science to increase the safety, versatility, autonomy, and rapid re-tasking of intelligent robots and automation technologies for smart manufacturing and cyber-physical systems applications. There are four thrust areas in the program: sensing and perception, manipulation, mobility, and autonomy. Sensing and perception enables next-generation robots to collaborate with humans in unstructured environments. Manipulation enables robotic dexterity essential for agile manufacturing operations and a greater breadth of applications through Robotic Industries Association (RIA) or ASTM standards for measuring performance. Mobility aims at allowing manufacturing vehicles to operate safely and more effectively in the same workspace as humans through the development of industrial vehicle safety standards. Finally, autonomy enables creation of agile and reconfigurable robots that are easily tasked to perform new manufacturing operations through standards and measurement tools for intelligent planning and modeling.

The Smart Manufacturing Controls Program objective is to advance measurement science enabling real-time monitoring, control, and performance optimization of smart manufacturing systems in the factory. There are three thrust areas in the program: factory networks, information modeling and testing, and performance measurement and optimization. The factory network thrust aims at enabling cost savings and ease of integration for networked equipment and sensors by developing performance and conformance tests for data exchange and cyber security standards through the Institute of Electrical and Electronics Engineers (IEEE) and International Society of Automation (ISA). The information modeling and testing thrust aims at 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). The performance measurement and optimization thrust aims at enabling optimization of manufacturing across the shop floor by developing standards for measuring key performance indicators through the Association for Manufacturing Technology (AMT).

The Systems Integration for Manufacturing and Construction Applications Program's objective is to develop and deploy measurement science for integration of engineering information systems used in complex manufacturing and construction networks to improve product and process performance by 2016. The program addresses industry's struggle to digitize manufacturing and thus achieve the level of integration needed to make substantial breakthroughs in manufacturing productivity, quality, and agility. The two major program thrusts are Model-based Engineering and Service-based Manufacturing. The Model-based Engineering thrust's objectives are to conduct research and deliver technical results to enable the transition from document-based data to model-based data, support new manufacturing processes and quality improvement, and enable end-to-end integration from systems engineering to manufacturing. The Service-based Manufacturing thrust's objectives are to develop service-oriented architectures for manufacturing, and to create supply chain service models that enable SMEs to participate in manufacturing supply chains.

The Sustainable Manufacturing Program's objective is to develop and deploy advances in measurement science to enable improvements in resource (energy, material) efficiency and waste reduction across manufacturing processes and product assembly by 2016. The program addresses the industry's need for well-defined sustainability metrics and a measurement science-based methodology to compose those metrics across global supply chains within manageable uncertainty. The two major program thrusts are Methodologies for Characterizing Sustainable Processes and Resources and Integration Infrastructure for Sustainable Manufacturing. The Methodologies for Characterizing Sustainable Processes thrust aims to define sustainability metrics of unit and assembly processes and use those metrics in life-cycle predictions and decisions. The Integration Infrastructure for Sustainable Manufacturing thrust aims to develop a sustainability testbed based on real manufacturing scenarios.

4.3 NASA Integrated Model-Centric Architecture

Paul Gill, NASA

The NASA Integrated Model-Centric Architecture is based on the general model-centric vision of advancing from a document-centric engineering practice to one in which structural, behavioral, and simulation-based models representing the technical designs are integrated throughout the lifecycle.

There are several problems to be solved, including:

- Lack of affordability of projects and activities
- Mission complexity growing faster than the ability to manage it
- Inability to share models in a collaborative environment
- Ineffective testing and too many design reviews
- Lack of early problem identification
- Necessity of searching for needed data
- Necessity of integrating pieces as opposed to total model solutions
- Data model quality uncertainty

Moving to a model-driven environment with integration and simulation capability will help resolve many of the issues listed above. NASA has developed three use cases to illustrate the benefits of deploying the model-centric vision. The first scenario is a change in requirements late in the development cycle where a fully model-centric program would enable the tracing of effect of a change across all aspects of the product. The second scenario is an in-flight anomaly, where a model-centric architecture would allow immediate definition of data and information needed to address the problem and locations of spare parts and needed materials. The third scenario involves the deluge of development data where the volume of data is huge, and a model-centric architecture would accommodate that requirement.

The means of establishing a model-centric environment comes in two parts. The first is the establishment of Communities of Practice (CoP) in several areas including model-based systems engineering, product data and lifecycle management, models and simulations, and computer aided design. The CoP mission goes beyond communication and discussion to include the deployment of model-centric toolsets. Seven teams have been established to address various aspects of the challenge. They are Benchmarking, Foundations, Current Architecture, Concept of Operations (ConOps), Communications Plan, Pilots, and Workforce Capabilities.

The second part is the development of a three-phase roadmap to guide the model-centric activities. The first phase is preparation, which involves establishing a common vision and developing strategic and implementation plans. The second phase is implementation, which involves developing standards and policies for new capabilities and developing a standard suite of modeling tools and technologies. The third phase is sustaining and improving, which involves establishing an operational model-centric infrastructure and a mature model-based development methodology.

Key benefits that NASA envisions from moving to a model-centric culture include enhanced affordability, increased collaboration, earlier identification of problems, and quicker diagnoses and solutions. Early results are already having an impact.

4.4 Affordable Readiness through Model-Based Enterprise

Shelley Diedrich, U.S. Coast Guard

A new goal for the Coast Guard is affordable readiness through a model-based enterprise. Coast Guard equipment is aging. Much equipment is at least 40 years old and no longer has data for sustainment and maintenance. The access to needed data for maintaining equipment is becoming an important issue.

The Coast Guard defines logistics as “all the activities associated with developing, acquiring, sustaining, and eventually retiring the components of capability, including people, systems and information.” This definition of logistics includes mission requirements and regulation requirements needed to support assets. This view of logistics is different from the more limited view of logistics in certain circles.

The Coast Guard vision includes:

- Affordable readiness
- Spiral MBE implementation
- Standard Coast Guard processes
- Integrated modular architecture
- A configuration-based business model
- Baseline management

The three elements of the vision are a standard product model, standard business model, and single information technology system. The approach to achieving the vision involves developing systems engineering for business model management and leveraging of government and industry best practices. A roadmap was created to outline the strategy plan for achieving the vision. Every organization within the Coast Guard must be transformed to embrace and implement the MBE solution.

Several risks have been identified and need to be addressed. These risks include lack of a comprehensive ISO 10303 (also known as "STEP" – the Standard for the Exchange of Product Model Data) [10] pilot, limited STEP expertise, competing standards and limited ability to sustain them, and revisions to STEP standards making the end state a moving target.

4.5 Model-based Engineering / Manufacturing Review from Y-12 National Security Complex

Donna Bennett, National Nuclear Security Administration

Y-12 is a manufacturing facility whose mission includes sustaining a safe nuclear arsenal, processing highly enriched uranium, and preventing nuclear proliferation and nuclear terrorism. B&W Y-12 operates it for the National Nuclear Security Administration (NNSA). Y-12 plays a vital role in DOE's Nuclear Security Enterprise. It has four core areas of research and development: defense programs, transformation, complementary work, and basic science.

Y-12 focuses on the link between design and manufacturing by emphasizing model-based engineering and manufacturing, which includes the use of 3D models for defining refurbished stockpile product, supporting certification, and integrating design, engineering, and manufacturing activities throughout the lifecycle. The model-based engineering and manufacturing concepts are applied during design, analysis/simulation, manufacturing, inspection, and packaging.

Y-12 has model-based activities in four areas: packaging of materials, life-extension programs, the integrated glove box program, and the uranium processing facility. Packaging of materials involves designing a product and testing it for requirement fulfillment (e.g., designing a container and then dropping it to analyze the impact result). Life-extension programs develop business rules around MBE needs and requirements, and complete process planning using work-in-process models. The integrated glove box program uses virtual process planning to identify problems in fixture design and allows for corrections of these problems before any builds. The uranium processing facility involves conceptual and ergonomic design with the intent of identifying and resolving problems early in the design process.

The Y-12 Complex collaborates with other Department of Energy sites and federal agencies as well as universities and private industry. The Plant Directed Research, Development, and Demonstration Program supports innovative or high-risk design and manufacturing concepts and technologies with potentially high payoff for the Nuclear Security Enterprise.

4.6 Model-Based Enterprise Impact on Organizational Behavior

James DeLaPorte, NexTec

Organizations have a large inertia, and change is difficult. It is analogical to Newton's law of motion stating, "A body in motion tends to stay in motion unless acted on by an outside force." The model-based enterprise (MBE) is an outside force that can drive change.

People in an organization tend to establish and to reinforce "normal" behavior. MBE is a fundamental shift to 3D from 2D for all major organizations, which is a major perturbation from the normal behavior. The impacts are felt in engineering, operations, quality, service and support, information technology, and finance and contracts. All of these business units are required to adapt, which means there is a need to rebuild the organization to support the use of 3D, to update training and instructions, and to manage new applications and processes.

In order to achieve MBE and organizational behavior transformation, four elements are needed: (1) empowerment of leaders at all levels, (2) adaptation to changing roles and responsibilities, (3) trust and encouragement, and (4) active pursuit of conflict resolution. People will follow the new behaviors defined by the organizational leaders. Keeping people involved and informed will increase the individual commitment to the new norms. This commitment will stabilize and sustain the new organizations. The new organizational behavior will be much more dynamic and flexible.

4.7 Engineered Resilient Systems

Scott Lucero, Office of the Secretary of Defense

Engineered Resilient Systems (ERS) is one of the seven Department of Defense (DoD) Science and Technology priorities. ERS was established to guide FY13-17 defense investments across DoD services and agencies. Although ERS is a systems engineering approach, it goes far beyond process. New technologies, applied across a broad community, are imperative in addressing the changing requirements. New tools help engineers and users understand interactions, identify implications, and manage consequences. This scenario of operations points to an ability to automatically evaluate many options, understand all implications, respond to requirements, propagate tradeoffs, and adapt through a continuous learning process.

A ten-year technology and science roadmap is currently under development. Four technology enablers have been identified. These are:

- System representation and modeling – capturing physical and logical structures, behavior, interactions with the environment and other systems
- Characterizing changing operational contexts – directly capturing operational data, deeper understanding of warfighter needs and operational impacts of alternatives
- Cross-domain coupling-– better interchange between incommensurate models, resolving temporal, multi-scale, multi-physics issues
- Collaborative design and decision support – well-informed decision support among many stakeholders.

Research will develop the tools and technologies to enhance engineering productivity, resulting in resilient systems that are effective in a wide range of situations, readily adaptable through reconfiguration or replacement, with graceful degradation. The goals for success of the roadmap include adaptable design, faster and more efficient engineering iterations, and decisions informed by mission needs.

4.8 The National Digital Engineering and Manufacturing Consortium

Dennis Thompson, South Carolina Research Authority

The National Digital Engineering and Manufacturing Consortium (NDEMC) is a public-private partnership that is part of the President's Advanced Manufacturing initiative. The goal of the NDEMC is to provide high performance computing capability for the small manufacturing community. The consortium is providing Software-as-a-Service access to high performance software and to the hardware on which it runs with an emphasis on modeling and simulation capabilities.

There are two major thrust areas: 1) specialized consulting or training in modeling, simulation, and analysis provided by teams of experts, and 2) on-line manufacturing support systems. NDEMC stresses shared solutions. The goal is to provide tools that can serve a broader community, not just satisfy very specific needs of a highly specialized application. The program is focused across the product lifecycle. The benefits are realized by the original equipment manufacturers, software providers, SMEs, and by the U.S. government.

Seven projects have been launched, and 30 to 40 projects are planned to be launched. A catalog of 143 software tools is being developed and will be accessible by SMEs through the NDEMC portal.

4.9 Department of Defense (DoD) MBE Program Reviews

4.9.1 Navy Digital Product Model

Ben Kassel, Naval Surface Warfare Center, Carderock Division

The Digital Product Model will be the authoritative source of data for the entire ship's lifecycle.[4] NAVSEA (Naval Sea Systems Command) is pursuing a two-level approach. At the first level, the ship design is a collection of parts with the model supporting the management of the collection. At the second level, there is an additional layer of information required to manage and

[4] A memo signed by the Chief Engineer and Deputy Commander, Naval Systems Engineering Directorate – SHIP DESIGN AND ANALYSIS TOOLS GOALS, Ser 05T/015, Naval Sea Systems Command, Washington D.C., Sep 29 2010 –"NAVSEA is committed to creating and maintaining LEAPS models for every major ship class in the U.S. Navy to enhance lifecycle support and incident response. A future goal is for NAVSEA to maintain a LEAPS model for every ship in the fleet." LEAPS (Leading Edge Architecture for Prototyping Systems) is NAVSEA's product model repository implementation.

support the product from the as-designed and as-built derived models of the product. The Navy believes that the STEP *Product life cycle support* standard (ISO 10303-239) [11] has emerged as a useful mechanism to define product structure, the relationship between objects, and configuration management, and that the STEP *Core data for automotive mechanical design processes* standard (ISO 10303-214) [12] is a relatively mature mechanism for managing product data. Contracts with the ship builder will specify that the contractor supply Data Exchange Specifications (DEXs) based on the ISO 10303-239 information model supporting the interpretation of data. In the future, the Navy will provide standard DEXs and will specify compliance with those DEXs in all contracts.

4.9.2 Air Force Technical Data Objectives

Brench Boden, United States Air Force

The Air Force program Expeditionary Logistics for the 21st Century focuses on the transformation of supply chain activities. It addresses major issues including data rights, data availability, and acquisition strategy. A ManTech opportunity is seen in PLM integration and new methodologies for managing product technical data. Interoperability is a major opportunity area. Studies show the lack of interoperability costs billions of dollars per year.[13] The Air Force ManTech program is developing a strategic vision and technical thrusts. The four focus areas are:

- Moving manufacturing left (i.e., developing technologies enabling early consideration of manufacturing requirements during design)
- Cradle-to-cradle digital thread
- Responsive integrated supply base
- Factory of the future

The *cradle-to-cradle digital thread* is particularly important to the TDP/MBE activities.

4.9.3 Army Research Objectives for MBE

Andy Davis, US Army Research Development and Engineering Command

The Army has identified three goals in achieving a model-based enterprise:

- Fully integrated manufacturing enterprise to support weapons systems development
- Digital thread connectivity from prototype to production
- Establishment and implementation of best practices and standards for product data use

The Army is addressing challenges including lack of resources, competition from industry, political interests, and institutional issues. Current investments include the Net-centric MBE project ($ 8.9 million over 4 years) and Accelerated and Adaptive Army Fabrication Enterprise

($9.2 million over 4 years). The latter is a major activity focused on establishing an organic capability within the army to pilot and demonstrate an advanced model-based enterprise.

4.9.4 Defense Logistics Agency Objectives for MBE

Rick Norton, Defense Logistics Agency (DLA)

There are three active MBE projects within DLA named Charter 1, 2, and 3. Charter 1 is an A-10 jet aircraft TDP exchange pilot. Charter 2 involves a contracting TDP within an MBE environment. Charter 3 addresses supply chain activities. The Charter 1 project is a partnership with the Air Force and Boeing that addresses parts provisioning using 3D model data. The objective is to modernize the means of exchanging data. Charter 2 will begin with an in-depth study of the present state of practice and emerging best practices in the model-based enterprise. The study will include benchmarking supporting gap and trend analysis, and business case analysis. Charter 2 will deliver a model-based enterprise/product lifecycle management technology discovery and investment strategy for DLA. In summary, Charter 1 defines what needs to be done in developing new MBE tools. Charter 2 determines what needs to happen to drive contract deliverables within an MBE. Charter 3 will make MBE happen within the supply chain.

4.10 Industry and ManTech Interaction Success

David Baum, Raytheon

Raytheon has four mission areas in addressing a technology-driven growth strategy:

- Sensing, which expands beyond traditional Radio Frequency/Electrical-Optical to new growth focus areas, including multi-mission areas.
- Command, Control, Communication, and Intelligence), which broadens market presence in communications, networking and knowledge management.
- Effects (military actions or outcome), which leverages kinetic energy-based expertise into Electronic Warfare, directed energy and cyber markets.
- Mission support, engineering services, and training.

The objective is to identify and establish common product data management (PDM) systems, engineering documentation standards, and process asset libraries. Technology-readiness level and manufacture-readiness level should be defined in each lifecycle phase.

Raytheon’s capability development timeline is as follows:

- 2011: model-based definition – complete an enterprise MBD specification,
- 2012: model-based manufacturing – establish global supplier communication and deploy CAD model derivatives,
- 2013: model-based engineering and lifecycle support – implement virtual verification and requirement allocations/derivations.

Raytheon leverages the Customer/Supplier Interoperability (CSI) ManTech program (see 4.13). The vision of CSI is a flexible, configurable, standard-based system that automates common tasks associated with customer supplier interoperability. Specific leveraging of the ManTech work includes:

- Working with industry partners PTC and ITI TranscenData to validate conversions of CAD file formats,
- Developing a standard MBD schema with start parts[5] and PDM attributes,
- Developing MBD model qualifications and workflows prioritized by modeling defect causes,
- Using ITI's model comparison software to identify model changes during the change management process.

4.11 Special Session: MBE for Quality Control / Quality Assurance

John Horst, National Institute of Standards and Technology

The summit included a mini-session on MBE for quality control and quality assurance. Several leading US quality measurement experts presented their perspectives on the potential offered by a model-based approach to performing quality measurement. The presentations shared as a common theme the improvement of the quality measurement process, i.e., making it more efficient, less error prone, and more cost effective. They also touched on improving the integration of the quality measurement process into the entire manufacturing enterprise – particularly that part of the enterprise focusing on product design, quality management, and production. A model-based quality measurement process promises huge benefits, but also presents huge challenges. A key challenge is intelligent use of model data.

4.11.1 Product Tolerance Representation: Critical Requirements for Product Definition and Metrology Interoperability

Curtis Brown, Honeywell Federal Manufacturing & Technology

Full semantic product tolerance representation in digital information models is a critical requirement for cost-effective and efficient manufacturing, where "full semantic" means that no information in the digital model is mere "decoration," but contains the complete and rich association between geometry, feature definitions, tolerance frames, datum definitions, etc.

Current standard model-based product representations define nominal shapes only, and unfortunately, one cannot manufacture nominally shaped parts. Parts that fit and function are

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[5] A "start part" is used to speed up the initial creation of a CAD model for a part, drawing, or assembly. Start parts can help to encourage common modeling practices throughout an organization. Start parts are analogous to the document templates often used with office suite applications to facilitate creation of reports, spreadsheets, or slide presentations.

manufactured via 2D drawings and, to a lesser degree, via proprietary 3D models. Product tolerance representation that is correct, complete, unambiguous, and verified is essential for the successful exchange of product models for next generation automated applications and the return on investment promised by MBE. There is currently no model-based CAD system with the level of robustness to adequately represent and transfer product tolerance.

A fully semantic product definition must include:

- Solid models augmented with product tolerance.
- "Tolerance features," *i.e.*, geometric features with tolerance frame attached, as is defined in GD&T standards like ASME Y14.5.[14]
- Correct tolerances automatically inferred per ASME Y14.5 and company standards.
- Part functional tolerance definitions that are checked, validated, and scored.
- The ability to exchange tolerance definition with other product definitions.
- A published application programming interface suite for extending tolerance analysis, integration with existing software applications, and supporting downstream activities like manufacturing and measurement.

Downstream machining and inspection processes require tolerance information. Therefore, product data standards such as STEP Managed Model Based 3D Engineering [15] [16], process data standards such as STEP Numerical Controllers [17], and the Dimensional Metrology Standards Consortium's (DMSC) Quality Information Framework (QIF) [6] all support representation and exchange of tolerance semantics. GD&T validation tools are needed to ensure the correctness of the tolerance information being exchanged.

4.11.2 MBE for Dimensional Quality within a Heterogeneous Supply Base

Nick Orchard and Ron Snyder, Rolls-Royce

There is a proliferation of incompatible CAD, PDM, PLM, and CAM software environments. Rolls-Royce wants one single integrated environment. In the current Rolls-Royce PLM environment, even though geometry can be linked between models, the system does not allow users to link PMI, a capability that is essential to achieve the "paperless office." In terms of CAD models, one important question to ask is whether one size could fit all? For example, if the analysis department doesn't like including blends and radii in the CAD Model but CAM programmers and quality engineers do, then the answer is no.

An "inflated CAD model" is a concept where the CAD model has elements useful to downstream processes. Such processes include analysis, machining, and inspection – particularly

[6] http://www.qifstandards.org

3D inspection (i.e., using non-contact optical systems). For point cloud data, there are concerns about how to determine the validity of the results, how to determine the correct point density, how to qualify optical measurement systems based on an optical based inspection standard, and whether there is an optical based inspection standard.

4.11.3 Improving First Article Inspection in a Model-Based Environment

Ray Admire, Lockheed Martin

First-Article Inspection (FAI) in a model-based environment, compliant with industry information standards (such as ISO STEP, Aerospace First Article Inspection [18], and the Dimensional Measurement Standards Consortium's Quality Information Framework), will deliver substantial benefits to manufacturers and their customers.

Challenges and risk to product quality in the supply chain include the uncertainty of experienced talent, the supplier value stream, fixed price contracts, technical challenges in achieving quality targets, vicissitudes in the national and international economy, uncertain performance of lower tier suppliers, changes in government policy, changes in trade regulations, and increasing Government Industry Data Exchange Program notifications.

Characteristic Accountability & Verification (CAV) is a process ensuring that all critical and major characteristics are defined and accounted for in the product technical data package. CAV also ensures that manufacturing and quality plans include controls adequate for conformance of these characteristics.

FAI can be improved in a model-based environment. However, a barrier to model-based FAI is that CAD data (including GD&T) does not flow seamlessly to downstream processes when components are not from the same vendor. The GD&T is not fully associated to critical characteristic features. This is because CAD vendors do not use standards, the standards are incomplete, end users do not enforce standards compliance, and there are no formal tools or methods for verifying CAD vendor compliance to the standards.

Top inspection process definition issues are:

- Lack of comprehensive non-shape information available from the product – including CAD tolerance data, material properties, and optical properties.
- Lack of a standard mechanism to capture and exchange knowledge – including methods, practices, resources, and rules.

As a result, costly rework is required at each step in the inspection process: planning, programming, results generation, and analysis.

The importance of FAI is that it reassures the customer or supplier that lower tier suppliers are compliant to all specified design characteristics (dimensional, material, etc.). The QIF model and schema (from the DMSC) holds promise for facilitating successful FAIs. A pilot demo involving joint efforts of NIST and Lockheed Martin is planned for demonstrating the joint benefits from FAI and QIF.

4.11.4 The Key to Intelligent GD&T

Bill Tandler, MultiMetrics

MBD is absolutely essential for ensuring the intelligent application of GD&T, since the concepts and symbolic language of GD&T are so complex that few individuals have the time, skill or interest to master them. This lack of mastery leads to improperly defined GD&T, which further leads to most GD&T being merely "decorative" and therefore, useless or even dangerous. MBD holds promise for automating precise application of GD&T to part geometry and features to enable correct execution of precision tasks such as tolerance stack-up analysis, manufacturing process management, coordinate metrology, and assembly.

Tandler presented a live example of the problems with a "decorative" GD&T application on a part not satisfying fit and function requirements, versus a correct GD&T definition satisfying fit and function. He described an experiment demonstrating this process. In concert with an unnamed "3D metrology" vendor, Tandler was able to encode the geometry and features of the same part, associate ASME Y14.5 standards-compliant and requirements-satisfying GD&T with the critical features on the part, and exchange this information with the 3D metrology vendor's software. The vendor's software then produced measurement results sufficient for analysis on fit and function.

Prerequisites to achieving the goal of model-based definitions that produce parts that assemble and function as required include:

- Significantly improving the ergonomics of MBD technology to encourage its use.
- Refining and solidifying the concepts, tools, rules, processes and best practices of GD&T to enable large-scale automation of the "encoding" and "decoding" processes.
- Largely automating the GD&T "encoding" process in the 3D CAD environment using the refinements referenced in the previous bullet.
- Fully automating the GD&T "decoding" process in the 3D CAD environment to graphically illustrate the impact of the "code" during the "encoding" processes.
- Largely automating the tolerance stack-up analysis process in the 3D CAD environment and providing intelligent feedback to enable iterative refinement of the GD&T code.

4.11.5 3D Technical Data Package Validation Demonstration

Roy Whittenburg, Universal Technical Resource Services, Inc.

The 3D technical data package validation demonstration provides an illustration in which a model is built and then broken down into segments, each segment having its own validation point. The approach focuses on defining what needs to be validated and then working with the industry to fill any technology gaps. Since DoD is inherently 2D and drawing based, there is a fundamental distrust of 3D data. Verification and validation is needed to gain this trust.

The objective of the project is to provide a process to verify and validate whether the data quality of the 3D TDP is sufficient for manufacturing. A team that consists of DoD service representatives, vendors, and subject matter experts executes the project.

The demonstration of the 3D technical data package validation process is provided in three steps: design model creation, product lifecycle management (PLM) check-in, and derivative model creation. The demonstration intentionally selects different tools for each section of the demonstration. The demonstration evaluates the model, determines issues causing deviations between the model and its derivatives, and offers assistance in resolving the issues. The issues are highlighted in the model and in the reports related to those models. The validation is not limited to parts, but also operates on assemblies.

In the demonstration, a model is created, initial validation is conducted, and the model is checked into the PLM system to enable sharing. An additional series of checks are executed to assure that the model has reached certain levels of model maturity and usability. If the model passes the checks, it is then available to be shared with others in either a released or unreleased state. After the model is checked in, derivatives (translations) are created. The derivatives must be validated, just like the original. In addition to the kinds of checking performed on the original model, derivative models must also be checked for deviations from the original.

4.12 The 3D PDF Consortium

Jim Merry, Tetra4D

A 3D PDF document is any PDF document that contains CAD data in Universal 3D (U3D) [19] or Product Representation Compact (PRC) [6] formats. Adobe no longer supports translation of CAD data to PRC or U3D. They are still supporting insertion of U3D and PRC to create 3D PDFs in their Acrobat Professional product. Although Adobe's Reader software will continue to support viewing of 3D PDF, partners have been chosen to continue the development and support of the CAD to 3D PDF conversion technology. Tech Soft 3D has taken on development and maintenance of the software toolkit for PRC-based CAD translator development, and is now leading the PRC ISO standardization effort. Tetra 4D is now the sole distributor of the 3D PDF conversion technology for the Adobe Acrobat platform and provides a plug-in enabling the latest version of Acrobat Professional to generate 3D PDF documents from multiple 3D formats from the mechanical CAD, architecture, engineering and construction, and digital content creation domains. ProSTEP AG now provides a server-level capability integrating 3D PDF generation in business processes and enterprise systems. Recent versions of Adobe Reader will read 3D PDFs, providing ubiquitous access to CAD model information.

While PDF is commonly perceived primarily as a presentation mechanism, PDF supports other functionalities relevant to the MBE environment such as information protection mechanisms and digital rights management. The ability for Adobe Reader users to interact with the 3D model via forms is another important capability. Support for digital signatures is important for document workflows requiring approval and/or certification for information authentication assurance.

The 3D PDF Consortium is a newly formed non-profit organization comprised of users, software developers, and solution providers whose goal is to accelerate 3D PDF standardization, implementation, and industry adoption. The consortium intends to achieve this goal through demonstration, communication, and evangelism. The consortium's website is http://www.3dpdfconsortium.org.

4.13 Engineering Software Provider Session

Rich Eckenrode, RECON Services, moderated a session consisting of CAD vendor demonstrations of new capabilities supporting MBE. Table 2 shows the vendors represented in the session, software products demonstrated, and the people who gave the presentations.

Table 2. CAD vendor demonstrations.

Vendor	Software Product	Presenter(s)
Dassault Systèmes	CATIA	Bob Brown and Israel Flores
PTC	Creo	Mark Nielson
Siemens	NX	Dennis Keating
Siemens	Solid Edge	Ricky Black
Dassault Systèmes	SolidWorks	Craig Therrien

4.14 Reducing New Product Introduction Time and Cost through More Effective Collaboration

John Gray, ITI TranscenData

Interoperability costs can easily add up. No manufacturer has an "explicit" interoperability budget. The Customer Supplier Interoperability (CSI) program is a solution to reduce interoperability costs.

The cost of interoperability is the summation of many small things that add to a significant dollar amount. For example, a forty-year program can have up to four million interoperability issues, costing in excess of $1 billion over the program's lifetime. Extrapolation of existing studies point to the fact that the lack of interoperability is a $2 billion per year problem for DoD. CSI sought to understand the interoperability issues and prototype some solutions. The steps in the CSI approach included review (data contract language), analyze (failures), prioritize (opportunities), identify (most value actions), and demonstrate (solutions in pilots).

The CSI vision involves a flexible and configurable standards-based system in which common tasks associated with Customer-Supplier Interoperability are automated. A model for effective interoperability was established and applied using a toolkit configured with tools from multiple technology suppliers. Prototypes of automated solutions have been demonstrated. To support the value proposition for CSI, a higher fidelity study of cost savings for the F-35 combat aircraft was undertaken. The potential savings for the F-35 program were conservatively estimated at $140 million over the life of the program.

The CSI program is now initiating four new activities. These are:

- Draw-to-PMI – automating merging of 2D GD&T into a 3D model, producing associative 3D PMI facilitating manufacturers migrating to a model based design methodology in new projects.
- Critical Problem Resolution Process – detecting and resolving model issues in design for manufacturability.
- 3D PMI Translation – translating associative 3D models and 3D PMI between dissimilar CAD environments with either BREP or Features.
- 3D ECO (Engineering Change Order) Documentation – documenting model changes in a 3D PDF format that improves communication between different organizations in an enterprise.

5 Conclusions

The December 2011 MBE/TDP Summit brought together a collection of stakeholders representing a wide variety of organizations spanning both the public and private sectors. Speakers included program managers, quality measurement experts, researchers, and solution providers. Conclusions and recommendations that emerged from the Summit are summarized in the following.

5.1 MBE is a key driver of affordability

Cost and affordability was a high priority for many organizations represented at the Summit. For instance, Paul Gill (4.3) pointed out that one of NASA's major problems is the lack of affordability of projects and activities. Other speakers agreed that implementing MBE can lead to cost savings and provided promising progress and results. Donna Bennett (4.5) highlighted a cost savings of $535K that resulted from using virtual testing instead of physical testing for packaging in the Y-12 program. Brench Boden from the Air Force (4.9.2) highlighted several studies substantiating the cost of the lack of interoperability in billions of dollars per year. In summary, the consensus is that cost control is crucial and the use of a model-centric architecture leads to increasing affordability.

5.2 MBE reduces errors

Current practices for communicating and accurately implementing changes in product requirements are inefficient. Such practices still depend on email, phone communication, and manual entry and reentry of data, creating opportunities for errors. These errors lead to delays and additional costs. John Gray (4.13) presented a demonstration scenario of interactions between an airframe manufacturer and mechanical equipment provider in the F-35 program. In his scenario, human interaction was required on numerous occasions to complete processes such as translating data into STEP, checking models for compliance issues, and verifying that the translated file is correct.

Implementation of MBE will increase the efficiency in dealing with changing requirements, especially during later development cycle stages. A fully model-centric software application could trace the effect of that change through many viewpoints. In an example use case from NASA (4.3) illustrating the use of such an application, a changing requirement resulted in successful identification of the affected mission segment, functions, and parts. David Baum also stressed (4.10) that one of the benefits of MBE is the reduction of time to implement changes in systems by enabling design reuse and configuration management. Successful change management and design reuse shows that MBE increases efficiency in processing change in design requirements.

5.3 MBE enables effective data reuse across the entire system lifecycle

Many presenters emphasized the ability to communicate and manage product data across the lifecycle. Paul Gill (4.3) stressed the ideal of a reusable model-driven environment with integration and simulation capability applicable to every activity and extending across the product lifecycle. Gill said that product data and lifecycle management are key to establishing a model-centric environment. Dennis Thompson (4.8) stated that the National Digital Engineering and Manufacturing Consortium (NDEMC) is focused on providing tools serving a broad community across the product lifecycle. Ben Kassel (4.9.1) emphasized that a goal for the Navy is the use of the digital product model as the authoritative source for the entire ship's lifecycle. Gill’s, Thompson’s and Kassel’s presentations indicate a growing consensus that while it is important to achieve a model-centric environment and incorporating technical data into 3D models, it is also equally important that this environment and the data contained in the models are easily accessible and usable during the entire product lifecycle.

5.4 We need new research to achieve true model-based quality control

Software implementations of 3D geometry and PMI, both proprietary and standards-based, are increasingly addressing information modeling requirements for automating downstream quality control and quality assurance (QC/QA) processes. The presence of QC/QA domain experts at the Summit (4.11) addressed the need to integrate manufacturing with QC/QA. The experts’ presentations articulated a shared commitment to improve the quality measurement process by making it more efficient, less error prone, and more cost effective. The development of new research areas in test methods, measurement methods, and standards is the key to improve product and process performance for manufacturing.

One key requirement for achieving these improvements is to fully incorporate GD&T data with CAD models and allow these data to flow seamlessly to downstream processes. Currently, GD&T data is often not associated with individual features of the part, making it impossible to automate inspection process programming. If GD&T information is expressed as individual lines and arcs in a CAD model or as notes on a drawing, it is not available to automated computer processes that can use it.

Another key area of need is to develop methods to verify and validate that the data quality of the 3D technical data package is sufficient for manufacturing. As Roy Whittenburg pointed in his presentation (4.11.5), there is a lack of trust in the data quality of 3D TDPs because current DoD practices are inherently 2D and drawing based, and there is no method of verifying the quality of the 3D data received. Hence, development of test methods for 3D TDPs is an area that needs more research.

5.5 We need new open standards to achieve the full potential of MBE

As the industry continues to make progress in implementing MBE, it is crucial that common conventions be agreed upon and that best practices are codified. Bill Tandler (4.11.4) argued that the full value of MBE and GD&T will not be realized until the standards that support MBD and GD&T are improved. He stated that GD&T almost fulfills its promise, but with great difficulty. Other speakers outlined and discussed the approach that their organizations are undertaking in developing new standards for MBE. David Baum (4.10) said that Raytheon is developing a standard MBD schema with start parts and PDM attributes. Ray Admire (4.11.3) mentioned that Lockheed Martin is working with other organizations to achieve agreement and common understanding of metrology issues to enable standardization and best practices.

Curtis Brown (4.11.1) stated that modern product definition systems can “successfully deliver the representation and exchange of nominal shapes.” However, “no one can manufacture nominally shaped parts.” The use of PMI enables semantic and accurate specification of product tolerances. As Brown pointed out, correct, complete, unambiguous, and verified tolerance definitions are the critical enabler for realizing successful representation of product models such that they can be consumed by next generation automation applications. Ron Snyder and Nick Orchard (4.11.2) also agreed that the move to PMI provides a pathway to a better modeling environment because this migration enables a participatory engagement in which manufacturing challenges are addressed in the design configuration.

6 References

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Appendix 1: Table of Acronyms

Acronym	Expansion
AMT	Association for Manufacturing Technology
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CoP	Communities of Practice
CAD	Computer Aided Drawing
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CAV	Characteristic Accountability & Verification
CSI	Customer/Supplier Interoperability
DoD	Department of Defense
DEDMWG	Department of Defense Engineering Drawing and Modeling Working Group
DEX	Data Exchange Specification
DLA	Defense Logistics Agency
DMSC	Dimensional Measurement Standards Consortium
DOE	Department of Energy
ECO	Engineering Change Order
ERS	Engineered Resilient Systems
FAI	First Article Inspection
FEA	Finite Element Analysis
GD&T	Geometric Dimensions and Tolerances
IEEE	Institute of Electrical and Electronics Engineers
ISA	International Society of Automation
ISO	International Organization for Standardization
LEAPS	Leading Edge Architecture for Prototyping Systems
ManTech	Manufacturing Technology
MBD	Model Based Definition
MBE	Model Based Enterprise/Engineering
NASA	National Aeronautics and Space Administration
NAVSEA	Naval Sea Systems Command
NDEMC	National Digital Engineering and Manufacturing Consortium
NIST	National Institute of Standards and Technology
NNSA	National Nuclear Security Administration
OSD	Office of the Secretary of Defense
PDF	Portable Document Format
PDM	Product Data Management
PLM	Product Lifecycle Management
PMI	Product Manufacturing Information
PRC	Product Representation Compact

QC/QA	Quality Control / Quality Assurance
QIF	Quality Information Framework
RIA	Robotic Industries Association
SCRA	South Carolina Research Authority
SME	Small or Medium Enterprise
STEP	Standard for the Exchange of Product Model Data
TDP	Technical Data Package
U3D	Universal 3D

Appendix 2: Final Agenda and Presentation Materials

The following pages contain:

1. The final MBE/TDP Summit agenda
2. Presentation materials from all Summit speakers who gave NIST permission to distribute their slides.

In order to minimize page count, each page of presentation materials contains six slides. In some cases, we deleted slides determined to be content-free (e.g., "Thank you" and "Any questions?" slides) and slides that were partial builds of other slides (useful for "animating" presentations but not of much value in a printed hard copy).

With the exception of presentations given by NIST staff (e.g., 4.2), inclusion in this Appendix implies neither endorsement nor approval by the National Institute of Standards and Technology.

MBE/TDP Summit

NIST, Gaithersburg, MD

Green Auditorium

12 Dec. 2011

Time		**Topic**		**Speaker(s)**
0730-0830		Registration		
0830-0840		Introductions and Admin		Simon Frechette, NIST & Paul Huang, ARL
0840-0900		Opening Remarks		Dr. Harary, NIST & Ms. Radcliff, OSD ManTech
0900-0930		OSD MBE/TDP Summit Objectives		Paul Huang/Simon Frechette
0930-1010		NIST Engineering Laboratory Manufacturing Programs Overview		Vijay Srinivasan, Simon Frechette, Fred Proctor, Alkan Donmez, Mike Shneier, NIST
1010-1030		Break		
1030-1110		NASA Integrated Model-centric Architecture		Paul Gill, NASA
1110-1150		Integrated Data Management Strategy in support of MBE life cycle management		Shelley Detrich, USGC
1150-1230		Model Based Engineering/Manufacturing Review from Y-12		Donna Bennet, NNSA
1230-1330		Lunch Break		
1330-1400		MBE Implementation at Enterprise Level Requirements		James Delaporte, NexTec
1400-1430		Engineering Resilient System		Scott Lucero, OSD
1430-1510		EDA Overview		Dennis Thompson, ATI
1510-1530		Break		
1530-1730		DoD Program reviews		
30 min		Navy		Ben Kassel, NAVSEA
30 min		Air Force		Brench Boden, AFRL
30 min		DLA		Ric Norton, DLA-LIS
30 min		Army		Andrew Davis, RDECOM
1730		Wrap-up		All

MBE/TDP Summit
NIST, Gaithersburg, MD
Green Auditorium

13 Dec. 2011

Time		**Topic**		**Speaker(s)**
0730-0830		Registration		
0830-0840		Opening Remarks		Paul Huang/Simon Frechette
0840-0920		Industry and ManTech Interaction success		David Baum, Raytheon
0920-0930		MBE for QC/QA		John Horst, NIST
0930-1010		Critical Product Tolerance Representation Requirements for MBD and Metrology Interoperability		Curtis Brown, DoE/KCP
1010-1030		Break		
1030-1110		MBD for Dimensional Quality within a Heterogeneous Supply Base		Ron Snyder, Rolls Royce
1110-1150		Improving First Article Inspection in a Model-Based Environment		Ray Admire, Lockheed Martin
1150-1230		MBE - Enabler of Intelligent GD&T		Bill Tandler, MultiMetrics
1230-1330		Lunch Break		
1330-1400		TDP Validation		Roy Whittenburg, UTRC
		Vendor Session - MBD/MBE Capabilities		Rich Eckenrode, Army-Support CTR
1400-1430		Dassault Systemes		Bob Brown, Michael Melton
1430-1500		PTC		Mark Nielson
1500-1515		Break		
1515-1545		Siemens		Dennis Keating
1545-1615		SolidEdge		Ricky Black
1615-1645		SolidWorks		Craig Therrien
1645-1715		3D PDF Consortium		Jim Merry
1715-1730		Wrap-up discussion		ALL
		Q & A session for vendors		

MBE/TDP Summit
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14 Dec. 2011 MIL-STD-31000 & 973

Time		**Topic**		**Speaker(s)**
0730-0830		Registration		
0830-0845		Intro and Admin		Paul Huang/Simon Frechette
0845-0935		MIL-STD-31000 Working Group Updates		
10 min.		Acquisition WG		Gary Sunderland/Hank Oakes
10 min.		Data Content WG		Ric Norton/Gordon Ney
10 min.		Data Delievery WG		Roy Whittenburg/Paul Huang
10 min.		Nomenclature		Simon Frechette
10 min.		Manufacturing WG		Fred Proctor/Rich Eckenrode
0935-1030		Review of 31000		Ric Norton/Paul Huang
1030-1045		Break		
1045-1130		Review of 31000		Ric Norton/Paul Huang
1130-1200		Customer Supplier Interoperability		John Gray, ITI
1200-1230		Update on PowerLOG-J PLCS Adapter & PLCS Implementor Form		Scott Motquin, LOGSA
1230-1330		Lunch Break		
1330-1400		Joint Service Product Data Requirement Detrmination		John Campbell, ARDEC
1400-1500		MIL-STD-31000 Review of Appendices		Simon/Roy
1500-1520		Break		
1520-1700		MIL-STD-31000 Review of Appendices		Simon/Roy

MBE/TDP Summit
NIST, Gaithersburg, MD
Gaithersburg Hilton

15 Dec. 2011 MIL-STD-31000 & 973

Time		Topic		Speaker(s)
0800-1045		MIL-STD-31000 WG breakout sessions		**All**
1045-1100		Break		
1100-1230		Wrap-up and closing remarks		Ric/Paul
1230-1330		Lunch Break		
1330-1600		AIA NAS3500 & 31000 WG joint discussion		Paul Huang/Robert Morris
1600-1630		Wrap-up and closing remarks		Paul/Simon/Robert

http://www.nist.gov/el/msid/tdpsummit_2011.cfm

US ARMY RDECOM

U.S. Army Research, Development and Engineering Command

DMC 2011

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

DEDMWG and MIL-STD-31000 Overview and Status of Model Based Definition Efforts

Paul Huang, U.S. Army Research Laboratory
28 Nov. 2011

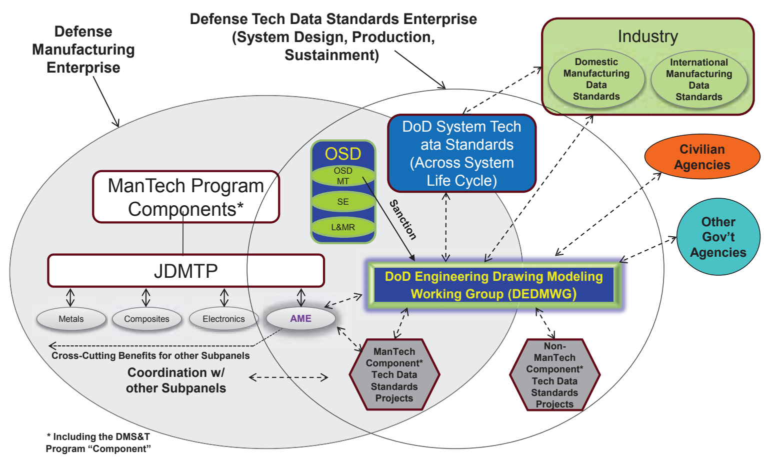
AGENDA

- •&Overview of DEDMWG History
- •&DEDMWG relationship within DoD/ManTech Community
- •&Scope & Objectives
- •&Current Relevant Projects
- •&Accomplishments
- •&Summary and Gaps
- •&Questions

DEDMWG History

- First Meeting hosted by the Army and Navy in Gaithersburg, MD November 2008.
- DoD Engineering Drawing and Modeling Working Group (DEDMWG) established by the Services and DoD in 2008 to establish a Community of Interest for sharing and leveraging ideas, tools, processes, and to be a unified voice within DoD and to Industry Standard Groups.
- Membership includes all the Services, Coast Guard, DoD and Industry partners. A Workspace is located at the Acquisition Community Connection (ACC).
- First task taken on was the update to MIL-DTL-31000C, which is being converted to a MIL STD. Also looking to update associated Data Item Descriptions (DIDs) Accomplished Nov 2009.
- Charter has been endorsed by OSD ManTech Director 29 June 2010
- Held multiple workshop/summits with SME from all services, NIST, NASA, USCG, Industry, Academia participants. The last meeting was in July 2011 with next meeting on 14-15 Dec.2011.

Leverage Between DMTP, AME Subpanel & EDMWG



Scope and Objectives

I. Scope:

DoD Engineering Drawing and Modeling Working Group (DEDMWG) is chartered to lead efforts for technical coordination and policy guidance on weapon systems technical data for acquisition, product design, analysis, simulation, manufacturing, provisioning and other product lifecycle management functions within a Model Based Enterprise (MBE). This includes offering guidance on technical data requirements for computer-aided design, engineering, manufacturing, data repository, data archival/retrieval tools, and related applications for total product lifecycle management.

II. Goals & Objectives:

Establish a group of respected subject matter experts (SMEs) across the DoD technical acquisition communities.

Work with DoD organizations to establish requirements for acquisition defined in the scope.

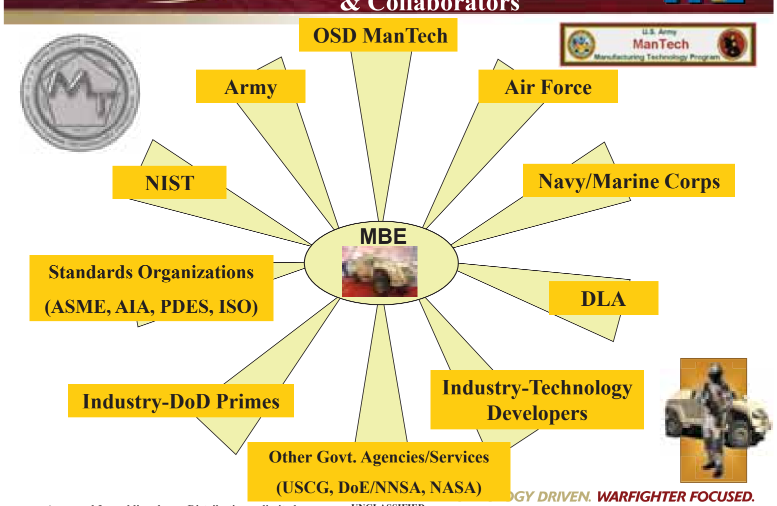
Investigate state of the art tools and technologies.

Revise current DoD specifications, standards, handbooks and other documents to incorporate requirements and guidance for (acquisition and management of) state-of-the-art model-based technical data.

Partner with government and non-government organizations that develop specifications and standards that are suitable for DoD Acquisition Programs to ensure DoD requirements are being met.

Work with domestic and international partners to access technology and tools to allow the DoD community to effectively perform life cycle support activities related to technical data, and define the terminology and definitions for this activity.

MBE/TDP Team Members & Collaborators



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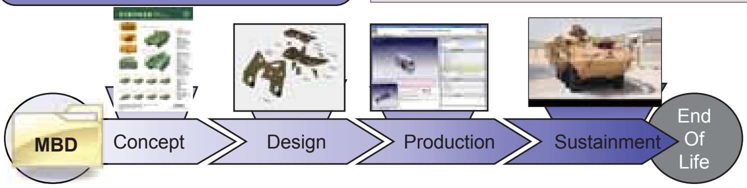
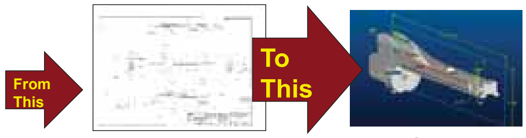
Model Base Definition (MBD) Model Base Enterprise (MBE)

The Model Based Definition (MBD) is created at the beginning of the lifecycle then reused throughout the enterprise, thus creating the Model Based Enterprise (MBE)

MBE is an integrated and collaborative environment, founded on 3D product definition (MBD) shared across the enterprise, enabling rapid, seamless, and affordable deployment of products from concept to disposal. a





To Improve how we sustain our weapon platforms thru MBD/MBE

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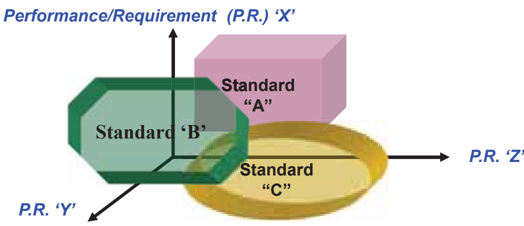
One Standards the Only Solutions?

Standards by themselves are not sufficient, but guidance/policy are required for implementation



- How do we determine which is the Applicable Standards based on the mission/requirements/performance to put on contracts?
  - Most often not one fits but several from various government/industry/associations, so how do we choose them correctly?
  - As technologies changes standards are usually lagging, how do we link them and speed up development to keep pace, but without overburden our acquisition personnel?

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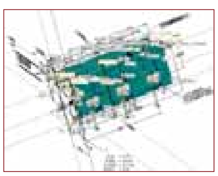
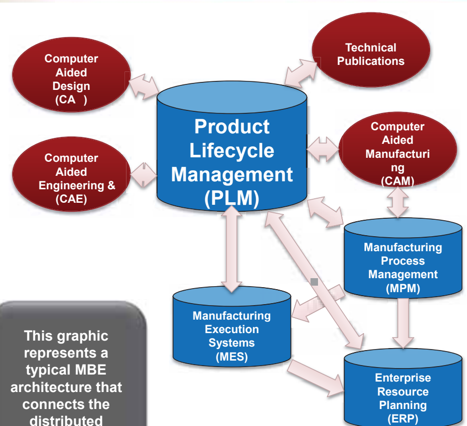
Example of Challenges:

In order to effectively use MBD,CAD file organization methods are required.



CAD File Fur ball

MBD Schema applied to "Tame" the Fur ball



This graphic represents a typical MBE architecture that connects the distributed enterprise

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ISO 10303 AP 242 Harmonization

- AP203, Configuration controlled 3D designs of mechanical parts and assemblies.
  - AP203 applies to representations of mechanical parts and assemblies.
  - AP203 files typically contains the boundary representation model, assembly data, and a limited amount of other product information.
- AP214, Core data for automotive mechanical design processes
  - AP214 applies to representations of data relating to automotive design.
  - AP214 files typically contain colors, layers, and generic resources.
- AP242, Managed model based 3D engineering (under development)
  - New AP combining AP203 and AP214
  - The objective is to develop a common application protocol for the automobile and aerospace industry.
  - Bundling the activities allows reacting faster industrial requirements.
  - Allow for integrating technologies like UML (Unified Modeling Language) and XML (Extensible Markup Language)
  - Lowers the costs for standard maintenance.
  - Envisioned to become the backbone for data exchange, data-sharing, visualization, and long-term archiving.

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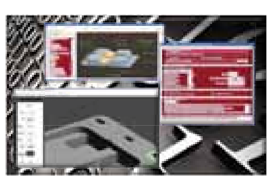
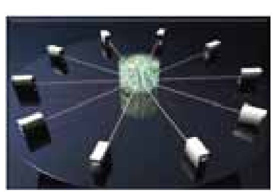
Current & Recent Army OSD ManTech Projects

- 3D Tech Data Package (TDP) Definition
  - Revision of MIL-STD-31000
  - Influencing other standards
  - Defining processes
- 3D Validation
  - Defining a certified 3D Model
  - Validation processes for the Model and the TDP
- Supply Chain
  - MBD Summits to raise MBE Literacy
- Reuse of 3D TDP in Techpubs
  - Influencing Standards
  - Proof of concept





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Accomplishments to Date

- Converted and updated MIL-DTL-31000C to MIL-STD-31000 (Nov. 2009)
- Held multiple workshops at NIST where over 60 SMEs participated in revision to MIL-STD-31000
- In process to seek to reactivate MIL-STD-973 Configuration Management
- Close coordination with ASME Y14.41 and AIA NAS3500
- Joined PDES Inc. to collaborate in various STEP AP development and to monitor LOTAR.
- Coordinating with NIST, NASA, USCG and DoE
- Refining annotations and delivery schemas, and validation guidebook into MIL-STD-31000
- Next MBE/TDP Summit will be held 12-15 Dec. 2011 at NIST

DEDMWG Workspace

https://acc.dau.mil/dedmwg

Summary & Gaps

- & The DoD has made a commitment to adopting MBE
- The team has made great progress towards creating a standard 3D TDP process, and demos.
- A process for validating 3D TDP quality is nearing completion of phase I
- We are committed to raising the MBE literacy throughout the supply chain and the DoD
- Still a long road to fully implement MBE and adoption within DoD

BACK UP SLIDES

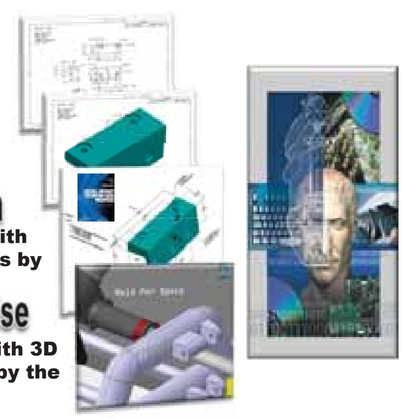
The Journey

Drawing Based
Master 2D Drawing

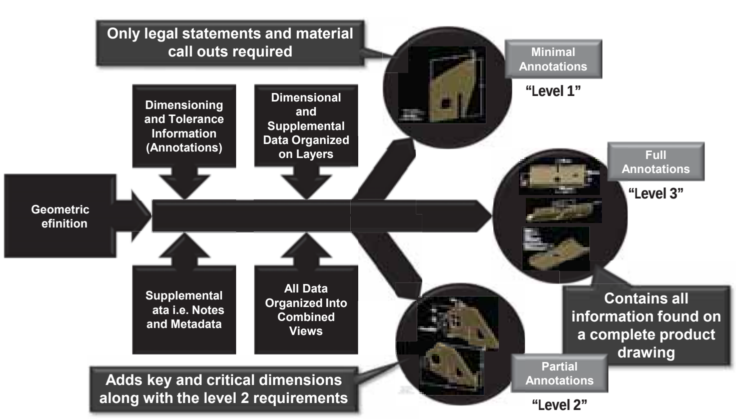
Model Centric
3D CAD Model with Master 2D Drawing

Model Based Definition
Master 3D CAD Model with 3D Drawing, 2D Drawings by exception

Model Based Enterprise
Master 3D CAD Model with 3D Drawing fully leveraged by the Supply Chain

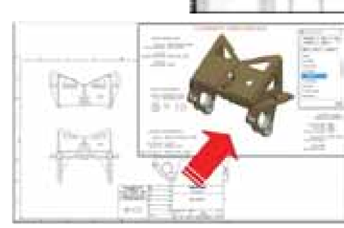


The Framework



The Purpose of the Schema

- In order for all the downstream users to consume the annotated model in place of a drawing it must be organized in a consistent and intuitive manner
- The Annotation Schema provides this consistency
- & Also, it enables much of the information to be programmatically extracted



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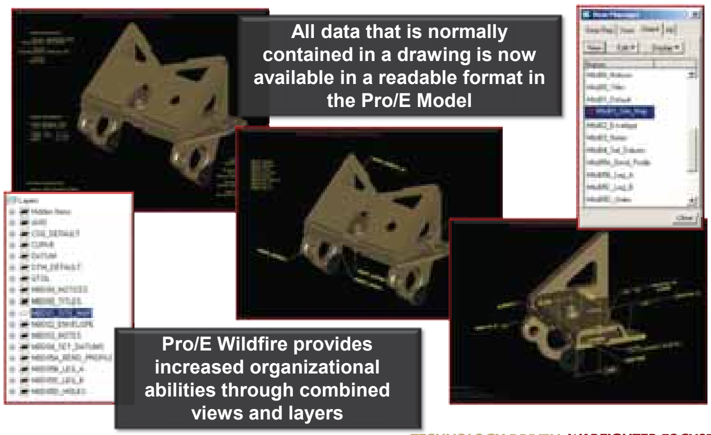
Annotated Models



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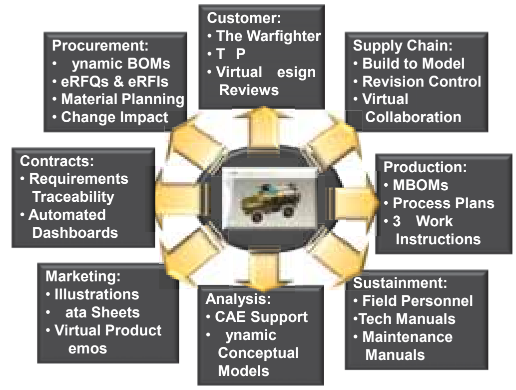
Why Are We Doing This?

The main purpose of the 3D TDP is to provide all Downstream users a 3D data set that they can reuse with out re mastering the data

For suppliers this means they will have the ability to drive their CAM software straight from the model along with numerous other process

All of this reduces the time to mission for the Warfighter



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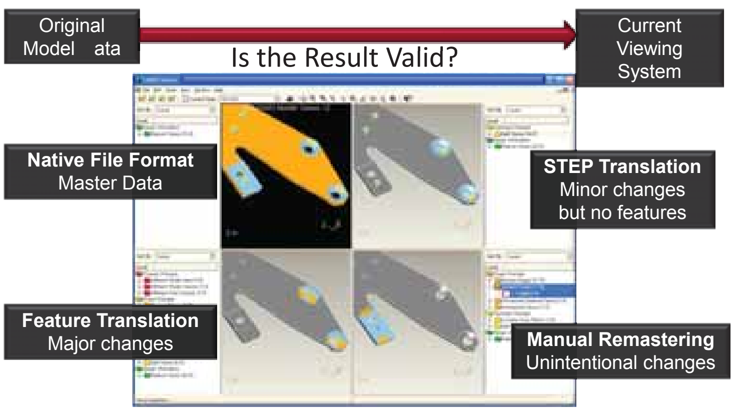
Translations Can be Validated



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Scope of Validation

Specialized Data
Geometry Graphics
Annotations (GD&T, PMI)
Model Structure
Model Attributes
Geometry Attributes
Wireframe Geometry
Solid & Surface Geometry
Metadata

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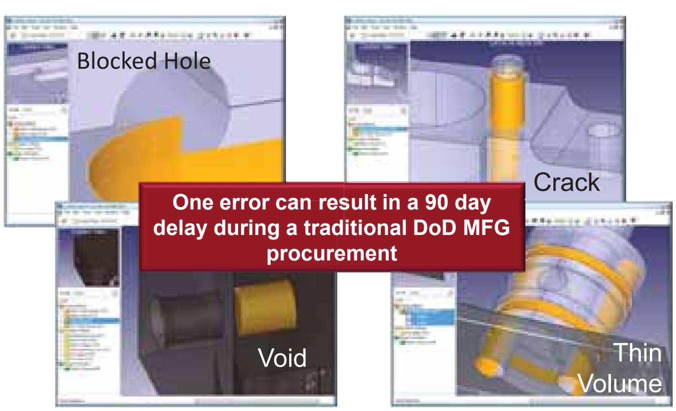
Examples of Bad Quality



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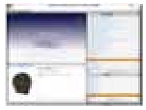
Supplier Summit

- Conducted 1st summit at DLA – DLIS Battlecreek, MI with over 80 attendees
- Conducted 2nd summit at Letterkenny Army Depot, PA with over 100 attendees
- Conducted 3rd summit at Huntsville, AL in coordination with NASA with over 80 attendees
- Consisted of a full day of technical and business presentations intended to raise their MBE literacy
- Participants completed a survey whose results will be used to modify the content of the next summit
- The surveys also indicated that the summits were a success by the attendees responses

MBE Focus Areas

- CAD Interoperability
  - Working with CAD providers and users to define and communicate translation requirements
  - Working with translation software providers to define and communicate requirements
  - Developing translation validation process
- Manufacturing Process Definition
  - Working closely with CAD/CAM providers to define and communicating requirements
  - Sub-contracting the develop of productivity scripts
  - Developing and deploying 3D interactive Work Instructions



MBD Focus Areas (Continued)

- Product Definition within the CAD model
  - Methods for organizing the PMI contained within the model (CAD Model Schema)
  - Developing requirements for enabling annotated models within the light weight viewers
  - PLM Schema for storing and delivering a 3D TDP

MBE Capability Index

Level 0	•Model Centric Drawings for Design and Manufacturing •Primary Deliverable: 2D Drawing
Level 1	•Model Based Manufacturing •Primary Deliverable: 2D Drawing and Neutral CAD Model
Level 2	•Native CAD Based Manufacturing •Primary Deliverable: 2D drawing and Native CAD Model
Level 3	•Model Based Definition •Primary Deliverable: 3D Annotated Model and Light Weight viewable
Level 4	•Model Based Definition With Data Management •Primary Deliverable: 3D Annotated Model and Light Weight viewable via PLM
Level 5	•Model Based Definition With Automated Technical Data Package •Primary Deliverable: Digital Product Definition Package and TDP
Level 6	•MBD With Automated TDP and On Demand Enterprise Access •Primary Deliverable: Digital Product Definition Package and TDP via the web

There is a comprehensive spreadsheet associated with the Index

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

engineering laboratory

Driving Manufacturing Technology Innovation Through Measurements and Standards

engineering laboratory

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

engineering laboratory

SMART MANUFACTURING PROCESSES AND EQUIPMENT PROGRAM

Alkan Donmez

engineering laboratory

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

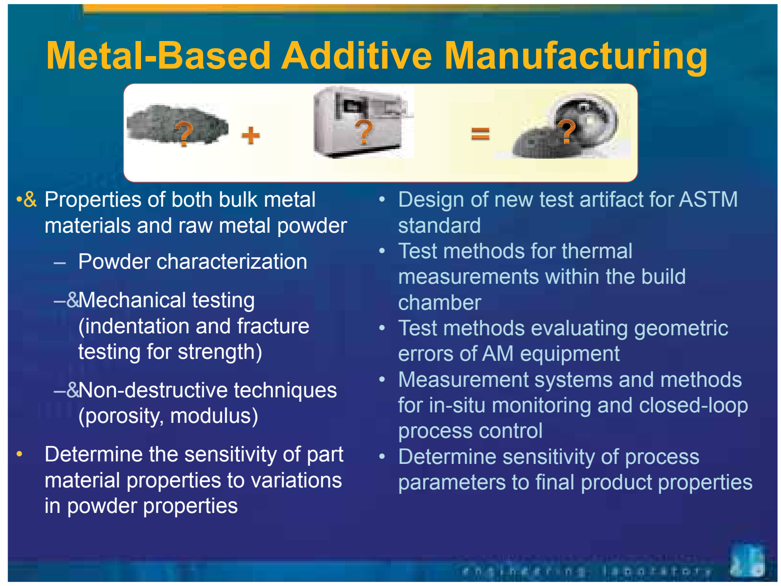
Smart machining - addressing the needs for rapidly turning new materials and designs into products by integrating modeling and simulation with real-time measurements to optimize processes and equipment

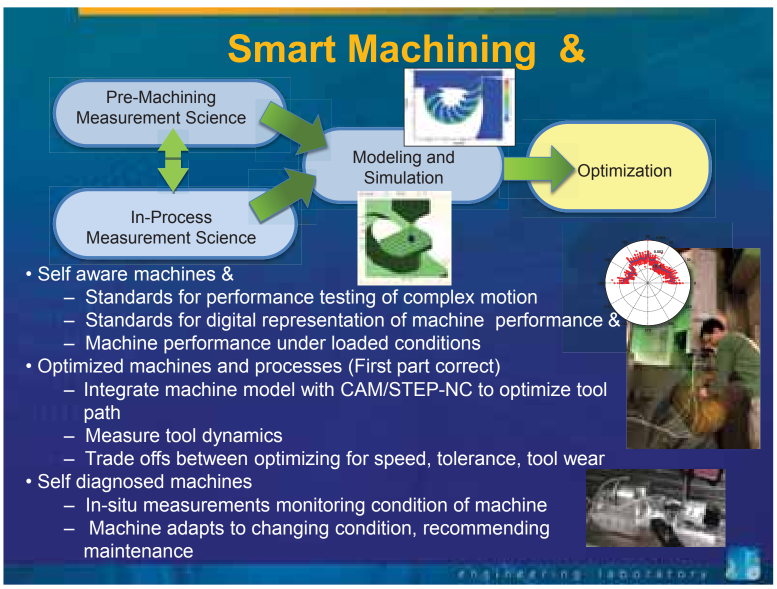
Micro- and nano-manufacturing - addressing the needs for improving the quality and yield of micro- and nano-scale products through new measurement methods for improved process control

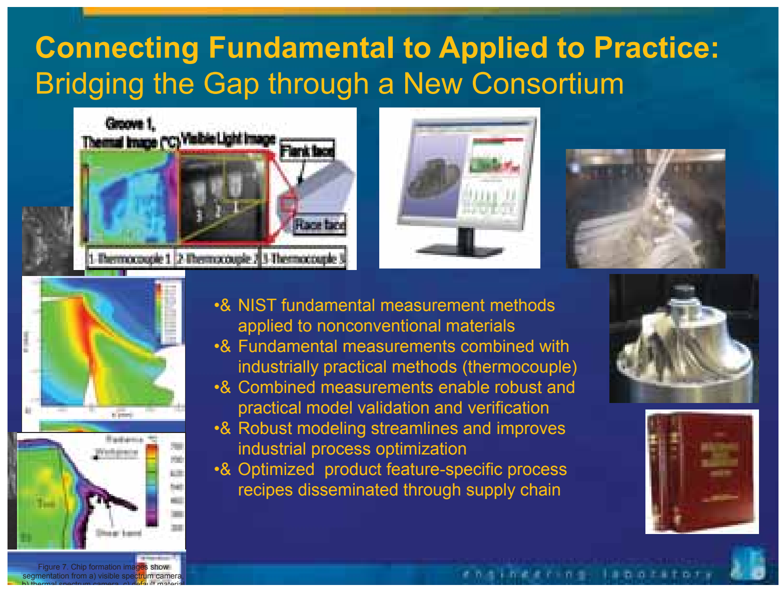
Contact: Alkan Donmez
alkan.donmez@nist.gov

engineering laboratory

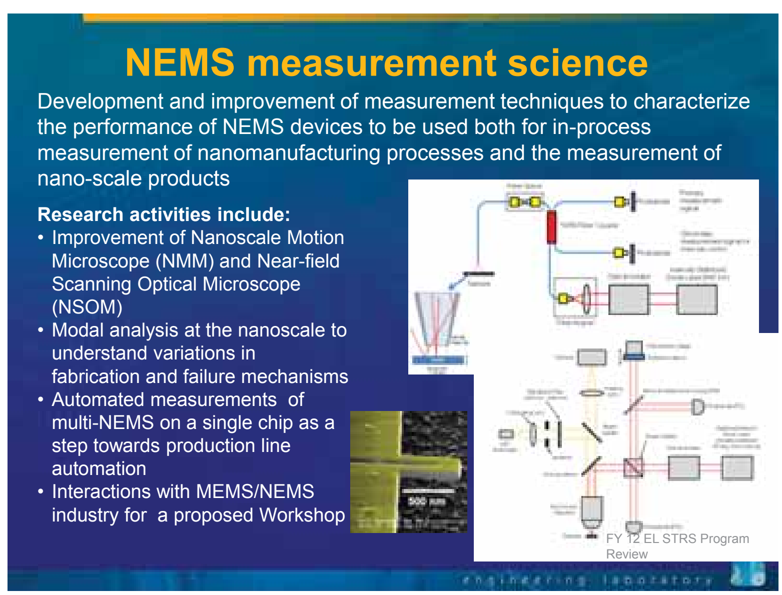

Metal-Based Additive Manufacturing
•& Rapid art-to-part capability of fabricating complex structures – revolutionary potential
•& Key barriers to the widespread adoption of metal-based additive processes:
–&part accuracy
–&surface finish
– material properties
– process certification
– process speed
– 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)
engineering laboratory


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
engineering laboratory


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
engineering laboratory


Connecting Fundamental to Applied to Practice:
Bridging the Gap through a New Consortium
Groove 1, Thermal Image (°C)
Visible Light Image
Flank face
Rake face
1-Thermocouple 1
2-Thermocouple 2
3-Thermocouple 3
•& 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
engineering laboratory


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
engineering laboratory


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
500 nm
FY 12 EL STRS Program Review
engineering laboratory

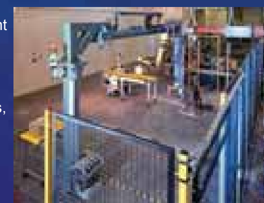
NEXT GENERATION ROBOTICS AND AUTOMATION PROGRAM

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

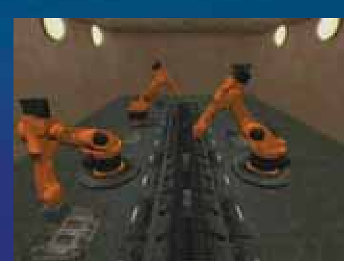
- Develop performance measures for dexterous manipulation
- Develop dynamic force measurements and force-based control of manipulation
- Develop collaborative manipulation strategies for safe human-robot or robot-robot operations
- Develop measurement methods and sensors for micro- and nano-scale objects
- 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

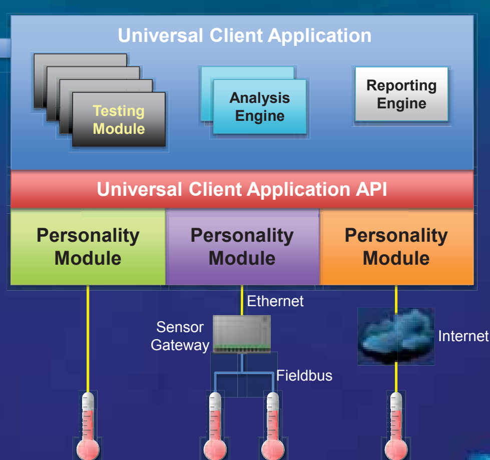
Smart Manufacturing Systems Program

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)

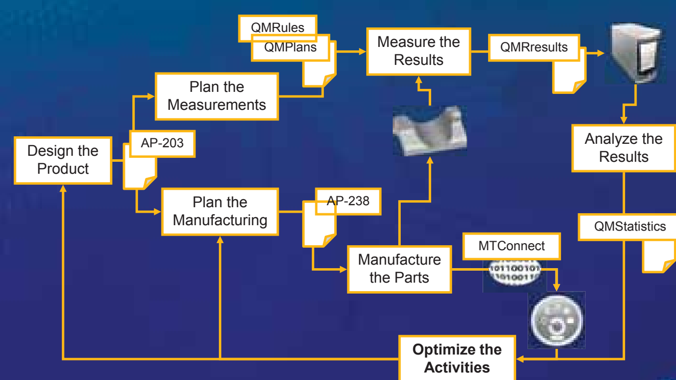
Factory Networks: Testing

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



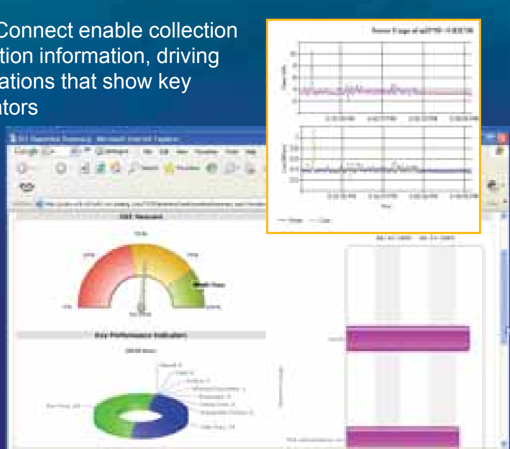
Information Modeling and Testing

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



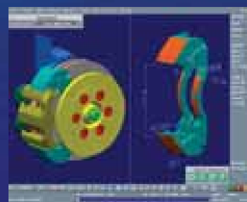
SYSTEMS INTEGRATION FOR MANUFACTURING AND CONSTRUCTION APPLICATIONS PROGRAM

Simon Frechette

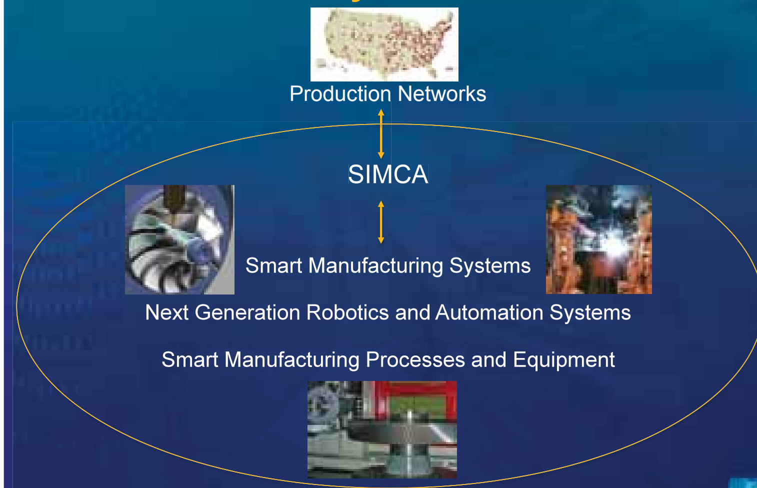
Systems Integration for Manufacturing and Construction Applications Program

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

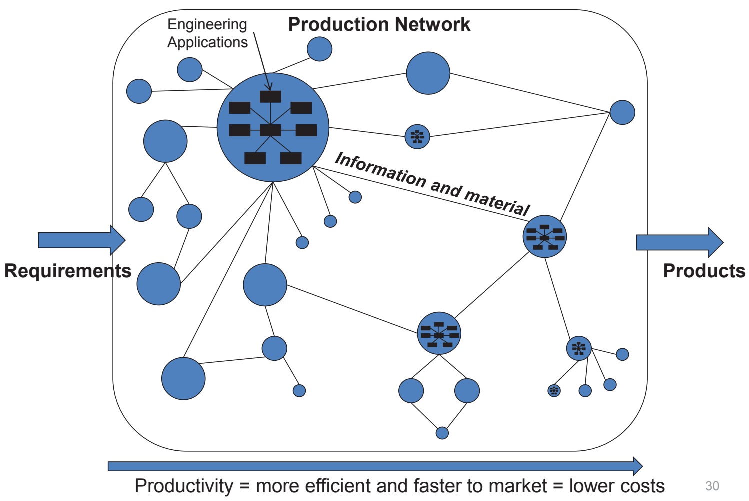
- **Engineering Systems Integration** – Enabling systems engineering standards that will reduce cycle time from product development to manufacturing
- **Production Network Integration** – Enabling network integration standards to improve efficiency and agility, and support new manufacturing services model
- **Production Network Data Quality** – Developing and testing standard methods for quantifying the quality of engineering and manufacturing data



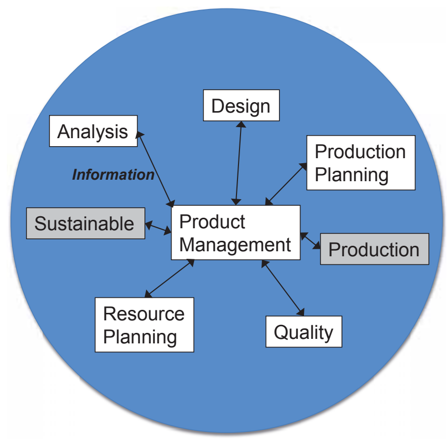
SIMCA is the Gateway to Production Networks



A Network of Enterprises



Production Network Enterprises Each have a Unique Set of Engineering Applications

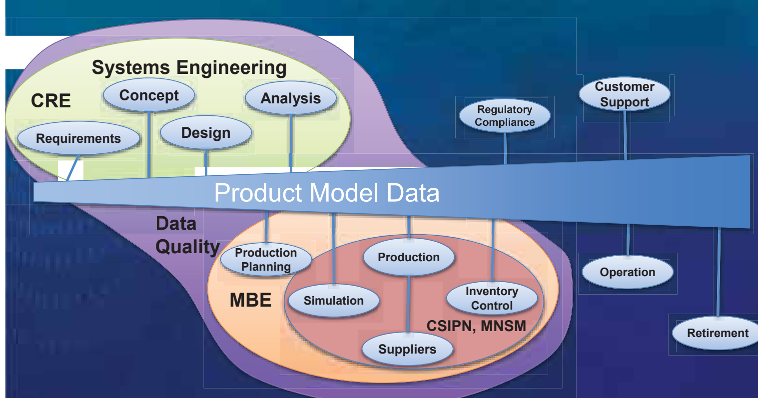


SIMCA Strategy

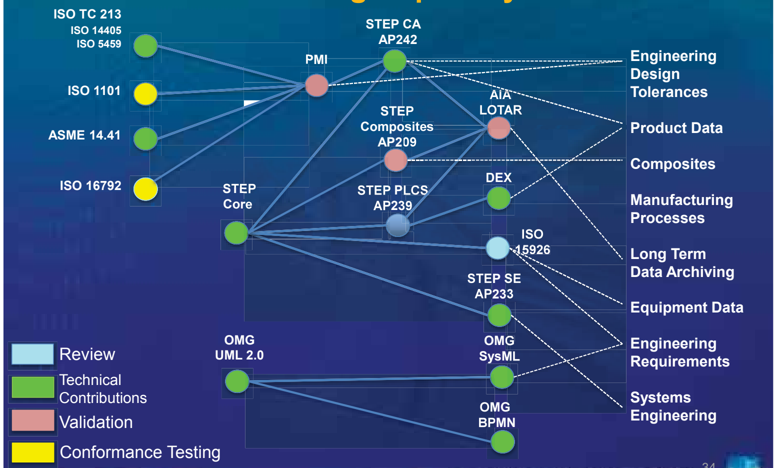
The SIMCA program addresses measurements and standards for

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

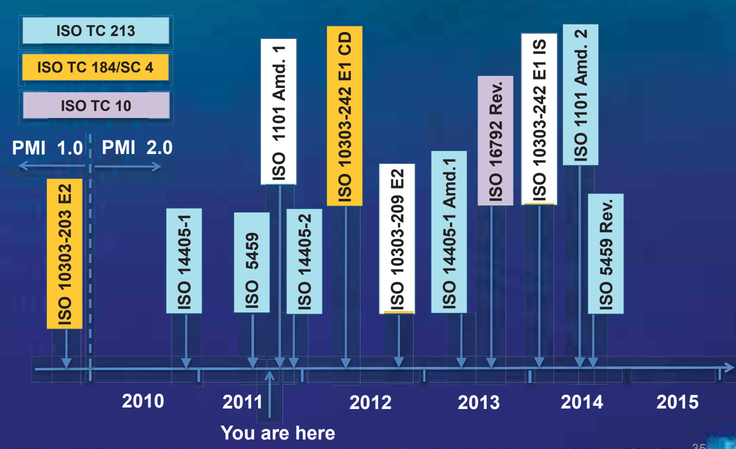
Seamless Access to Information Throughout the Product Lifecycle Greatly Improves Productivity



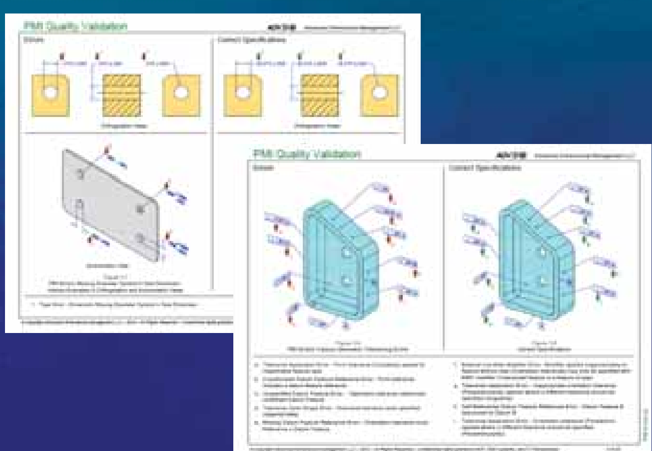
How do Standards Relate to Manufacturing Capability?



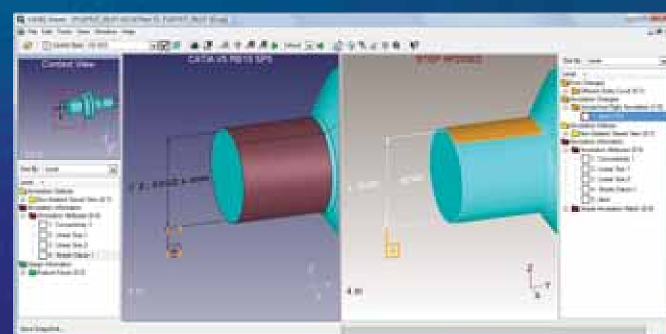
ISO PMI Standards Roadmap for CAD/CAM/PLM Software Vendors



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

NASA Integrated Model-Centric Architecture (NIMA) Concept

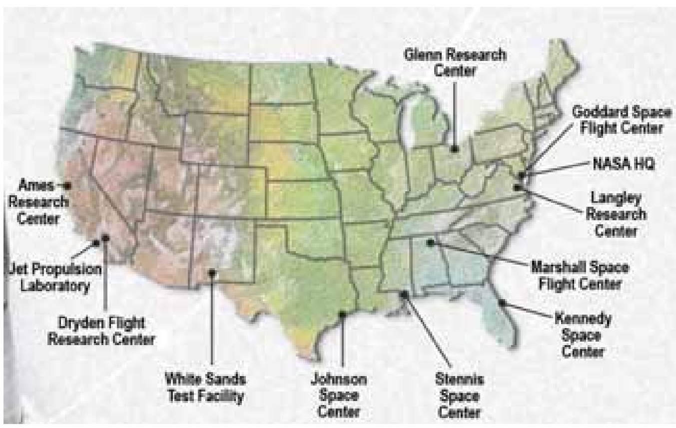
Presented at the Model Based Engineering (MBE) Summit at NIST

December 12th, 2011
Paul S. Gill

Contents

- NASA Overview
- Problem to be Solved
- Model-Centric effort
- Benefits
- Vision/Use Cases
  - Determining the effect/impact of a requirement change
  - Designing a system
  - Performing a review
  - Working a mission anomaly
- Goals
- Roadmap

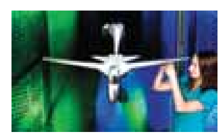
NASA Overview

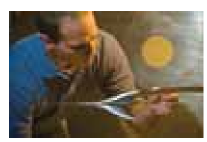


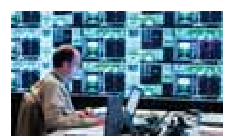
Variety of Missions

- **Aeronautics** – Pioneers and proves new flight technologies that improve our ability to explore and which have practical applications on Earth
  - Green aviation
  - Next Generation Air Transportation System (increasing safety and managing traffic congestion)


Test Flight of the blended wing body X-48B

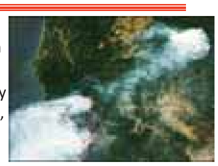

Subscale model wind tunnel testing

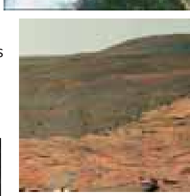

Supersonic jet concept

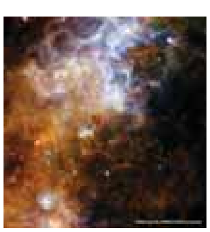

Researching ways to improve air traffic flow in NASA's Air Traffic Operations Lab

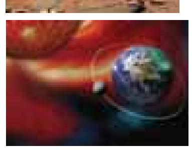
Variety of Missions (Cont'd)

- **Science** – Explores the Earth, solar system and universe beyond; charts the best route of discovery; and reaps the benefits of Earth and space exploration for society
  - Earth: Weather, Carbon Cycle & Ecosystems, Water & Energy Cycles, Climate Variability & Change, Earth Surface & Interior, Atmospheric Composition
  - Heliophysics: Heliosphere, magnetospheres, Space Environment
  - Planets: Inner Solar System, Outer Solar System, Small Bodies
  - Astrophysics: Stars, Galaxies, black holes, the big bang, dark energy, dark matter, planets around other suns



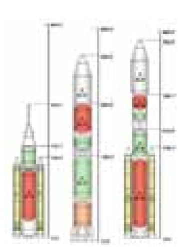






Variety of Missions (Cont'd)

- **Human Exploration and Operations** – Focuses on International Space Station operations and human exploration beyond low Earth orbit
  - ISS
  - Multi-Purpose Crewed Vehicle (Orion)
  - Space Launch System
  - 21st Century Ground Operations



Problem to be Solved

•&Looking at our past experiences, our technical, cost and schedule performance needs to be enhanced in order to accomplish our future plans
•&Some of the problems to be solved are:
  •&Lack of affordability of projects and activities
  •&Mission complexity is growing faster than our ability to manage it
  •&Not identifying design or integration problems until late in lifecycle
  •&Having to Search for data or supporting material during mission anomaly resolutions
  •&Inability to share models in a collaborative environment
  •&Ineffective use of precious testing time and resources
  •&Too many design reviews that reviews documents vice the design
  •&System design emerges from the pieces, not from an architecture
  •&Use of unvalidated models in simulations leading to incorrect/invalid results
•&Moving to a more model-centric philosophy within the Agency will help resolve many of these issues

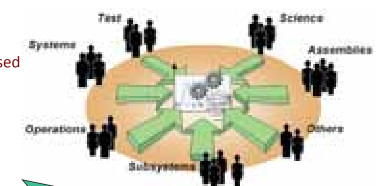
Model-Centric Concept

Goals &

•& **Goal 1:** Increase *affordability* through use of a model-centric architecture
•& **Goal 2:** Achieve *interoperability* within and among programs/projects, centers and external partners through use of a model-centric architecture
•& **Goal 3:** Inform/train invigorate *workforce* on model-centric architecture
•& **Goal 4:** Improve product *quality* and success through use of a model-centric architecture

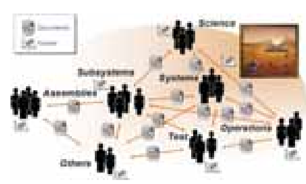
General Model-Centric Vision

Mission: Advance from our current document-centric engineering practice to one in which structural, behavioral, physics and simulation-based models representing the technical designs are integrated and evolve throughout the life-cycle, supporting trade studies, design verification and system V&V



Future: Reusable model-driven with integration & simulation capability

To do this we must provide:
- Modeling development environment and standards
- Reusable models repository
- Tool/model integration
- Training
- User community support
- Partnerships



Today: Document driven & standalone models

Use Throughout Lifecycle

•& Use of a model-centric enterprise system throughout the lifecycle of a product will greatly enhance its quality and affordability
  •& Work products will be built and matured seamlessly eliminating need to re-create them over the lifecycle
•& Example products are:

Pre-Phase A	Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
Concept Studies	Concept & Tech Dev.	Prelim. Design	Final Design & Fab	Assembly, test & Launch	Ops & Sustainment	Closeout
Conceptual Models Cost Estimation	Requirements Functional Flows	CAD designs Analysis Models Prototype test data Refined Costs	Refined CAD Refined Analysis Engineering Data Manufacturing	Integration Simulations Verification Certification	Operations Anomalies Simulations Science Data	Decommissioning Simulations Data Archiving Final Costs

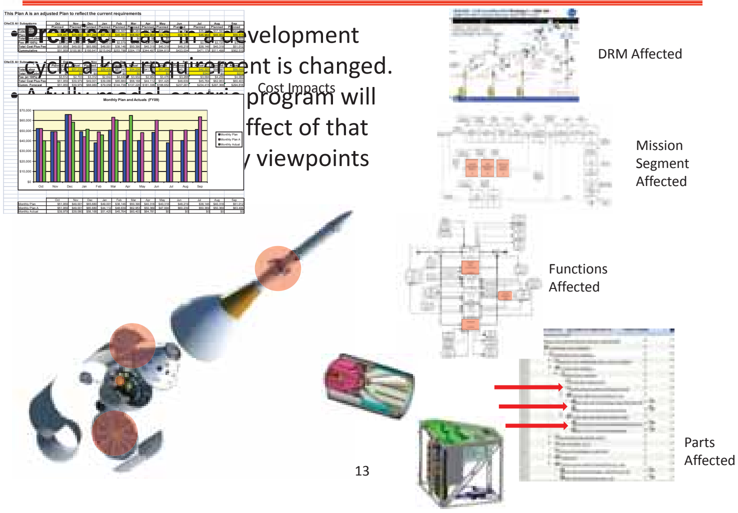
Enhances Sound Engineering Practices and Experience – Does Not Replace It!

Vision/Use Case Examples

- Determining the effect/impact of a requirement change
- Working a mission anomaly

Determining an Effect of a Requirement Change

- Premise: Late in a development cycle a key requirement is changed.
- A fully model-centric program will ... ffect of that ... viewpoints



Scenario 1: Generic In-Flight Anomaly

10 years ago we developed a Flagship Class spacecraft.

Nearing the end of a very long cruise mode, the vehicle must be configured for planetary arrival.

While coming out of cruise, the self-monitoring system on the CEU indicates a device on one processor card is not functioning properly.

Mission team has 12 hours to fix the problem prior to entering into orbit or the mission will be lost.

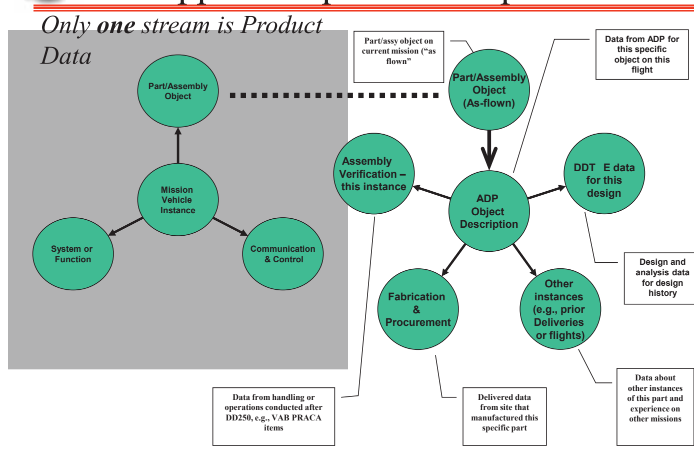
The Question at hand: What data will be needed, and how does a PM plan for it a decade or more beforehand?

IFA Data Needs < 4 hrs: Partial List

- ✓ As-designed/as-purchased/as-tested/as-built/as-flown product structure and definition
- ✓ Circuit card schematic
- ✓ Specifications (e.g., materials, acceptance testing)
- ✓ Where (else) used
- ✓ Location and status of spares
- ✓ Firmware, software, parameters
- ✓ Circuit card testing and failure history
- ✓ Impact analysis of failure (e.g., FMEA)
- ✓ Failure history of components in similar settings
- ✓ History of component/card/sub-system behavior over course of mission
- ✓ Trades/Design Rationale

ACCESS to the Right data by the Right People at the Right Time is the desired end state.

IFA Support Requires Multiple Streams



Notional Model for Multi-path Product Data Streams

Scenario 2: Development Data Deluge

We are seeing some very large amounts of data created during Design Testing

- ✓ Scale of product, types of analysis testing, procurement strategy affect this
- ✓ But no project or product is immune

Illustrative Cases from Constellation Program (CxP)

- ✓ Core Input for Analysis: Outer Mold Line
- ✓ Analysis, Testing & Simulation Data Deluge
- ✓ Sample Documents CAD Models: Ares & Orion at PDR

*** Documents: Ares 1 PDR reviewed ~500 documents and two drawings with ~38,000 documents in Ares ICE Windchill Project Folders**

CAD: 16 months later at Orion PDR, LMSSC delivered ~11,000 discrete 3D models for Service Module, Crew Module, Launch Abort System (with ~250,000 versions, iterations, or variants in LMSSC's Windchill vault)

** - Does not include the material at any primes or on local vaults or servers at the centers.*

&

"How Big is the Problem"?" (Life Cycle Data Management Challenge)

The amount, type, and fidelity of the data generated and requiring storage and access increases over the program life cycle. The scale and complexity of the storage and retrieval system will need to respond to these challenges.

 Source: CxP ISO Office

How do we establish a Model Centric Environment and Culture?

Communities of Practice

- This effort is primarily the integration and expansion of the work already being performed separately in the following Communities of Practice (CoP):
  - Model-Based Systems Engineering (MBSE)
  - Product Data and Lifecycle Management (PDLM)
  - Models and Simulation (M&S)
  - Computer Aided Design (CAD)
    - Mechanical CAD
    - Electrical CAD
- The tools and methodologies are being employed by these CoPs in support of existing and future Project and Programs
- By having a common vision we will be able to coordinate and enhance this work in a more effective way, learning and leveraging off each others discoveries and insights

Teams

•& **Team 1: Benchmarking** – this team will be doing benchmarking trips and research. Trips will be to external organizations such as Boeing, LM, ATK, Whirlpool, etc. and will also be internal to other NASA centers. Also included are web and literature searches to determine the real value of moving an organization to a model-centric basis.

•& **Team 2: Foundations** – this team will look at the basics needed for this effort – framework, data integrity, reuse of models, etc.

•& **Team 3: Current Architecture** – this team will identify the current existing architectures at each of the centers and its readiness to handle moving to a model-centric culture. Includes identification of any issues and gaps with the current IT structure.

•& **Team 4: ConOps** – this team will work on a more detailed Concept of Operations depicting how we would use a model-centric architecture, use cases, examples, etc.

•& **Team 5: Communications Plan** – this team will identify who are our stakeholders, what are their expectations and how will we need to communicate with them to ensure the success of moving to a model-centric culture.

•& **Team 6: Pilots** – this team will identify the work that is currently being performed at each of the centers and determine if there are additional pilots that need to be initiated in FY12 in order to move a area forward in accomplishing the model-centric architecture

•& **Team 7: Workforce Capabilities** – this team will look at what capabilities/skills will be needed to accomplish a model-centric culture, what capabilities/skills we already have, determine capability/skill gaps and develop a training plan for closing that gap.

&

Multi-Year Roadmap

Phase 1: Preparation	Phase II: Implementation	Phase III: Sustaining/Improving
Key Activities: • Establish a common vision • Establish an integrated governance structure • Develop a Strategic Plan with Needs, Goals and Objectives • Develop a detailed roadmap/Implementation Plan • Establish a model-centric friendly infrastructure that facilitates collaborative activities • Perform piloted capabilities for key areas • Identify and develop initial standards, policies and processes • Develop a cadre of trained users • Develop User's guides and handbooks • Establish an initial CM controlled model repository	**Key Activities**: • Incrementally bring on more capabilities per Implementation Plan • Develop/update standards, policies and processes as new capabilities are brought on-line • Establish a standard suite of modeling tools and methodologies • Populate the CM controlled repository with validated reusable models created from formulation to implementation • Train at all levels – users, managers, executives • Identify what's not working and fix it • Identify what is working and duplicate it	**Key Capabilities**: • A fully operational model-centric Infrastructure that enables integration of physical models with domain discipline analytical models, simulations and cost models to support activities throughout lifecycle from concept through disposal • A matured model-based development methodology and standards with training support • A fully CM controlled operational model repositories that collaboratively managed by projects, lines and Institution • Models as well as processes/methodologies are continuously improved and updates as more experience is gained

Continuous Practice

FY11 → FY18

Benefits

- Moving to a model-centric culture will provide NASA many benefits
  - Enhanced affordability
  - Increased ability for collaboration
  - Identification of problems earlier
  - Quicker and more accurate diagnosis and resolution of mission anomalies
  - More effective use of testing resources
  - Better cost estimation and control
  - Better, more effective design reviews
  - Quicker understanding of cost, schedule and technical impacts of requirement or design changes
  - Enhanced ability to do systems engineering
  - Quicker and more accurate analysis/simulations

In Closing

NASA Programs face <u>non-trivial</u> challenges re: Product data

✓ Distributed, production & use over extended life span

✓ Mixture of internal and external sources – Centers, primes, academia; NASA cannot control how things are done

✓ Need access to PRE-RELEASE product data
  - ✓ Early decision support
  - ✓ High analysis demands, high volumes of ancillary data &

✓ Long project life cycles

✓ Need for IFA reach-back

✓ Need a flexible solution within NASA due to project diversity

December 2011

AFFORDABLE READINESS THROUGH MODEL BASED ENTERPRISE (MBE)

Agenda

- CG Introduction
- CG Definition of Logistics
- Vision Concept of Operations
- Scope
- Approach
- Deliverables
- Risks Discussion

INTRODUCTION

- One of the 5 Armed Forces
- Only Military Org w/in DHS
- Guardian of our Nations Maritime Interest Environment around the World since 1790
  - Broad legal authorities
- USCG impact: LOCAL, REGIONAL, NATIONAL INTERNATIONAL

WORKFORCE TOTALS	
Enlisted	33,200
Officers	8,398
Civilians	8,342
Sub Total	**49,940**
Reserves	7,997
Sub Total	**57,937**
Auxiliary	31,419
TOTAL	**89,356**

9 DISTRICTS

35 SECTORS

1208 UNITS

195 AIRCRAFT

247 CUTTERS

1784 BOATS

AVERAGE COAST GUARD DAY

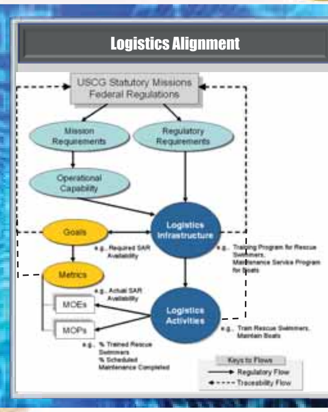
- Saves 12 Lives
- 64 Search Rescue Responses
- 842 lbs. of Cocaine kept off the streets
- Services 116 bouys
- Screens 720 commercial Vessels & 183,000 Crew
- Issues 173 credentials to Merchant Mariners
- Investigates 13 Marine Accidents
- Inspects 68 Containers
- Inspects 29 Vessels for air emissions standards Compliance
- Performs 28 Safety Environmental Exams of Foreign Vessels
- Boards 13 fishing boats ~ fisheries law compliance
- Responds/Investigates 10 pollution incidents

USCG Definition of Logistics

Coast Guard Logistics

- *"all the activities associated with developing, acquiring, sustaining, and eventually retiring the components of capability, including people, systems and information"*
- Logistics performs most Coast Guard activities outside those carried out by:
  - Operations, who perform the USCG's direct missions, and
  - The Commandant and his staff, who provide organizational governance

Logistics Alignment

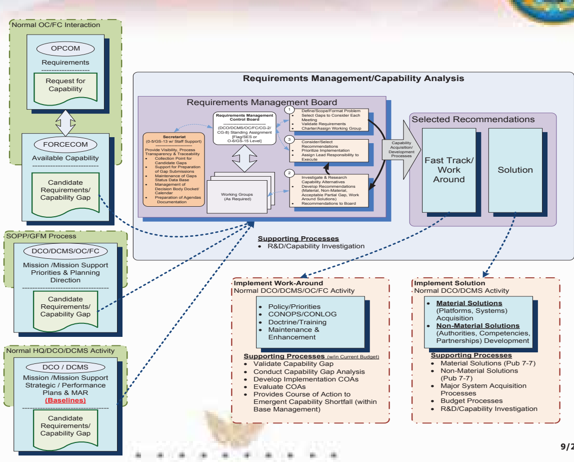


Composite Requirements Management/Capability Analysis Process

- Request for Forces/Capability
- Resource Allocation
- Platform Scheduling
- Readiness/ Standardization Assessments
- After Action Reports/ Patrol Summaries
- OPARs
- CASREPs/MISHAPS
- Lessons Learned
- Field Unit Requests/Studies
- R&D/Capability Investigation

- Commander's Planning Assessment (CPA)
- Strategic Planning Direction (SPD)/Operational Planning Direction (OPD)
- Operational Planning Assessment Reports (OPAR)
- R&D/Capability Investigation

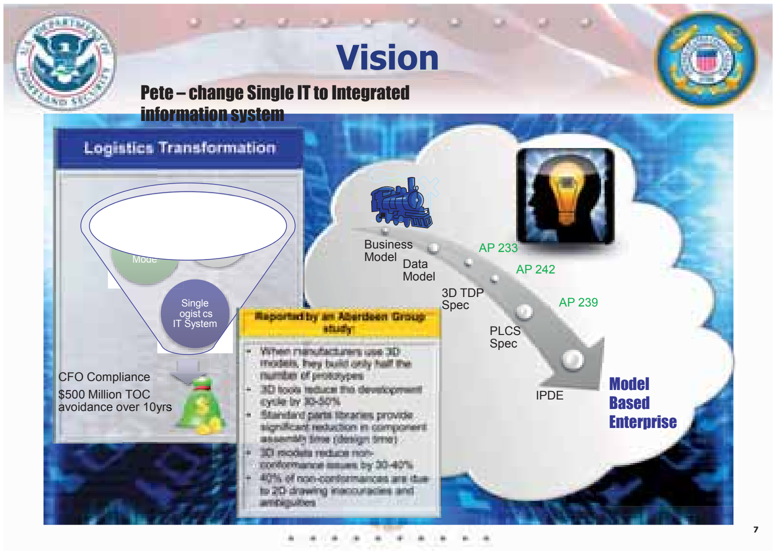
- External Mandates
- QHSR/QDR
- Evergreen
- Strategy
- Mission/ Mission Support Analysis
- Strategic Plans
- Performance Plans
- Policy
- Investment Plans
- Budget Development
- GAO/OMB Reports
- NTSB/MISHAPS
- R&D/Capability Investigation

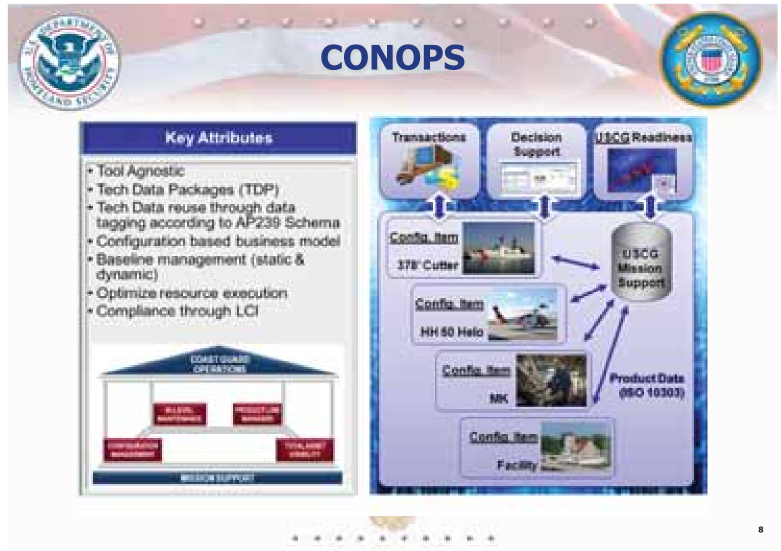


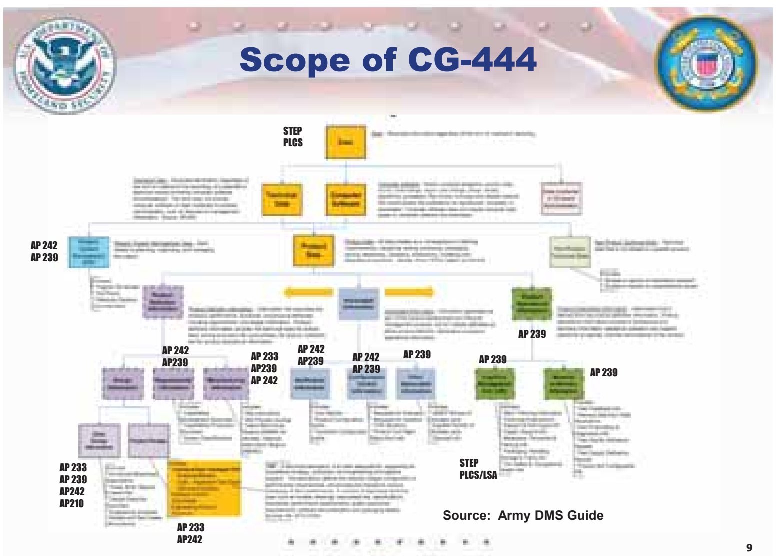
Vision

Program Objectives

- Affordable Readiness
- Spiral MBE implementation
- Standardize CG processes across domains
- Implement integrated modular architecture
- Implement Configuration Based Business Model for: Air, Naval, Facilities, C4ISR Communities
- Baseline Management **


Vision
Pete – change Single IT to Integrated information system
Logistics Transformation
Single ogist cs IT System
CFO Compliance
$500 Million TOC avoidance over 10yrs
Business Model
Data Model
3D TDP Spec
PLCS Spec
IPDE
AP 233
AP 242
AP 239
Model Based Enterprise
Reported by an Aberdeen Group study:
When manufacturers use 3D models, they build only half the number of prototypes
3D tools reduce the development cycle by 30-50%
Standard parts libraries provide significant reduction in component assembly time (design time)
3D models reduce non-conformance issues by 30-40%
40% of non-conformances are due to 2D drawing inaccuracies and ambiguities
7


CONOPS
Key Attributes
Tool Agnostic
Tech Data Packages (TDP)
Tech Data reuse through data tagging according to AP239 Schema
Configuration based business model
Baseline management (static & dynamic)
Optimize resource execution
Compliance through LCI
COAST GUARD OPERATIONS
MISSION SUPPORT
Transactions
Decision Support
USCG Readiness
Config. Item
378' Cutter
Config. Item
HH 60 Helo
Config. Item
MK
Config. Item
Facility
USCG Mission Support
Product Data (ISO 10303)
8


Scope of CG-444
STEP PLCS
AP 242
AP 239
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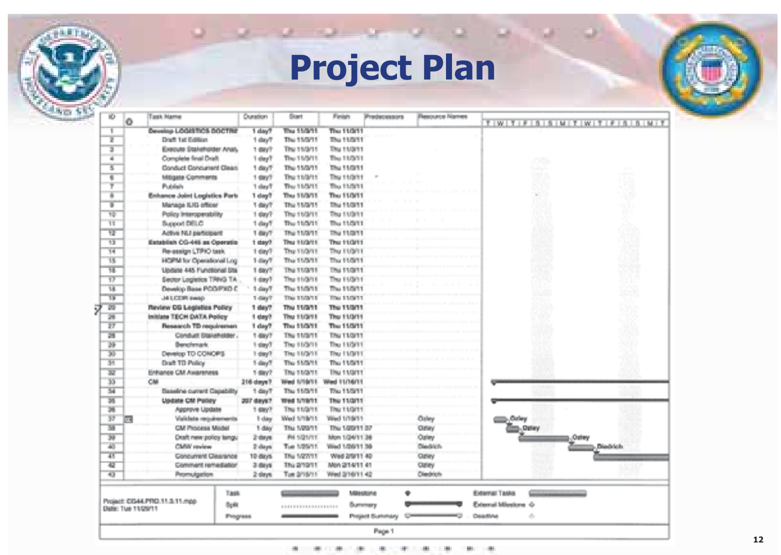
AP 233
AP 239
AP242
AP210
AP 233
AP242
STEP PLCS/LSA
Source: Army DMS Guide
9


Approach
CG-444 Strategic Capability Development Roadmap
2011
2012
2013+
10


Approach
CG-444 Strategic Capability Development Roadmap
2011
2012
2013+
11


Project Plan
Task Name
Duration
Start
Finish
Predecessors
Resource Names
Page 1
12

Deliverables

Deliverable	Status	Expected Completion
Standardized Business Model	80%	Continuous
CM & TD Capacity & Capability Baseline •Processes, Tools, Systems, Training	100%	2014
TD Tailoring Guide • Contract Spec • CDRLs / DIDs	75%	2012
Benchmarking • OGA and Industry	75%	2012
Gap Analysis	75%	2012
Strategy • ISO 10303 Business Case	35%	2012
Step Implementation Planning •Policy, PG, Spec, CDRL, DID, IT Req, Data Migration Protocol	50%	2012
STEP Pilots •DLA 3D TDP survey •NAVSEA Config Log STEP data exchange	Ongoing	Ongoing
IPDE Requirements	10%	2012

USCG CM/PDM CAPABILITIES CAPACITIES BASELINE ANALYSI

- **Methodology: Conduct an independent assessment of existing CM and PDM capabilities (Aviation, Surface, Shore, and C4I Communities)**
  - Assessment covered: Policy, Spec & Standards, Tool s & Capabilities, Processes, and Training, Staffing, & Resources
  - Baseline established
- **What's Working :**
  - Configuration Planning and Control
  - MPC/Technical Manual Development, Management, and Distribution
- **Efforts Underway to Resolve Gaps:**
  - Policies and Standards
    - Concise, Actionable, and Enforceable
    - Developing Framework for Product Data Life Cycle Management (PDLCM)
      - Data format/compatibility
      - Data Rights
      - Exchange Capability
      - Tailoring Guidance
  - Tools and Capabilities
    - IPDE CONOPS
    - IPDE Requirement Definition
    - IPDE Interface Control Documents

USCG CM/TDM CAPABILITIES CAPACITIES BASELINE ANALYSI

- CG LIMS
- Legacy Data Strategy
- Processes
  - Baseline Management
  - Communication
  - Metrics
    - Process and Data
    - Compliance
- Training, Staffing, and Resources
  - CM Certification Programs
  - CM Core Competencies
  - Competency Alignment within the Organization
  - PDM?
- **Approach**
  - Systems Engineering Approach for Business Model Development Management
  - Leverage Government and Industry Best Practices
  - Benchmarking Opportunities with Government and Industry

USCG CM/TDM CAPABILITIES CAPACITIES BASELINE ANALYSI

- **Our Methodology: Conduct an independent assessment of existing CM and TDM policies, processes, tools, and infrastructure capabilities in the CG Aviation, Surface, Shore, and C4I Communities**
  - Assessment covered 4 major areas: Acquisition Policies and Standards, Tool Capabilities, Processes, and Training, Staffing, & Resources
  - Baseline established through interviews with CG SMEs
- **What's Working :**
  - Configuration Planning and Control
  - Technical Manual Development, Management, and Distribution
- **Efforts Underway to Resolve Gaps:**
  - Acquisition Policies and Standards
    - Writing CG Policy and Process Guide to be more Concise, Actionable, and Enforceable
    - Developing Framework for Product Data Life Cycle Management (LCM)
      - Data format/compatibility
      - Data Rights
      - Exchange Capability
      - Tailoring Guidance
  - Tools and Capabilities
    - IT LCM Infrastructure CONOPS
    - IPDE Requirement

USCG CM/TDM CAPABILITIES CAPACITIES BASELINE ANALYSI

- CG LIMS
- Legacy Data Strategy
- Processes
  - Baseline Management
  - Communication
  - Metrics
    - Process and Data
    - Compliance
- Training, Staffing, and Resources
  - CM Certification Programs
  - CM Core Competencies
  - Competency Alignment within the Organization
  - TDM?
- **Approach**
  - Taking a Systems Engineering Approach for Management of Enterprise Capability
  - Leveraging Government and Industry Best Practices
  - Discussing Benchmarking Opportunities with Government and Industry
    - CG more aligned to Industry with regard to our desires to execute Configuration and Technical Data Management

Risks

- **No comprehensive STEP pilot**
  - No Proven Spec
- **Limited STEP expertise**
- **Competing Standards**
- **Organic Ability to Sustain**
- **Process Independence**
- **Data Schema Interface Control**
- **Revisions to APs make end-state a moving target**
- **Funding constraints**
- **Complexity and coordination of efforts government wide**
- **Benchmarking with Industry and OGAs**

CG-LIMS
CDMD-OA VLS
TMAPS MEARS
CMIS TDMIS
NE-TIMS ALMIS
Powerlog-J DOORS

MIL-STD 973 EIA 649
DEDMWG Acquisition Workforce (AWF) WG CG CM WG GEIA-STD-0007
CG Requirements Management WG Lifecycle Logistics WG PDRD
MIL-STD 31000 RACER / NSERC CG TDM WG CG SDLC WG RRPB

Model-Based Engineering/Manufacturing Review from the Y-12 National Security Complex

MBE/TDP Summit
December 12, 2011

Donna F. Bennett
Manager, Engineering Analysis Technology Engineering
B&W Y-12

Overview

- **Introduce the Y-12 National Security Complex**
  - nearly 70 years of expertise in science and technology
- **Discuss the unique facilities, technology capabilities, knowledge and expertise that Y-12 offers,**
  - as part of the Nuclear Security Enterprise, for finding solutions to scientific and technological challenges
- **Describe Y-12 programs and partnerships**
  - providing a wide network of specialists with an array of knowledge and skills
- **Open the door to future collaborations**
  - working with federal agencies and others to advance science and technology to meet national and global needs

Who Are We?

- The Y-12 National Security Complex is a premier manufacturing facility dedicated to making our nation and our world a safer place
- Operated by B&W Y-12 for the National Nuclear Security Administration (NNSA), Y-12 plays a vital role in the Department of Energy's (DOE's) Nuclear Security Enterprise (NSE)

http://www.y12.doe.gov/

Uranium Center of Excellence
Located in Oak Ridge, Tennessee
More than 8,000 uniquely skilled, dedicated employees

Y-12—One Part of DOE's NNSA

Y-12 National Security Complex Missions

- Sustain a safe, secure and effective nuclear arsenal
- Processes highly enriched uranium for the U.S. nuclear Navy to propel nuclear submarines
- Prevent nuclear proliferation and nuclear terrorism
- Solve global security challenges





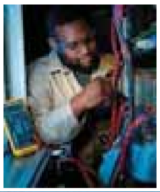
Y-12 Engineering

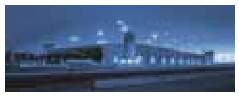
Engineering has 626 employees including 88 Development employees

Four Core Areas of Research and Development

•& Technology development, maturation and deployment activities at the Y-12 Complex focus on four core areas:

- Defense Programs
- Transformation
- Complementary Work
- Basic Science





Y-12 Model-Based Engineering

Y-12 effectively integrates model-based engineering and manufacturing

(MBE/M)

Model-based Engineering and Manufacturing (MBE/M)

•&Y-12 is modernizing the business of science-based stockpile stewardship by creating and using 3-D geometric models for

1. Defining the refurbished stockpile product
2. Supporting certification, and
3. Integrating design, engineering and manufacturing activities across the NSE

ORNL Topaz Detector Array Tank, TOPAZ DAT

Y-12 Effectively Integrates Model-Based Engineering/Manufacturing (MBE/M)

- MBE/M concepts are applied during
  - Design and analysis/simulation
  - Manufacturing
  - Inspection
  - Packaging
- Projects often involve hazardous materials
- Y-12 expertise ensures that MBE/M is applied **safely and securely**

MBE/M (cont.) &

•&MBE/M is used at various project stages
- Total life cycle
  - Life extension program (LEP)
  - Uranium Processing Facility (UPF)

•& Single phase of life cycle
- Conceptual design only
- Design only
- Manufacturing (fabrication/inspection)

•& Blend of several phases

MBE/M Technology Applied to Many Projects

- Packaging Engineering designs packaging for shipping/transporting nuclear materials

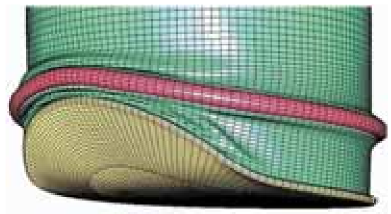
•&Life Extension Programs (LEPs)
- Full product life cycle
- Started MBE/M pilot project for NSE in FY 2002

- Integrated Glove Box System (IGBS) for dismantlement project installed FY 2010

- Uranium Processing Facility (UPF) ongoing

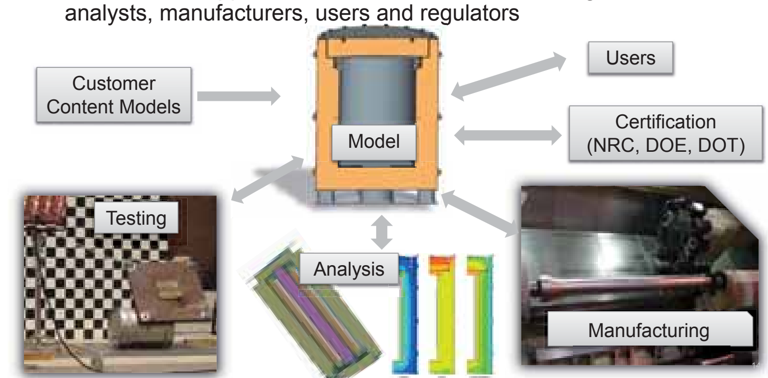
Packaging Engineering

- Long history of successful designs in a wide variety of containers and shipping packages
- Thermal and impact analysis experience and capability
- Complete support solution, including concept design, end-user support, maintenance and decommissioning
- Experience with certification of hazardous material packages in a strictly regulated environment



MBE/M Saves Packaging Engineering Time, Money

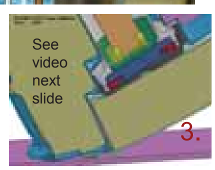
- Cradle-to-grave design authority over packages used on-site and worldwide
- Model-centric approach eases communication among customers, analysts, manufacturers, users and regulators



Packaging Engineering Using Virtual Testing

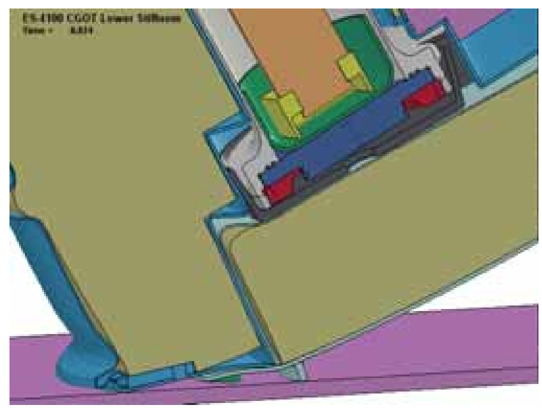
3-D Scan of ES-4100 Abnormal Surface Feature

1. 3-D scanner creates virtual model after physical testing—good for capturing data
2. Photo of item for comparison
3. Finite element analysis (FEA) used for virtual testing/refining design (creates prediction of item after testing)



Packaging Engineering Using Virtual Testing *(cont.)*

3-D Scan of ES-4100 Abnormal Surface Feature



Avoid Physical Testing: Use MBE for Virtual Testing

Cost of 6 prototypes in 2005	$150K
Regulatory drop testing on 6 units	$400K
Revision of safety analysis report (SAR) to add new test results	$ 25K
FEA engineering and SAR revision only	$ 40K

Cost difference…

$575,000 (drop test) vs $40,000 (MBE)

Life Extension Program—Pilot Project

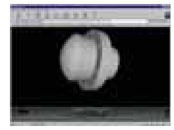
- MBE/M concepts were applied in all life cycles in this project
- Conducted first pilot MBE/M project between design agency and Y-12 starting in FY 2002
- Developed business rules around MBE/M needs and requirements
- Developed verification process for electronic Pro/Engineer model
- Embraced concept of trinity (drawing, model, pdf or tiff for legacy standard format)
- Conducted MBE/M workshop to help facilitate change of Y-12 culture

Life Extension Program—Pilot Project *(cont.)*

- Used Pro/E models in tooling design
- Completed process planning using work-in-process models
- Programmed numerical control (NC) machines directly from Pro/E model
- Used models for analysis and simulation at various stages
- Captured coordinate measuring machine (CMM) inspection data electronically for documentation for as-built models

Life Extension Program—Pilot Project *(cont.)*

- A process for verifying Pro/E models was deployed in FY 2002 and was used in FY 2003 for models-based product definition received from the design agency



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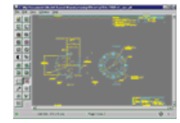
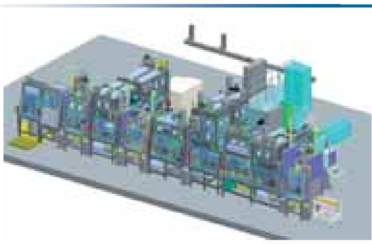


Model verification—a very important 1st step

- The process addresses
  - Geometric integrity and translatability
  - Standards compliance
  - Pro/E model and Pro/E drawing consistency
  - Design intent (in addition to normal design reviews
  - Policy and guidelines developed

Integrated Glove Box System (IGBS)

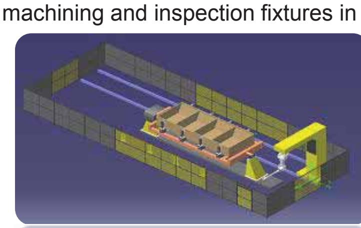


~ 50 feet long
~ 20 feet wide
~ 20 feet high

- Multiple glovebox zones with fully integrated environmentally interlocked system
  - hoists, one in each zone
  - fully integrated machine tools
  - ventilated hoods
  - drum transfer system

IGBS Implementation Completed in FY 2010

- Designed as general-purpose glovebox in existing facility
- Designed by outside architect engineer
- Manufactured by external subcontractor
- Used currently for specific purpose (dismantlement)
- Modeled legacy weapons parts in Pro/E
- Designed all machining and inspection fixtures in Pro/E

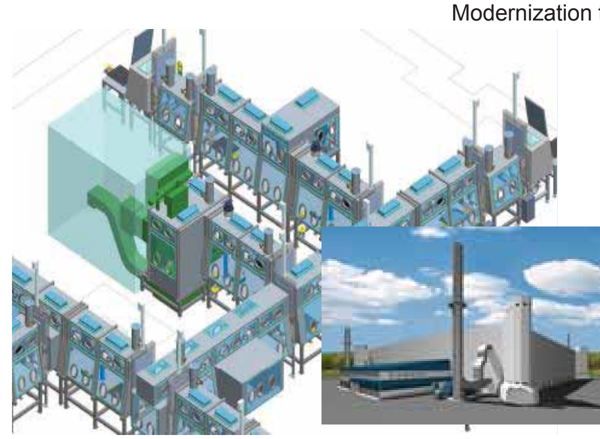


IGBS Applied MBE/M Technologies &

- Process operation was simulated in Delmia and Pro/E Manikin software
- Generic facility (IGBS) presented many challenging requirements
  - Large dismantlement part
  - Very little operating room available
- Virtual process planning identified and avoided several trouble spots in fixture designs
- Simulations were provided for operator training
- Simulation was an excellent communication tool for commissioning activities

Support to Uranium Processing Facility (UPF)

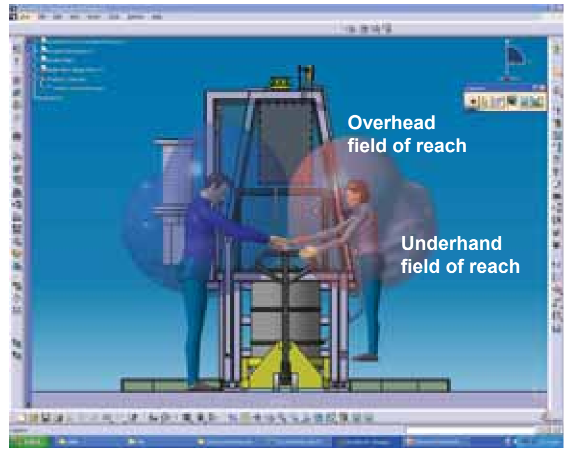
Modernization to Y-12



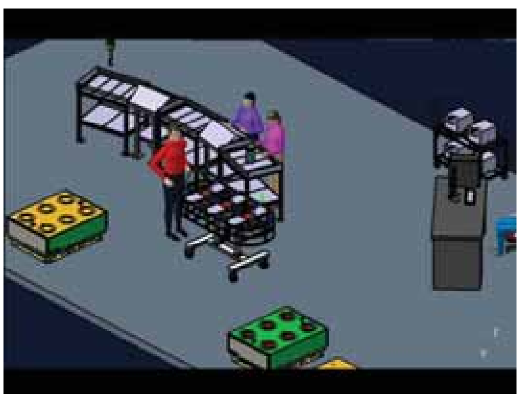
UPF Applies Many MBE/M Concepts &

- &Conceptual design
  - Used knowledge capture to support MBE/M
  - Used Extend software models for process design
  - Varied facility design virtually to evaluate cost/schedule impact
- &Ergonomic design
  - Reviewed fit and function of proposed design
  - Avoided costly design flaws not typically caught before facility walk-down
  - Avoided health and safety problems with ergonomic design

UPF Design for Ergonomic Consideration



UPF Design for Ergonomic Consideration &



Y-12 Partnerships and R&D Programs

- &As part of the Nuclear Security Enterprise, the Y-12 Complex works with other Department of Energy sites and federal agencies as well as universities and private industry
- &Y-12 participates in various partnerships and in groups dedicated to improving communications and facilitating the exchange of technical data and advancing technologies
- &The Plant Directed Research, Development, and Demonstration Program (PDRD) supports innovative or high-risk design and manufacturing concepts and technologies with potentially high payoff for the Nuclear Security Enterprise
- Nuclear Safety Research & Development (NSR D)
- &Cooperative Research and Development Agreements (CRADA)

University Partnerships with Y-12 &

- &University of Tennessee, Knoxville and Chattanooga
- &University of Alabama, Huntsville
- &University of Florida
- University of North Carolina, Charlotte
- Georgia Tech
- &Syracuse University

Y-12 researchers and members of the University of North Carolina at Charlotte—recipients of an R&D 100 Award in 2010 for the Modulated Tool-Path Chip Breaking System

Y-12 Participation in IMOG

- &Interagency Manufacturing Operations Group (IMOG)
  - Oldest NSE working group (60+ years)
  - Involves participation from majority of NNSA sites
  - SMEs exchange technical information—on design, manufacturing and acceptance problems—to maintain the manufacturing operations capability of the DOE weapons complex (NSE)

Y-12 Participation in MBIT

•&**M**odels **B**ased **I**ntegrated **T**ools, a model-based working group, was formed 15 years ago and consists of managers, SMEs, from all NSE sites as well as other DOE labs and vendor of ProE - PTC

“Before all NSE sites adopted the computer software ProEngineer (ProE), each site had its own computer-aided design (CAD) system. The Department of Energy spent lots of time, effort, and money so the different CAD systems could communicate….

“We find a lot of value in [MBIT] relationships. When new ProE versions roll out, we all save money by avoiding reinventing the wheel or paying consultants.”

- *Y-12 Steering Group Rep*
  Y-12 Information Technology

Snapshot of MBIT

•&MBIT members
- Lawrence Livermore National Laboratory
- Sandia National Laboratory, California
- Los Alamos National Laboratory
- Sandia National Laboratory, New Mexico
- Pantex Plant
- Savannah River National Laboratory
- Y-12 National Security Complex
- Kansas City Plant
- Parametric Technology Corporation (PTC)—vendor for standardized design tool Pro/Engineer

The network saves money in licensing fees and in economies of scale in processes and techniques

&

Benefits of MBIT Participation

“By participating in MBIT, Y-12 engineers, designers, drafters, and numerical-control part programmers can share knowledge across the Nuclear Security Enterprise. That information exchange maximizes efficiency and quality in the creation of models, drawings, and machine tool programs and in file management.”

- *Manager, NC Machining*
  Y-12 Mechanical and Manufacturing Engineering

What Does MBIT Do?

•&Develops and maintains model-based standards and best practices for product realization

• Brings together users, SMEs, managers and vendors

•&Serves as the user voice to communicate business and technical requirements related to model-based tools and processes

•&Promotes common tools and processes that support NSE programmatic missions

•&Promotes seamless sharing and reuse of models and associated data within the NSE and with commercial partners

•&Forms strategic partnerships with vendors that support NSE product realization activities

•&Collaborates with outside industry to share lessons learned and validate MBIT’s vision and guiding principles

&

Summary

• Y-12 has diverse experience in all stages of design and manufacturing. This history gives Y-12 a unique, in-depth understanding of the engineering and manufacturing challenges that confront national security

• Model-based approach guarantees success through excellence in manufacturing

• Y-12’s work with other NSE sites and Y-12’s programs and partnerships create a vast network of highly skilled specialists and research facilities

• We look forward to expanding partnerships to advance science and technology to meet national and global security needs

Model Based Enterprise Impact on Organizational Behavior

James DeLaPortet
Partner and Business Transformation Leadert
jamesdelaporte@nextec-et.comt

NEXTEC

MBE and Organizational Behavior

- A body in motion stays in motion, A bodyd at rest stays at restd
  - Recent CELEBREX Commercialt
- A body in motion tends to stay in motiond unless acted on by an outside fdrcea
  - Sir Isaac Newtont
- Organizations behave the same wayd
  - They are difficult to moved
- MBE is that outside forced

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MBE and Organizational Behavior

- David and Goliath?d

DEDMWGd

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MBE and Organizational Behavior

- Why is this?d
  - Organizations are complex open social systemsd
  - Organizations develop distinct and persistentd behavior patterns or cultured
  - Culture is the beliefs, assumptions and resultantd behaviors efine by the lea ersd
  - Leaders teach new members methods of thinking,d perceiving and problem solvingd
  - Managers select new members based onCd similarities to these traitsCd
  - Strengthens the cultureCd

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MBE and Organizational Behavior

- Why is this?d
  - People are multifaceted and complexd
  - People make sense of past behavior by formingd beliefs that rationalize itd
    - "It makes sense to me why we do this"d
  - Effect is to escalate commitment to these beliefsd
  - People avoid embarrassment or threat to selfd
    - "We have always done it this way"d
  - These human characteristics cause organizationald behaviors to persist in the face of new realitiesd
    - Michael Beer Harvard Universityd

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MBE and Organizational Behavior

Organizationald Commitmetd

"Keeping yourd ducks in ad row"d

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MBE and Organizational Behavior

- Model Based Enterprise represents ad fundamental shift to 3D from 2D for alld major internal organizationsd
  - Engineering – design and configure in 3Dd
  - Operations – build to 3D graphical instructionsd
  - Quality – inspect and buy off to 3Dd
  - Service and Support – 3D support documentationd
  - Information Technology – store and distribute 3Dd
  - Finance and dontracts – budget and deliver 3Dd
- All organizations will need to adaptd

MBE and Organizational Behavior

Change can bed chaoticd

"Βut what do Id o without a drawing?"d

MBE and Organizational Behavior

- Need to rebuild each organization around the exclusive use of 3Dd
  - Engineering – the hardest to pull the drawing fromd
  - Operations – need to become Pd and App savvyd
  - Quality – may need updated training in GD&Td
  - Service and Support – learn to read 3D instructiond
  - IT – new processes for application managementd
  - Finance and dontracts – identify cost advantagesd
- New organizations will be flexibled

MBE and Organizational Behavior

Can we reallyCd move theCd continents?Cd

MBE and Organizational Behavior

- The short answer isdYES!
  - Although the process can be difficult and emotionald
- Must consider Organizational Behavior changesd
  - Can NOT just implement new technologyd
- Technology is used by Peopled
- People belong to Organizationsd
- Organizations have defined behaviorsd
- Organizations must change to lead people tod change to use new technologiesd

MBE and Organizational Behavior

- How do we affect such change?d
- Empower leaders at all levelsd
  - The folks closest to the topics know them bestd
- Redesign the Organization Chartd
  - Adapt to changing roles and responsibilitiesd
- Trust and encourage people to think anewd
  - Unlock the internal process innovationsd
- Actively pursue the resolution of conflictd
  - Get it out – don't let it brewd

MBE and Organizational Behavior

- People will follow the new behaviors defined by the organizational leadersd
- Keeping people involved and informed willd increase the individual commitment to thed new normsd
- This commitment will stabilize and sustain thed new organizationsd
- The new organizational behavior will be muchd more dynamic and flexibled

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MBE and Organizational Behavior

- Strategy to define the new behaviorsd
  - onsider these questions:d
- What are we doing today that we are not goingd to be doing in the duture?d
  – and equally importantd-d
- What are we going to be doing in the futured that we are not doing today?d

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MBE and Organizational Behavior

Enhanced Organizationald Performanced

“Now the ducksd are back in ad row”d

NEXTEC

Engineered Resilient Systems (ERS)
DoD Science and Technology Priority

Mr. Scott Lucero
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December 12, 2011

Engineered Resilient Systems (ERS): A DoD Perspective

Resilience: Effective in a wide range of situations, readily adaptable to others through reconfiguration or replacement, with graceful degradation of function

ERS: a DoD-wide science and technology priority

- Established to guide FY13-17 defense investments across DoD Services and Agencies
- Ten year science and technology roadmap under development
- Five technology enablers identified

> “...our record of predicting where we will use military force since Vietnam is perfect. We have never once gotten it right.
> There isn t a single instance ... where we knew and planned for such a conflict six months in advance, or knew that we would be involved as early as six months ahead of time.
> ... we need to have in mind the greatest possible flexibility and versatility for the broadest range of conflict...”
>
> The Honorable Dr. Robert M. Gates
> 22nd Secretary of Defense
> 24 May 2011

Uncertain futures, and resultant mission volatility, require affordably adaptable and effective systems – done quickly

The Problem Goes Beyond Process: Need New Technologies, Broader Community

Today

Rapidly necks down alternatives | *Decisions made w/o info* | *50 years of process reforms haven't controlled time, cost and performance*

AoA · Competing designs · Rqmts2 · Eng. design · Risk reduction · Redesign · Compete LRIP · Etc. · Rqmts1 · T&E · T&E

Sequential and slow | *Information lost at every step* | *Ad hoc reqmts refinement*

The Future

Fast, easy, inexpensive up-front engineering:

- Automatically consider many variations
- Propagate changes, maintain constraints
- Introduce and evaluate many usage scenarios
- Explore technical operational tradeoffs
- Iteratively refine requirements
- Adapt, and build in adaptivity
- Learn and update

New tools help Engineers & Users understand interactions, identify implications, manage consequences

Engineered Resilient Systems Key Technical Thrust Areas

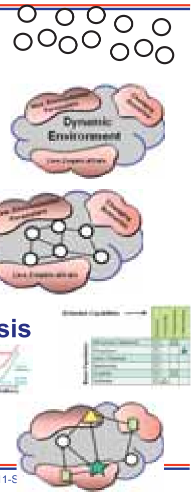
Systems Representation and Modeling
- Capturing physical and logical structures, behavior, interaction with the environment, interoperability with other systems

Characterizing Changing Operational Contexts
- Deeper understanding of warfighter needs, directly gathering operational data, better understanding operational impacts of alternative designs

Cross-Domain Coupling
- Better interchange between "incommensurate" models
- Resolving temporal, multi-scale, multi-physics issues across engineering disciplines

Data-driven Tradespace Exploration and Analysis
- Efficiently generating and evaluating alternative designs, evaluating options in multi-dimensional tradespaces

Collaborative Design and Decision Support
- Enabling well-informed, low-overhead discussion, analysis, and assessment among engineers and decisionmakers



System Representation and Modeling: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Capturing • *Physical and logical structures* • *Behavior* • *Interaction with the environment and other systems*	**Model 95% of a complex weapons system**	• Combining live and virtual worlds • Bi-directional linking of physics-based & statistical models • Key multidisciplinary, multiscale models • Automated and semi-automated acquisition techniques • Techniques for adaptable models

We need to create and manage many classes (*executable, depictional, statistical...*) and many types (*device and environmental physics, comms, sensors, effectors, software, systems ...*) of models

Characterizing Changing Operational Environments: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Deeper understanding of warfighter needs *Directly gathering operational data* *Understanding operational impacts of alternatives*	**Military Effectiveness Breadth Assessment Capability**	• Learning from live and virtual operational systems • Synthetic environments for experimentation and learning • Creating operational context models (missions, environments, threats, tactics, and ConOps) • Generating meaningful tests and use cases from operational data • Synthesis & application of models

"Ensuring adaptability and effectiveness requires evaluating and storing results *from many, many scenarios* (including those presently considered unlikely) *for consideration earlier* in the acquisition process."

Cross-Domain Coupling: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps

Better interchange between incommensurate models
Resolving temporal, multi-scale, multi-physics issues
	Weapons system modeled fully across domains	• Dynamic modeling/analysis workflow
		• Consistency across hybrid models
		• Automatically generated surrogates
		• Semantic mappings and repairs
		• Program interface extensions that:
		  • Automate parameterization and boundary conditions
		  • Coordinate cross-phenomena simulations
		  • Tie to decision support
		  • Couple to virtual worlds

Making the wide range of model classes and types work together effectively requires new computing techniques (not just standards)

Tradespace Analysis: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Efficiently generating and evaluating alternative designs *Evaluating options in multi-dimensional tradespaces*	**Trade analyses over *very large* condition sets**	• Guided automated searches, selective search algorithms • Ubiquitous computing for generating/evaluating options • Identifying high-impact variables and likely interactions • New sensitivity localization algorithms • Algorithms for measuring adaptability • Risk-based cost-benefit analysis tools, presentations • Integrating reliability and cost into acquisition decisions • Cost-and time-sensitive uncertainty management via experimental design and activity planning

Exploring more options and keeping them open longer, by managing complexity and leveraging greater computational testing capabilities

Collaborative Design & Decision Support: Technical Gaps and Challenges

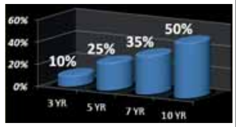
Technology	10-Yr Goal	Gaps
Well-informed, low-overhead collaborative decision making	**Computational / physical models bridged by 3D printing** ***Data-driven* trade decisions executed and recorded**	• Usable multi-dimensional tradespaces • Rationale capture • Aids for prioritizing tradeoffs, explaining decisions • Accessible systems engineering, acquisition, physics and behavioral models • Access controls • Information push-pull without flooding

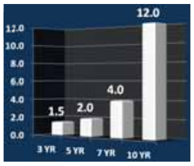
ERS requires the transparency for many stakeholders to be able to understand and contribute, with low overhead for participating

What Constitutes Success?

Adaptable (and thus robust) designs

– Diverse system models, easily accessed and modified
– Potential for modular design, re-use, replacement, interoperability
– Continuous analysis of performance, vulnerabilities, trust
– ***Target: 50% of system is modifiable to new mission***



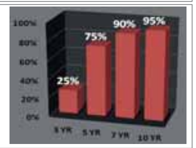


Faster, more efficient engineering iterations

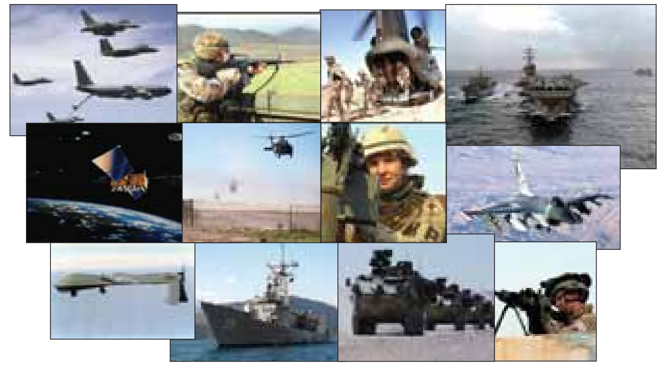
– Virtual design – integrating 3D geometry, electronics, software
– Find problems early:
– Shorter risk reduction phases with prototypes
– Fewer, easier redesigns
– Accelerated design/test/build cycles
– ***Target: 12x speed-up in development time***

Decisions informed by mission needs

– More options considered deeply, broader trade space analysis
– Interaction and iterative design among collaborative groups
– Ability to simulate experiment in synthetic operational environments
– ***Target: 95% of system informed by trades across ConOps/env.***



Engineering: Critical to Capability Delivery



SCRA
Applied R&D

NDEMC: A Public-Private Partnership to bring MS&A and HPC to SME's

Dennis Thompson
Sr. VP SCRA
and
Technical Project Manager for NDEMC

SCRA Public-Private Partnerships

Public Private Partnerships (PPPs) are innovative methods used by the public sector to partner with the private sector, who bring capital and expertise to deliver projects on time, on budget and meeting expectations. PPP's are effective and efficient ways of deploying solutions at scale for the social and economic benefit to the public.

PPPs are important tools to bridge innovation strategies where the marketplace has not been effective at scale to date. PPPs can provide a number of specific benefits to enhance economic development and economic return through:

- increased product quality at same or lower cost
- higher levels of service
- reduced risk
- decreased time to market
- enhanced capabilities offered in bidding
- the creation of highly-skilled technical workforces

SCRA Example of a Successful PPP

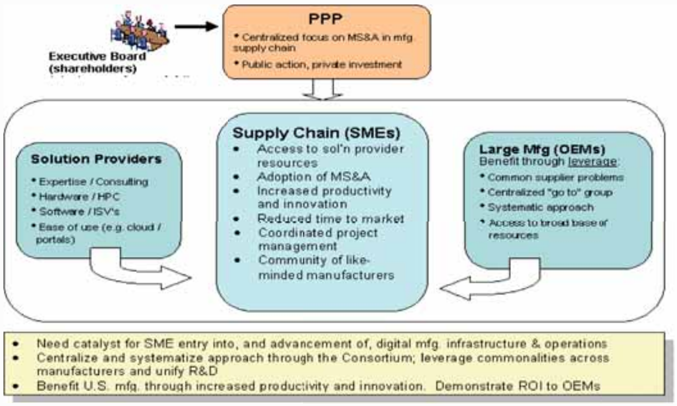
The ***National Digital Engineering and Manufacturing Consortium (NDEMC)*** is being developed for the purposes of piloting a program to promote adoption and advancement of Modeling Simulation and Analysis (MS&A) in Small Manufacturing Enterprises (SMEs) and the U.S. manufacturing supply chain, initially focused in the U.S. Midwest. The end goal is to give U.S. based manufacturers tools that will help them be more competitive in the global economy and help retain and grow a strong manufacturing in the U.S.. NDEMC has two initial focuses:

1. Create a single point of entry portal that will support Software as a Service (SaaS) in a cloud environment that will link High Performance Computing (HPC) providers, university researchers and other technical support and private sector consultants.
2. Do a series of demonstration project that prove the business case for MS&A and HPC in the SME community and develop a replicable model that can be expanded to other regions of the U.S.

SCRA NDEMC: Midwest Project Team

- **OEMs**
  - The Procter & Gamble Company
  - Lockheed Martin
  - General Electric
  - Deere Co.
- **Solution Partners**
  - Ohio Supercomputer Center
  - National Center for Supercomputing Applications (U. of Illinois)
  - Purdue University
  - National Center for Manufacturing Sciences
  - SCRA/ATI
  - Council on Competitiveness
- **State Governments**
  - State of Ohio
  - State of Indiana
- **Federal Government**
  - White House
  - Dept of Commerce (EDA)
  - Department of Defense (OSD/AFRL/ ARDEC)
- **Other MOU signees**
  - DOE
  - NIST
  - NASA
  - OSTP

Public-Private Partnership



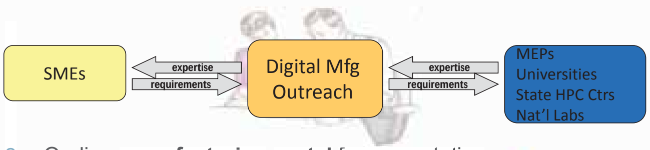
NDEMC

NDEMC is developing and fostering a new manufacturing focused community linking:

- U.S. Manufacturers,
- Commercial software developers,
- Hardware vendors,
- Universities, and
- National laboratories

NDEMC (2) Thrusts Areas

1. Teams of experts provide **specialized consulting/training** in MS&A
   - Deployed to SME sites for personalized consulting and training
   - Based at institutions with modeling and manufacturing expertise



2. On-line **manufacturing portal** for computation
   - Access to broad base of expertise
   - On-line interactive professional education
   - Cloud-based computing resources
   - Easy web-based access to engineering and manufacturing so

Deployed field consultant/trainers will be key to ensuring these two thrusts complement, and are informed by, each other

NDEMC Portal

Portal will have (4) major pieces:

1. Commercial financial transaction capabilities (like amozon.com)
2. Searchable catalog/database of MS&A software's and other analysis software's
3. MS&A tech support/counseling from a trusted 3rd party (universities, etc)
4. MS&A consulting service providers

NDEMC

NDEMC is designed to accommodate the broad MS&A needs of SMEs

- **Common issues / leveraging**
  - SMEs can **share** solutions and influence 3rd party development
  - Domain application portals **simplify** usage of codes
  - Needs served by **existing** commercial codes and readily available hardware resources

vs.

- **Highly customized needs and requirements**
  - SMEs require **specialized** capabilities not currently available in commercial software
  - **Collaboration** with external R&D may be needed (universities and/or national laboratories)

In both cases, *community promotes efficiency*

Benefits of NDEMC

- **OEMs**
  - Increased collaboration with supply chain
  - More innovative, integrated, and efficient supply chain
  - Access to large community of MS&A/HPC expertise and influence
- **Software Providers**
  - Increased market penetration of products
  - First-hand access to requirements for product development roadmaps
- **SMEs**
  - Reduced time to market
  - Enhanced throughput
  - Reduced waste
  - Increased safety and sustainability
  - Reveals critical information to inform decision-making.
- **U.S. Government**
  - Highly skilled U.S. workforce
  - Increased global competitiveness

NDEMC Progress To Date

- (7) Demonstration projects launched in November. All will be completed within 90 days (first of 30-40 demonstration projects)
  - Demonstration projects will include MS&A applications across the entire product life cycle
  - Case studies will be developed and published on all demonstration projects
- Portal is underdevelopment with direct linkage to High Performance Computing (HPC) through a cloud application
- Created a searchable catalog of (143) software's available to SMEs through the portal
  - Negotiating with other software supplier to expand the catalog of products available to the SMEs

Leveraging NDEMC in the DoD?

The DoD has a number of active programs that could benefit from the work of NDEMC and build off of it instead of reinventing it. Examples:

- Advanced Manufacturing Enterprise (AME)
- Model Based Engineering (MBE)
- Connecting American Manufacturing (CAM)
- DARPA's Open Manufacturing
- Others????

Raytheon
Customer Success Is Our Mission

AIR
LAND
SEA
SPACE
CYBER

Industry and ManTech Interaction Success

David Baum

Common PDM MBE Solution Architect

Dec. 5, 2011

Raytheon
Customer Success Is Our Mission

Industry and ManTech Interaction Success

Raytheon Corporation
Hardware Engineering
Common Product Data Management (PDM)
Model Based Enterprise (MBE) Solution Architect
David Baum
Dec. 5, 2011

Raytheon

Agenda

- Who we are and what we make at Raytheon
- Our EDS & IPDS Support Standards of Excellence across multiple Businesses
- Our Common PDM Information System
- Raytheon's MBE
- Use Case Standards for MBD models.
- ManTech Projects & their value to Raytheon

Who we are at Raytheon → Business Process Integration Need → Targeting MBD Benefits → Capability Roadmap Use Cases → Leveraging DoD Funds For MBD

Raytheon

Who We Are

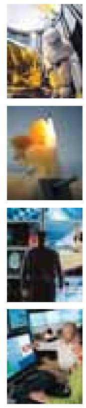
- A technology and innovation leader specializing in defense, homeland security and other government markets throughout the world
- 2010 net sales: $25 billion
- 72,000 employees worldwide
- Headquarters: Waltham, Mass.

A global leader in technology and innovation

Raytheon

Our Strategy

- Focus on key strategic pursuits, Technology and Mission Assurance to sustain and grow our position in our four core defense markets:
  - *Sensing: Expand beyond traditional RF/EO to new growth focus areas, including multi-mission areas.*
  - *Effects: Leverage kinetic energy-based expertise into EW, directed energy and cyber markets.*
  - *C3I: Broaden market presence in communications, C2, networking and knowledge management.*
  - *Mission Support: Expand beyond product support, engineering services and training.*
- Leverage our domain knowledge in all markets, including Homeland Security and Cybersecurity.
- Expand international business by building on our relationships and deep market expertise.
- Continue to be a Customer Focused company based on performance, relationships and solutions.



A technology-driven growth strategy

Raytheon

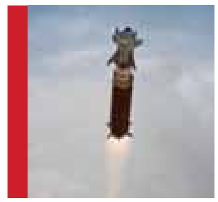
What We Make

Core Market: Sensing

Technologies that acquire data and create accurate, reliable information for effective battlespace decisions.

Core Market: C3I *(Command, Control, Communications and Intelligence)*

Integrated real-time systems that optimize operational planning and execution.



Core Market: Effects

Technologies that achieve specific military actions or outcomes — from striking targets to disabling hostile information systems.

Core Market: Mission Support

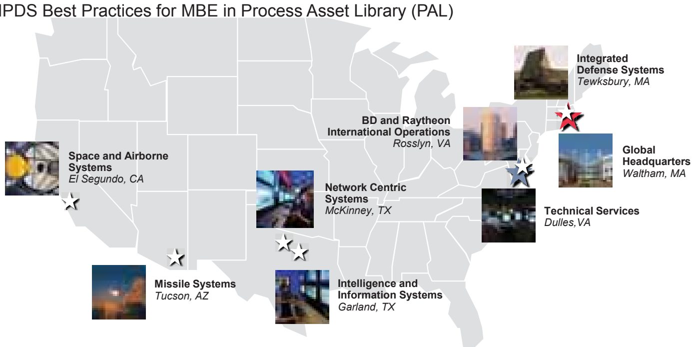
Total life-cycle solutions that ensure performance, no matter the mission, no matter the platform.

Systems and solutions to ensure flawless performance.

Raytheon

Common Design Controls and Practices

- Common Product Data Management (PDM) Workflows
- Engineering Documentation Standards (EDS)
- IPDS Best Practices for MBE in Process Asset Library (PAL)



72,000 employees; 2010 net sales: $25 billion

National Defense Industry Association Position High Level MBE Benefits

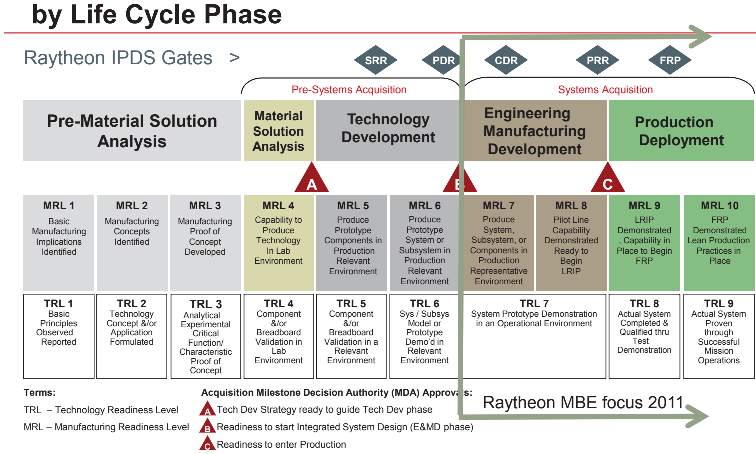
Raytheon

- Reduce time to acquisition of first article for systems and solutions
  - More complete evaluation of the trade space
  - Earlier risk identification and mitigation
  - Concurrent and collaborative engineering
  - Design reuse
  - Accelerated development
- Reduce the time to implement planned and foreseen changes in systems
  - Design reuse
  - Rapidly evaluate changing threats and explore trade space
- Enhance Reliability
  - Earlier and continuous requirements and system verification
  - Identify and resolve errors/issues/fewer post-fielding issues
- Enhance Interoperability
  - Inclusion of the operating environment and external interfaces in system models
  - Early and continuous interface and interoperability verification

Reference:
Final Report MBE Subcommittee
Jeff Bergenthal (Subcommittee Lead)
NDIA Systems Engineering Division
M&S Committee, February 2011

DoD TRL & MRL Requirements by Life Cycle Phase

Raytheon



Predefined TRL & MRL Levels must be met at Program Milestones

Model Based Enterprise Capability Development

Raytheon

- **Complexity & Functions requires System Decomposition**
  - **Model Based Definition (MBD) – 2011**
    - Enterprise MBD Specification completed in 2010
    - MCAD Models that are Qualified for defined Life Cycle Use Cases (Standards)
    - New visualization tools (ProductView)
  - **Model Based Manufacturing (MBM) – 2012**
    - Global supplier communication and support of product IP
    - MCAD Models transitioned from "*As Designed*" to "*As Planned*"
    - Derivatives from MCAD models used for process plans.
  - **Model Based Systems Engineering (MBSE) – 2013**
    - Virtual verifications at the core of these capabilities
    - Requirement allocations derivations
    - "As Verified" status linked to PDM
  - **Model Based Life Cycle Support**
    - Reuse of MBD for technical manuals

Model Based Enterprise Framework is Common PDM

Common PDM MBD Capability Use Case Requirements

Raytheon

- **Authoring** – defining all the features, annotations, and attributes required of a model for its defined use cases.
- **Checking** – verifying that all Hardware Development Plan (HDP) specified "use cases", and modeling standards are met for model integrity before formal release to PDM.
- **Design Review** – verifying that the model is complete for form, fit, and function. &
- **Concurrent Engineering** – inputs (analysis, annotation, feature changes, etc.) to the design model from functional SME's determined to be critical to the part/assembly..
- **Configuration Management** – identification of all correct attribute data for formal control.
- **Manufacturing Process Flow**
  - First Article Inspection – Identification of critical features/dimensions in model
  - Assembly Aids – extraction of parts list; geometry for assembly aids/work instructions
  - CNC Programming – geometry and tolerances needed to drive CNC programming
- **Supplier Review** – distribution of a formally controlled model with all information needed for review of HDP planned "use cases".
- **Technical Manuals** – similar to Assembly Aids with identification of replaceable assemblies.

Use Cases Keep Model Development in Scope

Exploring Solutions For Improved Interoperability

- Customer / Supplier Interoperability During Collaborative Design (CSI)
  - Solution addressing AFRL BAA: 08-08-PKM
    - Air Force Research Laboratory
    - Defense Manufacturing Science & Technology (MS&T)
    - High Performance Manufacturing: Model Based Enterprise

International TechneGroup Incorporated, LOCKHEED MARTIN, Honeywell, Rockwell Collins, PDES, Inc., ATI

CSI Overview

POC: Steven Turek
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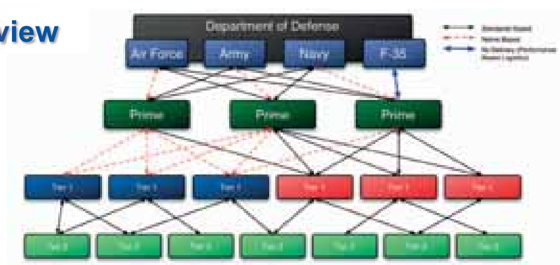
Contractror: ATI



DoD Problem:

Lack of defined data exchange format requirements between suppliers and customers generate significant hidden costs for weapons systems

Approach: &

- Capture, validate and test "data-contract" requirements by & assessing the requirements, evaluating the highest priority requirements, and developing prototype solutions for the most critical requirements &
- Using the DEXcenter, ITI will develop CSI modules, to include contract mapping tools, and software libraries
- Conduct a demonstration to highlight the savings achieved through automation and develop a commercialization plan

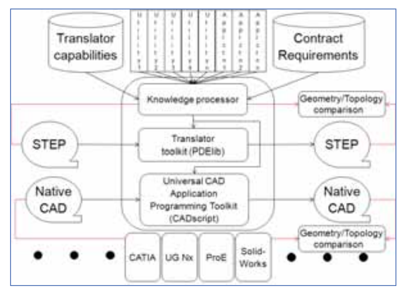
Warfighter Benefits: &

Reduced costs and higher quality data. Improvements in business practices will be seen in:

- Less cost to deliver products to the warfighter by eliminating non-value added data manipulation tasks and elimination in errors introduced in the manual manipulation of the data
- Less time for new capabilities to reach the warfighter because of streamlined processes through the supply chain during early product development phases
- Cost savings are estimated to be over $35 million per major program

Vision

- A flexible, configurable, standards based system which automates common tasks associated with Customer Supplier Interoperability
  - Easily / quickly configurable to handle different contract requirements
  - Leverages existing ITI technologies (DEXcenter, PDElib, CADscript, CADfix, CADIQ, etc)
  - & Supports typical requirements like:
    - & Model preparation
      - Removing / adding / hiding data
      - Organization
      - Coordinate systems
      - Renaming
      - Abstraction / simplification
      - Adding IP / ITAR notes
    - & Translation
      - Neutral standards (STEP, IGES)
      - CAD Native formats
      - Visualization
    - Validation
      - Geometry, topology, PMI
    - & Delivery
      - Encrypted
      - & IP protection
      - & ITAR controls
      - Direct (https web, sftp) or via PLM
    - & Tracking / auditing



Accelerating MBE deployment – CSI contract addendums

Benefits

- Potentially enables a more efficient transition from drawing to model-based definition
- May provide an alternate path to translation of featured models

Honeywell

Draw-to-PMI (MBD Generator)

Automation to merge associative 2D GD&T into the model and produce associative 3D PMI

Rockwell Collins

Critical Problem Resolution (CPR) Process

etects and resolves model issues in design for manufacturability

Benefits

- Eliminate un-producible features – better quality model
  - Identify potential problems; collaboratively resolve with supply chain
    - Reduce rework or scrap due to design escapes
      - Eliminate model ambiguity that otherwise drives design revision
      - Improve model translation success and designer productivity

Benefits

- Support MBE approach - maintain the digital thread
- Streamlines design to manufacturing process within supply chain
- Increased product quality due to higher confidence in data handoff
- Reduce scrap due to conversion/interpretation issues
- Reduce cycle time through automation of conversion validation

3D PMI Translation

Translation of associative 3D models and 3D PMI between dissimilar CAD environments

Lockheed Martin

3D ECO Documentation

Document model changes in a 3D format that greatly improves communication in the MBE

Rockwell Collins

Benefits

- Eliminates need for drawing-based documentation of design change
- Improves designer productivity (reduces time) in model/drawing revision
- Improves quality; model is explicit master; fully represents/documents change
- Necessary step toward full model based design (eliminating drawing)

ManTech Projects Leveraged

Raytheon

Addendum 1 to Statement of Work

Customer/Supplier Interoperability during Collaborative Design (CSI)

Task 3.1 - 3D Mode Comparison and Validation for ECOs: The contractor shall develop a prototype solution that integrates 3D Modeling Comparison and Validation for ECOs with the existing CSI platforms. The 3D ECO Documentation capability will document differences in 3D Model Based Designs after a revision or change is made in the model. That changed model could then be compared to the original model and all differences would be reported in a 3D viewing format with annotations sufficient to highlight each change and permit the user to graphically manipulate the model.

Piloting CADIQ model comparison capability, with Pro/E models, to identify model changes during change management process.

Use Case Applications:
- MBD Authoring
- MBD Checking
- Configuration Management
- Concurrent Engineering

ManTech Projects Leveraged

Task 3.2 - **Migration to Model-Based (MBD) with PMI**: The contractor shall develop a prototype solution that enables the Mitigation to a Model-Based Definition (MBD) with PMI for existing CSI platforms. This capability will automatically interpret dimensions, tolerances, symbols and notes on the 2D drawing along with associated features/geometry so that PMI can automatically populate the 3D model space with all necessary associations, eliminating the need for a 2D drawing.

Established a Raytheon Standard MBD Schema, with start parts and PDM attributes, for use with tools that enable Model-Based Definition".

Use Case Applications:
- MBD Authoring Standards
- MBD Checking Standards

ManTech Projects Leveraged

Task 3.3 - **PMI Conversion Process Enhancements:** The contractor shall develop a prototype solution that demonstrates PMI conversion capabilities to enable the translation of PMI data in one CAD system (source system) to a second CAD system (target system). The PMI conversion capability will track the dimensions, text, tolerances and symbols along with the associated features/geometry of the source system as the translation of the underlying features/geometry are processed and associated with the appropriate features/geometry in the target system.

Raytheon is working with its industry partners, PTC and ITI, to validate conversions of CAD file formats.

Use Case Applications:
- Configuration Management
- Supplier Review
- Technical Manuals

ManTech Projects Leveraged

Task 3.4 - **Critical Problem Resolution for Manufacturing:** The contractor shall develop a prototype solution that demonstrates a critical problem resolution (CPR) process to remedy manufacturing modeling issues early in the design process. The CPR process should identify critical manufacturing problems and their corresponding resolutions, and integrate with the existing CSI platform. The results of this continuous analysis should be fed into the configuration files for quality tools that can be used to validate engineering models prior to engineering release and manufacturing.

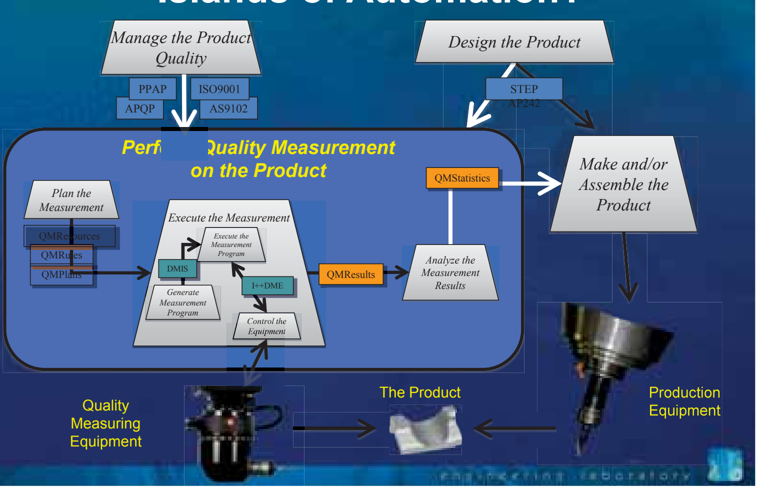
Raytheon is developing MBD model qualifications workflows that are prioritized by modeling defect causes .

Use Case Applications:
- Design Review
- Concurrent Engineering
- First Article Inspection
- Assembly Aids
- CNC Programming
- Supplier Review

MBE for Quality Measurement: Opportunities and Challenges

John Horst
NIST DMSC

Design, Manufacturing, and Quality: Islands of Automation?



Challenges with MBE for Quality

- Natural cultural resistance
  - Relatively small community
  - Small-sized vendors
- Excessive costs
  - "Native CAD interfaces"
  - Engineering rework:
    - Sometimes reverting to blueprints
    - Redefining/defining datums/features
    - Manually ballooning of drawings per AS9102
  - Loss of IO due to mergers and acquisitions

Challenges with MBE for Quality

- Link with QMS is paper-based or spreadsheet-based, not digital
- Document revision control
- CAD vendors reluctant to provide digital and fully semantic association between PMI and Geometry
- Slowly moving standards-based CAD + PMI
- Crowded and unreadable drawings

Opportunities with MBE for Quality

- Centralized data model for CAD/PMI/QMS/Inspection
- Increased automation
- Increased product quality
- Easier to manage engineering changes
- Easier to visualize deviations of actuals from nominals
- "Notes" and "balloons" are unambiguously associated with models/features/tolerance_frames

Introductions

- Curtis Brown, Honeywell FM&T
- Ray Admire, LMCO
- Bill Tandler, MultiMetrics
- Nick Orchard & Ron Snyder, Rolls Royce

Kansas City Plant
National Security Asset

DOE/NNSA
Kansas City Plant

Product Tolerance Representation

Critical Requirements for Product Definition and Metrology Interoperability

Technology that Reduces the Complexity of:

Representing Exchanging Fully Semantic Model-Based Tolerancing
Generating Correct CMM Measurement Programs for Rapid Certification

Curtis W. Brown, P.E.
Principal Mechanical Engineer

MBE/TDP Summit
12 December 2011

NNSA
National Nuclear Security Administration

The Kansas City Plant is Operated for the United States Department of Energy under Contract No. DE-NA0000622

We make products for national security.

Kansas City Plant
National Security Asset

Who is the Kansas City Plant?

- Established by DOE in 1949 with over 3.2 million ft^2, 2800+ people &
  - Classified Secured Facility
- Managed and Operated by Honeywell & Federal Manufacturing & Technology
- Primary Mission: Build & Sustain Non-Nuclear Portions of the Nuclear Arsenal
- Engineering & Manufacturing are Primary Core Competency's - very diverse capabilities
- Responsible to provide (make and/or purchase) 100,000 + items for DOE
- Mission includes partnering with
  - Other Government Agencies - Work for Others (WFO) Program; and
  - Companies – Cooperative Research Development Agreement (CRADA)

We make products for national security.

Kansas City Plant
National Security Asset

Agenda

Fully Semantic Tolerance Definition (PMI)

- **Understanding**
- **Critical Requirements**
- **Enablers to Manage Complexity**
  - **Feature-Based Tolerancing (FBTol) Brief**
  - **Feature-Based Measuring (FBMeas) Brief**
  - **Optional Demonstration (via .wmv video)**
- **Progress PMI Agenda (Way Forward)**
  - **Collaboration**

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Overview

- Status of Complete & Unambiguous Product Modeling
  - Today's product definition systems *successfully deliver* the representation and exchange of *nominal shapes.*
  - Unfortunately, *no one can manufacture nominally shaped parts.*
  - *However, we can make parts that fit and function* according to correctly specified and accurately conveyed product tolerances.
  - Correct, complete unambiguous, and verified tolerance definitions are the critical enabler for realizing:
    - successful representation, consumption, and/or exchange of product models for next generation automation applications
    - return on investment promised by MBE
  - Presently, there is likely no single CAD-based system available with the level of robustness to adequately represent and transfer product tolerance information.

We make products for national security.

Overview

- Status of Complete & Unambiguous Product Modeling
- Requirements for a Fully Semantic Tolerance Definition
- Basic Understanding of Model-Based Product Tolerance Technology
- **Promote a Fully Semantic Representation and Exchange of Tolerance Definitions**
  - Representation vs Presentation (Annotation)
    - FBTol
  - Tolerance Related Standards
    - ASME Y14.X
    - ISO 13030 STEP AP203e2
    - ISO 13030 STEP AP242
  - Process Related Standards
    - ISO 13030 STEP AP238
    - DMSC's QIF - QMP

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Overview

- Status of Complete Unambiguous Product Modeling
- Requirements for a Fully Semantic Tolerance Definition
- Basic Understanding of Model-Based Product Tolerance Technology
- Promote a Fully Semantic Representation and Exchange of Tolerance Definitions
- Demonstrate a Product Tolerance Application and Rapid Metrology Generation Application (optional)
- **Investigate Opportunities to Progress the Realization of Investments Promised by Model-Based Enterprise.**

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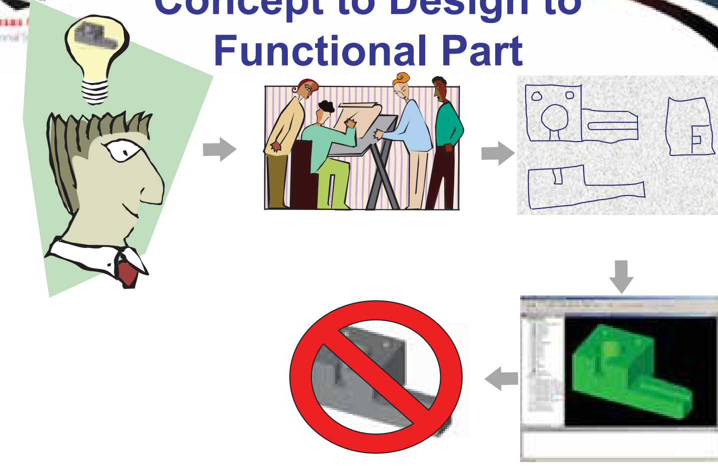
Concept to Design to Functional Part



We make products for national security.

Regrettably

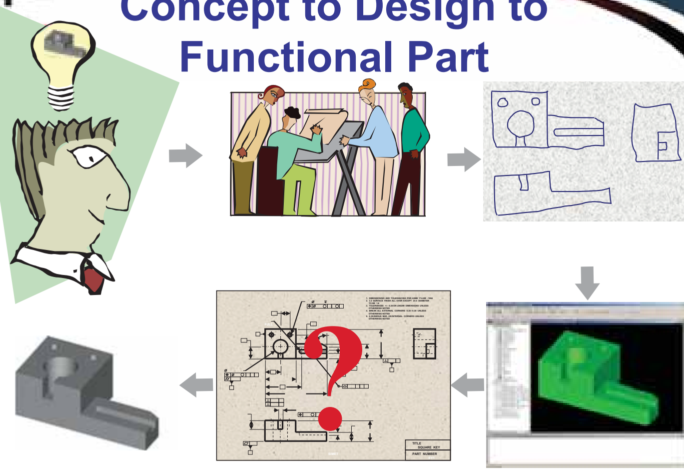
"Nobody can build perfect parts….

but we can build parts that fit and function,

by applying and communicating functional product tolerance information."

We make products for national security.

Concept to Design to Functional Part



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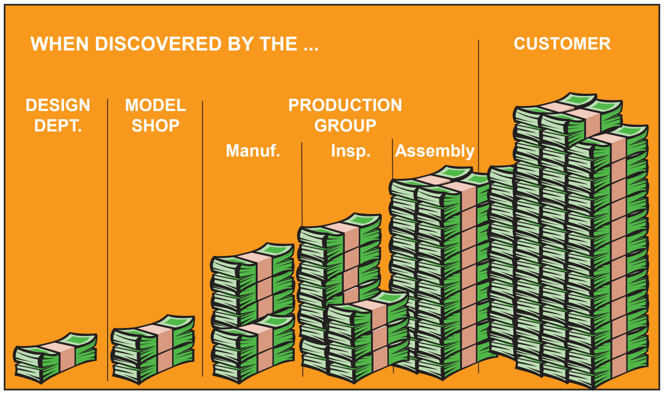
Cost of a Design Error



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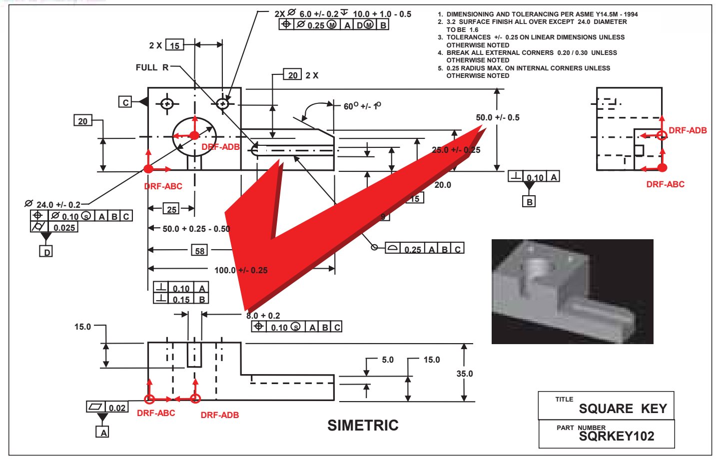
Tolerance Checking



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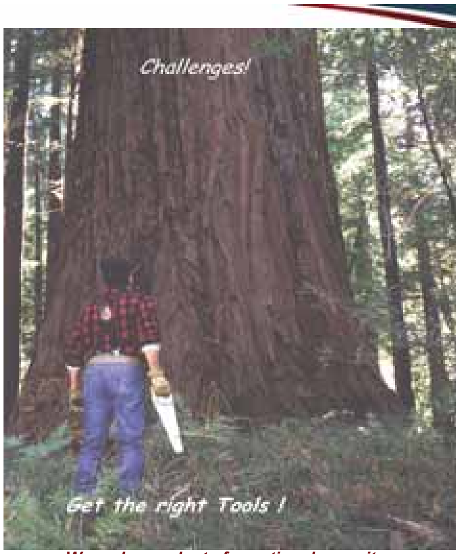

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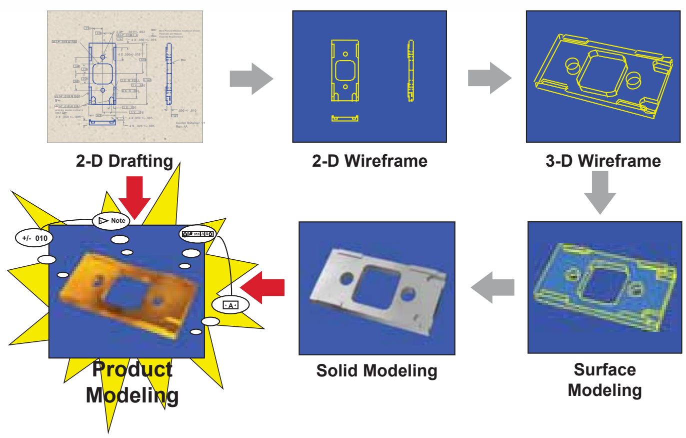
Transformation of Product Definition



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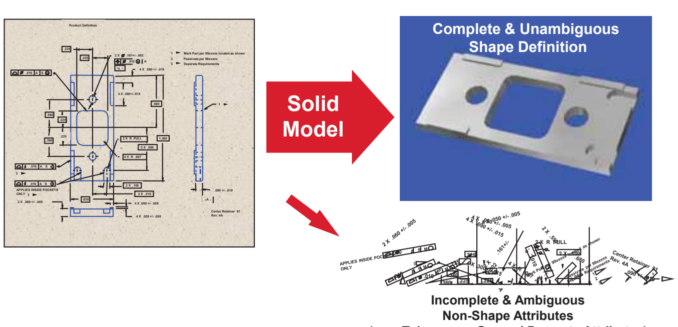
Current Product Definition Challenges

INCOMPLETE AND AMBIGUOUS PRODUCT DEFINITION



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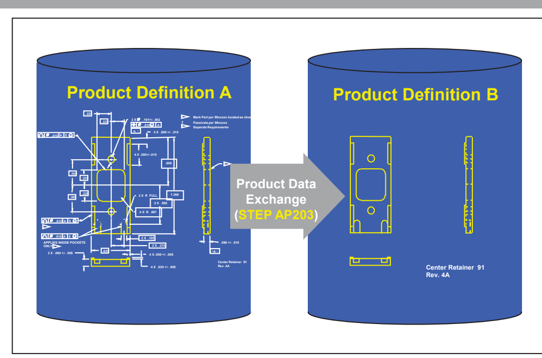
Current Product Definition Challenges

INCOMPLETE PRODUCT DATA EXCHANGE



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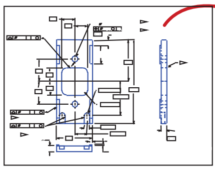
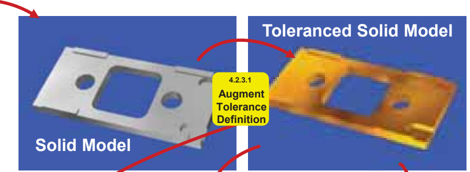
Current Product Definition Challenges

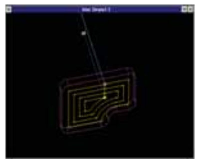
Augment Product Tolerance Information for Downstream Applications





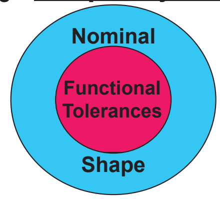
CMM
Part
Program
Generation

Other Applications
- Tolerance Analysis
- Assembly Analysis
- Process Planning
  - Manufacturing
  - Measurement
- Measurement Results Analysis



So What's the Problem?

Current *electronic* product definition systems represent and/or exchange *only a segment* of the required product's design <u>completely and unambiguously</u>.



NEED: Fully Semantic, Complete, Unambiguous & Correct Tolerance Definition, NOT just Annotations!

Product Model Tolerances

"It is the representation, not the presentation."

"One can create the presentation (e.g., ASME Y14.41) from a validated representation."

ISO 2768-1

"The Designer's Challenge"

&"Tolerancing … should be complete to ensure that *all aspects of a* feature are controlled. Nothing shall be implied or left to judgement in the workshop or in the inspection department"

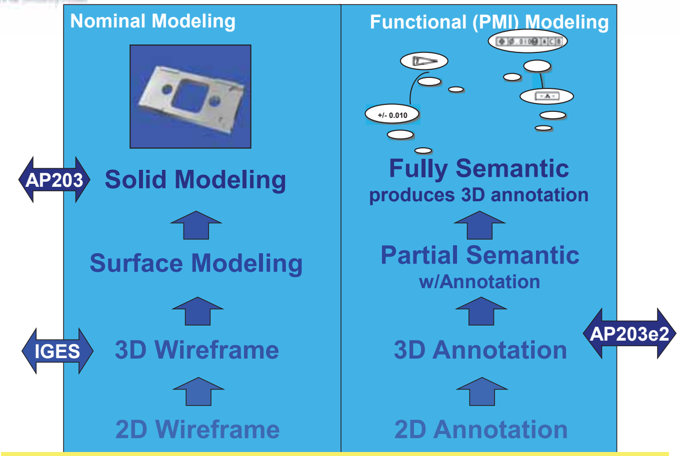
Model-Based Tolerance Requirements

- Augment a Solid Shape w/ Product Tolerances
- &Implement the Notion of Tolerance Features (collection of one or more topological face entities)
- &Fully Semantically Represent Tolerances
  - & Dimensional / Coordinate Tolerances (e.g., Size, Distances, Angles)
  - & Geometric Tolerances (e.g., Position, Profiles, Flatness, Perpendicularity)
  - & Surface Textures
  - & Specifications (e.g., Thread Specs., Welding)
  - & General Property Attributes (e.g., Notes, Markings, Cosmetics)
  - & Criticality Designation
- &Designate Functionally Important Tolerance Features as Functional Datum Features
- &Build Datum Reference Frames from Datum Features
- &Assign DRFs to Appropriate Tolerances

Model-Based Tolerance Requirements

- Purposely Associate Tolerances to Appropriate Tolerance Feature(s)
- & Recognize Tolerance Features (Auto, Interactive)
- & Infer Correct Tolerances Automatically
  - & Per ANSI Y14.5
  - & Per Company Standards
- & Check, Validate, & Score Piece-Part's Functional Tolerance Definition
- & Publish Application Programmers Interface Suite
  - & Extend Tolerance Analysis
  - & Integrate with Existing Applications
  - & Support Downstream Applications (e.g., Measurement)
- & Exchange Tolerance Definition to other Product Definitions

Mechanical Model-Based Progression

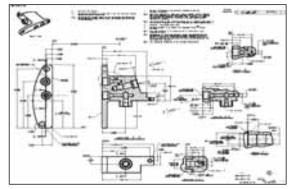


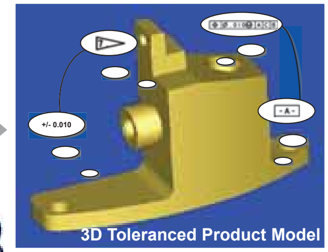
FBTol progresses Annotation like Solid Modeling progressed Wireframes

FBTol™

Feature-Based Tolerancing™

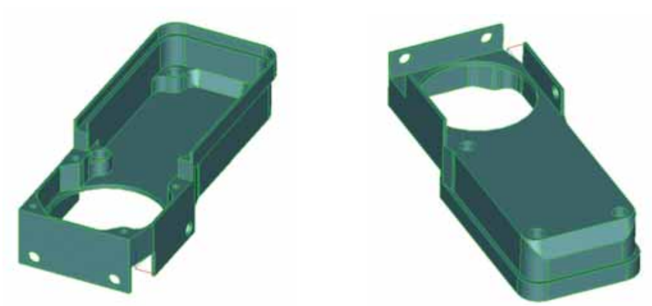
a Component Technology for Fully Semantic Product Modeling.





Augmenting Solid Model Shapes With Complete and Unambiguous Part Tolerances and Other Non-shape Attributes (i.e., Virtual Drawing)

Multiple Perspective of Shape Features



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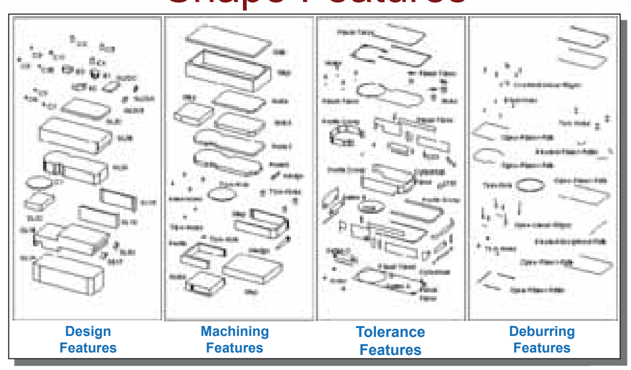
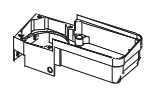
Multiple Perspective of Shape Features





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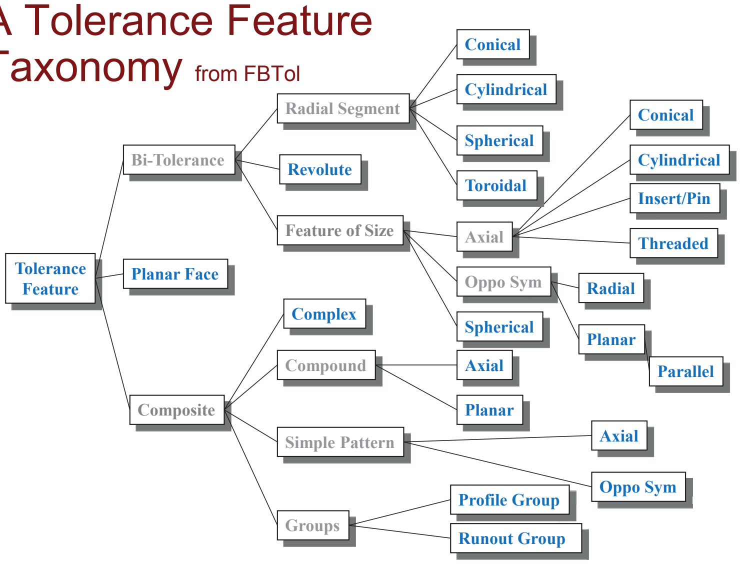
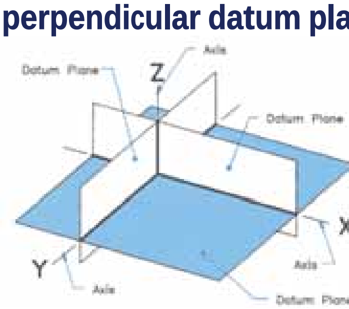
A Tolerance Feature Taxonomy from FBTol



Datum Reference Frame

A datum reference frame is defined by three mutual perpendicular datum planes.



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Datum Reference Frames
from FBTol

⌖ Ø0.14 Ⓜ A B C

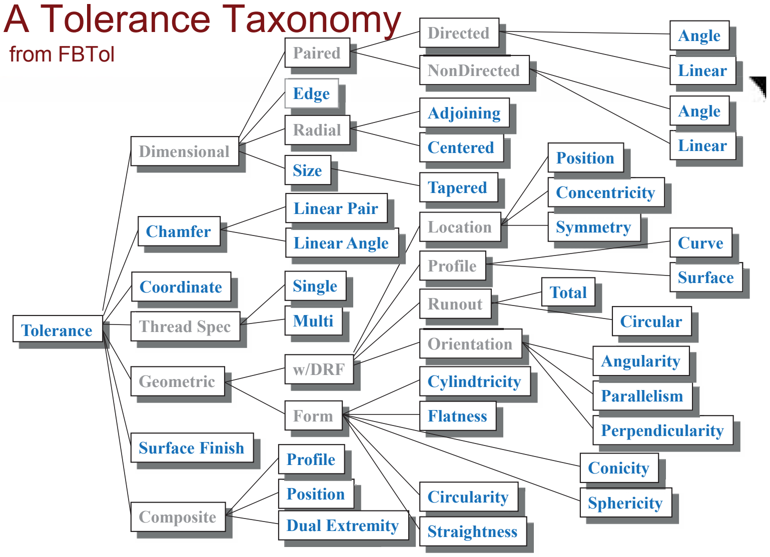
- Presented within a Geometric Tolerance Feature Control Frame
- Defined by One, Two, or Three Datum Features
- Defines Explicit Mathematical Coordinate System
- Constructed from Left to Right Order of Precedence

Datum Reference Frame
from FBTol

⌖ Ø0.14 Ⓜ A B C

- Classified per DRF's Datum Feature(s)
  - Class (e.g., planar, axial, full)
  - Precedence within DRF
  - Geometric Relationship with other Datum Features
  - Simple and Compound Datum Features
  - Extends ASME Y14.5.1M-1994 - DRFs
- Accommodates Compound Datum Features (e.g., S-T)
- Introduces Part Master DRF Concept

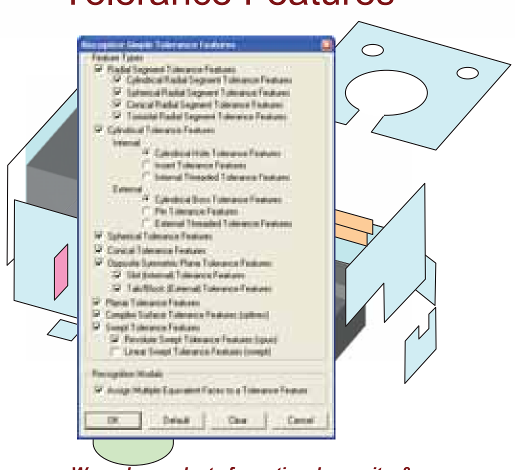
A Tolerance Taxonomy
from FBTol



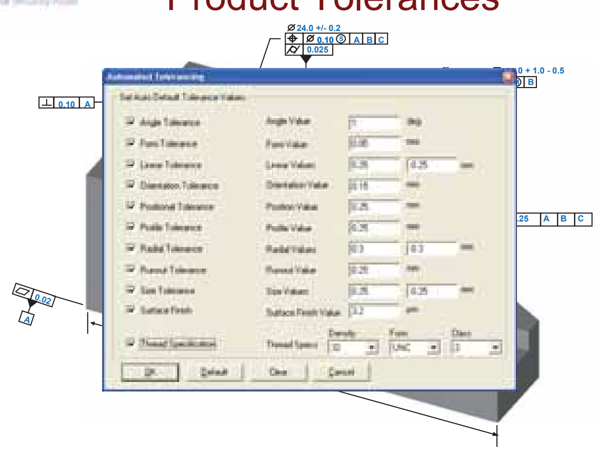
General Property Attribute

- Notes
- Specifications
- Cosmetic
- Markings
- . . .
- Assign to any entity.

Recognize Tolerance Features

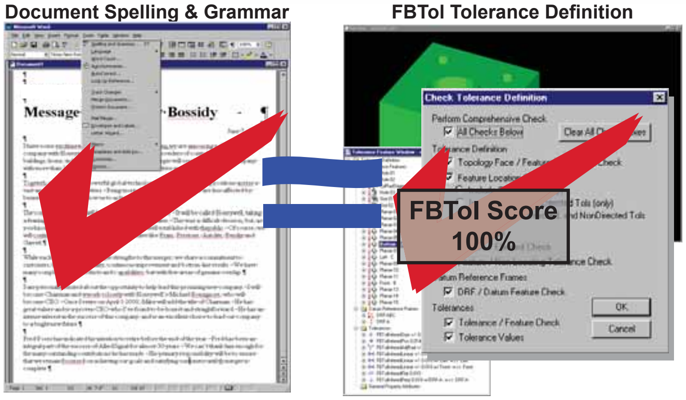


Infer Correct Product Tolerances

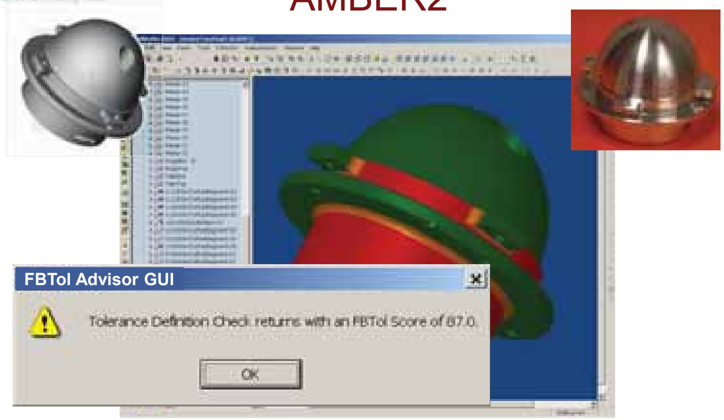


Check / Score Tolerance Definition

Document Spelling & Grammar | **FBTol Tolerance Definition**



Tolerance Definition Review AMBER2



Tolerance Definition Issues AMBER2

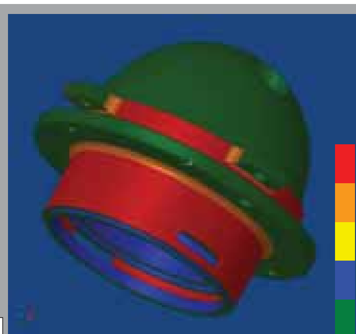
87.0 / 100 FBTol score

28 issues identified

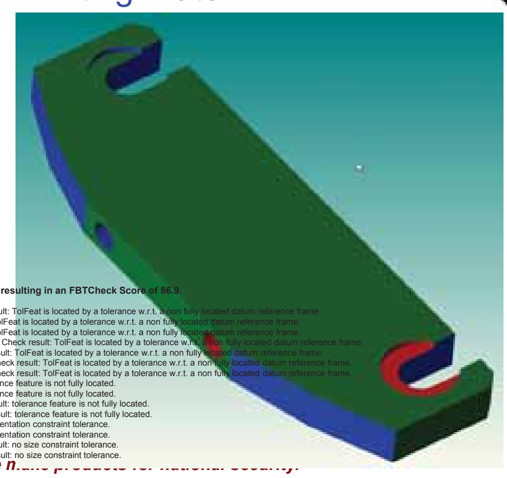
- 1 tolerance with incomplete data
- 18 features not fully located
- 7 features with no orientation constraints
- 2 features with no form constraints

Check result level colors

- 5 RED TolFeats.
- 13 ORANGE TolFeats.
- 0 YELLOW TolFeats.
- 4 BLUE TolFeats.
- 49 GREEN TolFeats.



FBTol Check Score: 86.9 Lifting Plate

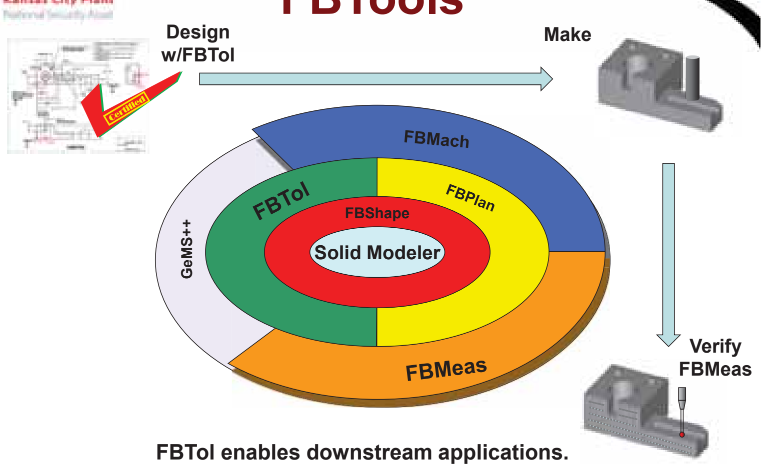


FBTol Check Result Level Summary:
TolDef has 4 RED check result level TolFeats.
TolDef has 0 ORANGE check result level TolFeats.
TolDef has 0 YELLOW check result level TolFeats.
TolDef has 7 BLUE check result level TolFeats.
TolDef has 10 GREEN check result level TolFeats.
TolDef has 0 DK GREEN GRAY suppressed TolFeats.
TolDef has 0 LT GRAY Faces without TolFeats.

FBT CHECK Detail: 15 issues have been identified resulting in an FBTCheck Score of 86.9.

FBTCheck Results Begin:
Tolerance Feature: 10.0dIntThread-02 has FBTol Check result: TolFeat is located by a tolerance w.r.t. a non fully located datum reference frame.
Tolerance Feature: 14.1wSlot-01 has FBTol Check result: TolFeat is located by a tolerance w.r.t. a non fully located datum reference frame.
Tolerance Feature: 14.1wSlot-02 has FBTol Check result: TolFeat is located by a tolerance w.r.t. a non fully located datum reference frame.
Tolerance Feature: 205.0rOutCylRadSegment-03 has FBTol Check result: TolFeat is located by a tolerance w.r.t. a non fully located datum reference frame.
Tolerance Feature: 26.0dInnerDiam-01 has FBTol Check result: TolFeat is located by a tolerance w.r.t. a non fully located datum reference frame.
Tolerance Feature: 7.1rInnCylRadSegment-01 has FBTol Check result: TolFeat is located by a tolerance w.r.t. a non fully located datum reference frame.
Tolerance Feature: 7.1rInnCylRadSegment-02 has FBTol Check result: TolFeat is located by a tolerance w.r.t. a non fully located datum reference frame.
Tolerance Feature: Planar-05 has FBTol Check result: tolerance feature is not fully located.
Tolerance Feature: Planar-09 has FBTol Check result: tolerance feature is not fully located.
Tolerance Feature: 10.0dIntThread-01 has FBTol Check result: tolerance feature is not fully located.
Tolerance Feature: 26.0dInnerDiam-02 has FBTol Check result: tolerance feature is not fully located.
Tolerance Feature: Planar-05 has FBTol Check result: no orientation constraint tolerance.
Tolerance Feature: Planar-09 has FBTol Check result: no orientation constraint tolerance.
Tolerance Feature: 10.0dIntThread-01 has FBTol Check result: no size constraint tolerance.
Tolerance Feature: 26.0dInnerDiam-02 has FBTol Check result: no size constraint tolerance.

FBTools



FBTol enables downstream applications.

Application Programmers Interface

- Direct Interfaces
- & API Interfaces

```
// api_fbt_new_tol_def
// api_fbt_create_tol_feat
// api_fbt_attach_face_to_tol_feat
// api_fbt_get_tolerances_of_tol_feat
// api_fbt_check_tol_ent
// api_fbt_get_gen_props_of_tol_ent
// api_fbt_create_tolerance
// api_fbt_attach_tolerance_to_tol_feat
// api_fbt_detach_tolerance_from_tol_feat
// api_fbt_get_tol_feats_of_tolerance
// api_fbt_show_tolerance
// api_fbt_get_tol_value
// api_fbt_get_or_construct_datum
// api_fbt_construct_drf
// api_fbt_create_gen_prop_attrib
…….
```

FBTol at the KCP

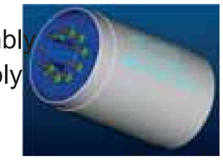
FBTol™ Technology Deployed as:

- FBTol™ Advisor standalone, with ACIS & Parasolid solid modelers
- Module inside of FBMeas™ Advisor

Reviewed over 175 Production Model / Drawings

- Average FBTol score 81.9/100
- Average 19.0 issues per analysis

Example: Launch Accelerometer Assembly



FBTol Analyzed 23 Parts in this Assembly

- 21 parts contained a total of 289 issues
- All 52 suggestions where accepted

Modeling Problems Uncovered

Customers more Receptive of Design Input

Considered Best Practice for new Product Programs

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FBTol Benefits

- **Product Modeling**
  - Defines the next generation of product definition
- **Tolerance Definition**
  - Creates and represents fully semantic 3D functional tolerances
- **Feature Recognition**
  - Recognizes tolerance features automatically
- **Tolerance Inference**
  - Infers correct tolerances automatically
- **Product Design Validation**
  - Checks and grades piece part tolerance representations
- **Semantics for Display of Annotations**
  - Provides basis for graphical annotations
- **Model-Base Applications**
  - Provides explicit tolerance data for downstream applications
- **Tolerance Data Exchange**
  - Generates and / or validates complete and unambiguous exchange

FBTol - Tactics & Strategies

Max - Min Material Part

- Create maximum and least material part from FBTol tolerances

Automated Drawing

- Generate drawings from validated FBTol tolerance definition

CAD System Augmentation

- Enable CAD systems / applications with smart 3D tolerances

Tolerance Data Exchange

- Exchange of tolerance data from system to system (AP203e2, AP242)

Feature-Based Measurement Planning

- Use FBTol for model-based measurement planning and auto generation of CMM measurement part programs

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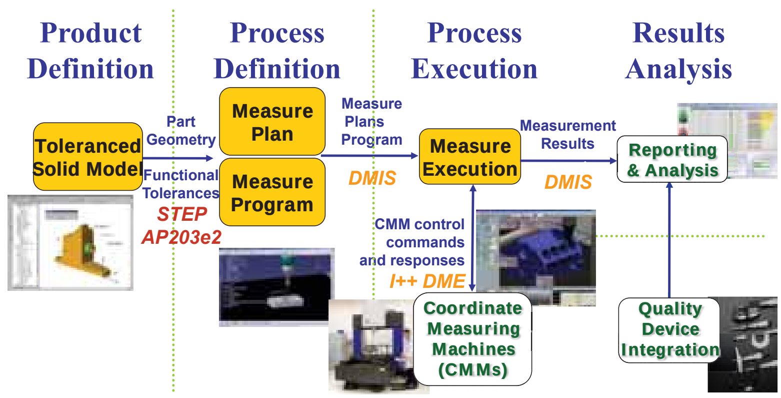
Dimensional Metrology Enterprise



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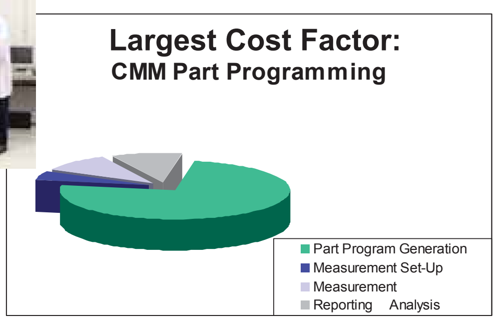
Coordinate Measurement Cost Budget



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FBMeas™

Feature-Based Measuring™

a Component Technology for Measurement Process Planning & Part Program Generation

ENABLED™

Transforms Product Requirements (Functional Tolerances) into a Measurement Action Plan that Produces a Viable ISO Standards-Based Dimensional Metrology Part Program

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Requirements for Next Generational Measurement Process Planner

Automation:

- ***Full Semantic Representation of Tolerances***
- ***Measure Feature Recognition***
- ***Part Coordinate System Recognition***
- ***Measurand Determination***
- ***Measure Point Generation***
- **DME Resource Selection**
- **Sensor Accessibility Analysis**
- **Workpiece Placement**
- **Sensor Selection & Orientation**
- **Measurement Plan Inference**
- **Measurement Plan Centric**
- **Inter & Intra Feature Clearance Moves**
- ***Measurement Part Program Output (ISO DMIS)***

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Feature-Based Measuring

Solid Modeler Kernel (Parasolid, ACIS)
Feature-Based Tolerancing (FBTol) Advisor

Feature-Based Measuring (FBMeas) Advisor

- From Tolerances, Auto Recognize Measure Features, Part Coordinate Systems, Measurands
- Distribution PtMeas
- Determine Resources (Sensors, CMMs)
- Generate CMM Measure Plan
- Output ISO DMIS Part Program

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Demonstration

From a Solid Model ….
to a Full-Semantic Toleranced Solid Model
to a Validated Tolerance Definition
to a Measurement Process Plan
to a CMM Part Program

…Model to Plan to Program in 10 Minutes

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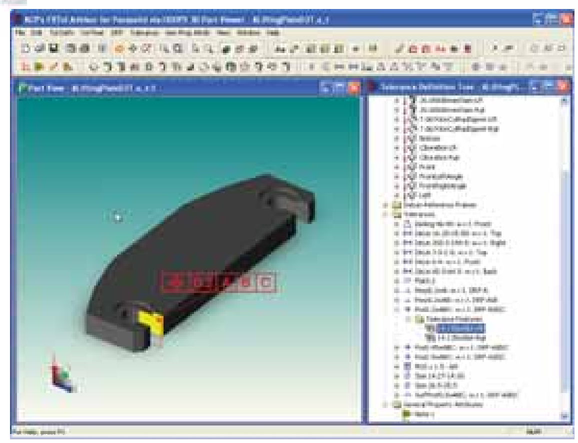
Fly-By Demonstration



Click for FBTol/FBMeas LiftingPlate Demo Video – by Curtis Brown

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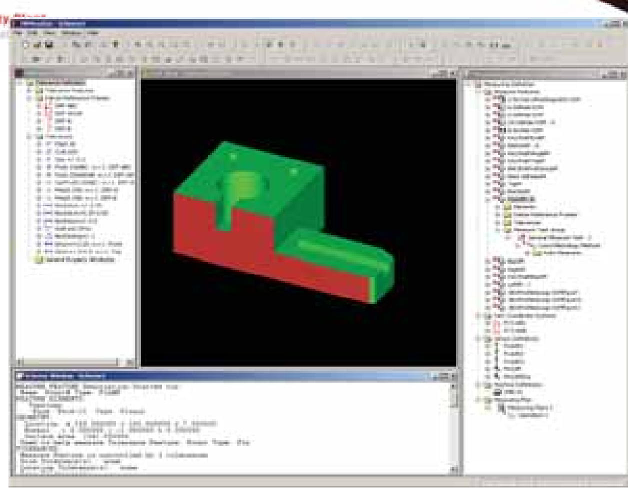

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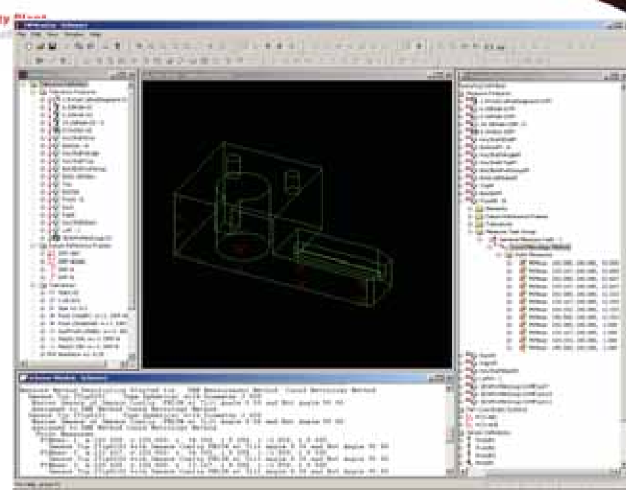

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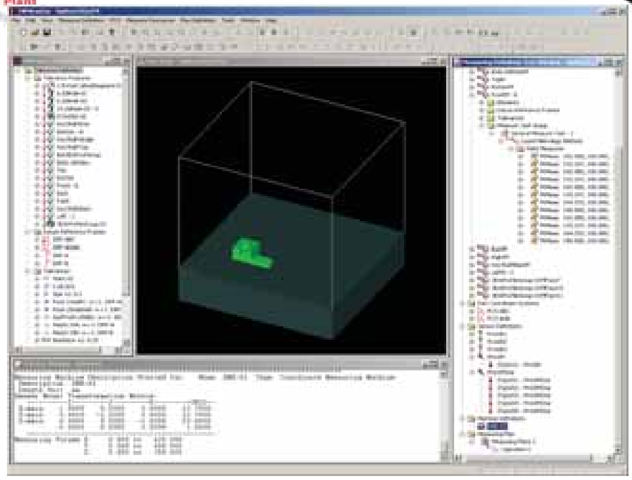

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Working with the KCP

Partnering Mechanisms:

- &*Work for Others* (WFO) Contract services from the KCP as cost recovery only.
- &*Cooperative Research Development Agreement* (CRADA) KCP and partner collaborate in creating new Intellectual Property
- &*Licensing KCP Intellectual Property* for the purpose of maturation and commercialization of KCP technologies.

Way Forward:

- &*Progress Shared Agendas* – Mandates NNSA (KCP) invented technology be transferred to the benefit of the US economy and/or US industry.

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Summary

- Feature-Based Tolerancing
  - Manages the complexity of ASME Y14.5 GD&T of piece parts.
  - Represents and checks part designs per standards.
  - Enables next generation (smarter) automation.
  - Could be integrated into a leading CAD system with the appropriate partnering.
- Feature-Based Measuring
  - Manages the complexity of rapidly generating valid CMM part program to dimensionally certify products.
  - Demonstrates a next generation manufacturing application from toleranced enable solid models
  - Functional prototype that could be extended/enhanced with partners.
- Partnering
  - Collaborate a common agenda
  - Progress your agenda

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Questions?

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Principal Mechanical Engineer
Kansas City Plant
816-997-3548 • cbrown@kcp.doe.com

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Rolls-Royce

MBD For Dimensional Quality Within a Heterogeneous Supply Chain

ARMY/NIST MBE Summit – December 13th 2011

Nick Orchard Rolls-Royce plc
Ron Snyder Rolls-Royce Corporation

Rolls-Royce today

We design, develop, manufacture and support power systems for use on land, sea and air.

Rolls-Royce

Extending our portfolio

A truly global company

9000 engineers spread over 8 countries worldwide

Rolls-Royce Indianapolis facilities

Rolls-Royce Corporation and LibertyWorks®

RRC Engines for Military and Commercial Applications

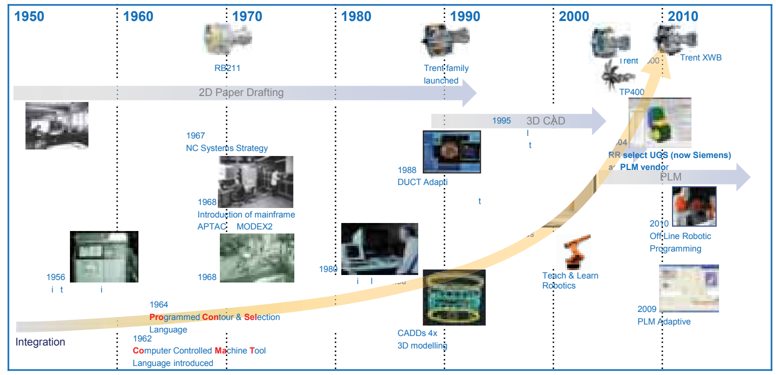
Unique STOVL technology for JSF

Partnerships with competitors

- **Pratt & Whitney – V2500**
- **GE F136 development**
- **Honeywell T800**

We don't make cars

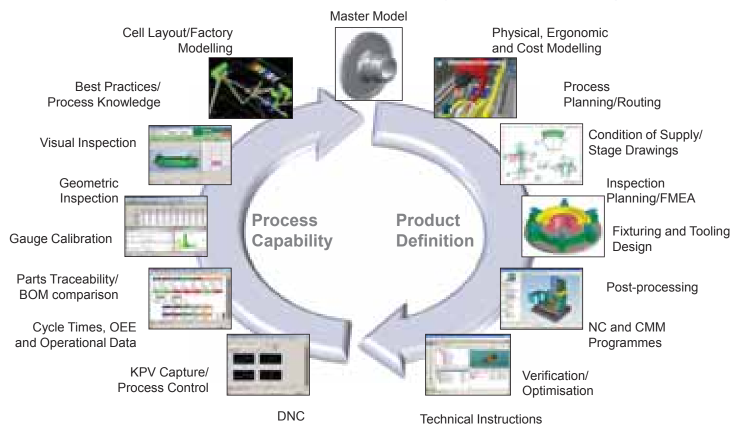
A History of CAD/ CAM – Rolls-Royce GTSC



- Migration from ***"Best in breed"*** applications to ***"Fully integrated solutions"***
- Deployed solutions need to support Product Lifecycles <u>**in excess of 25 years**</u>

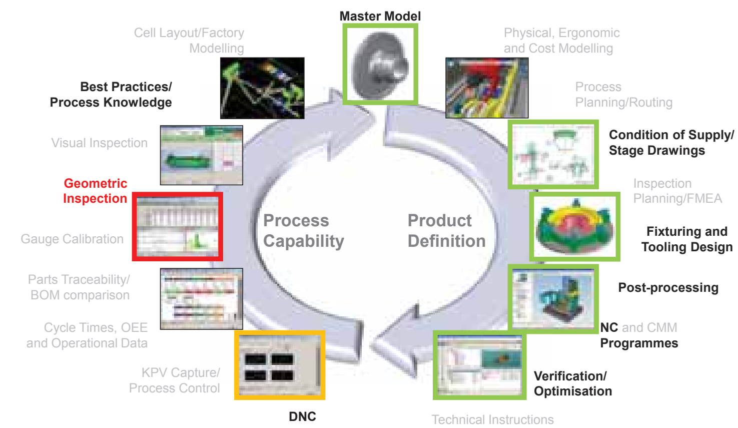
Rolls-Royce

Sustainable world-class performance though cross-functional process and systems integration



Rolls-Royce

How does CAM deliver the vision? &

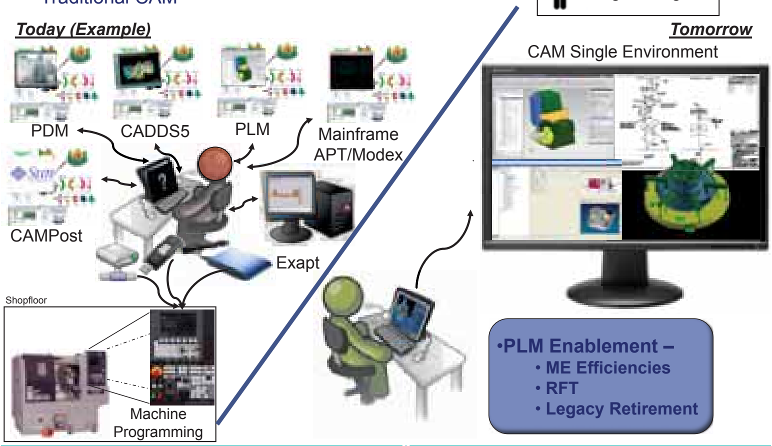


Rolls-Royce

"A Day in the life of an ME"

Traditional CAM

Manufacturing Engineering



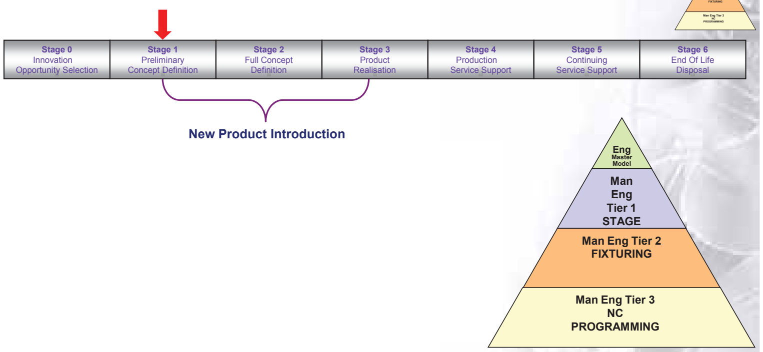
Rolls-Royce

What is CAM Capability Development in PLM?

Technical Package Deliverables are authored <u>concurrently</u> and managed within the PLM environment. This 'approach' enables the delivery of CAM (PLM) components as part of the Concurrent Engineering Process.

Rolls-Royce

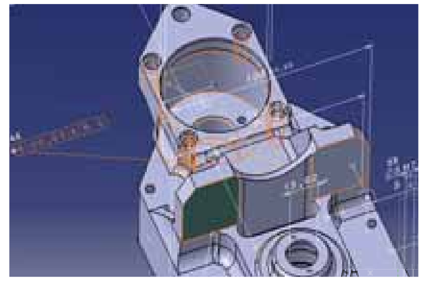
PLM ‘supporting’ R-R’s Concurrent Engineering Process



- **Definition evolves over time**
- **Downstream data content increases**

What is PMI?

- Product and Manufacturing Information is a set of annotation tools used to document products in 3D environments
- It allows definition of more useful information than is possible on a 2D drawing
  - For example, each PMI object can have associated geometry, thereby conveying information to downstream applications
- PMI objects include:
  - 3D Dimensions
  - Datums
  - Datum targets
  - Feature control frames
  - 3D annotations
  - Notes
  - Symbols
  - Geometric tolerancing
  - Security markings
  - User defined PMI
  - PMI Section Views



Manufacturing Pull or Engineering Push?

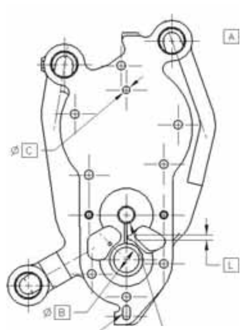
- Stage Inspection
  - Manufacturing Engineering Populate Model
- Machining Knowledge Editor (CAM) utilises PMI to aid feature recognition and recommend cut strategy
- Final Inspection
  - Engineering Populate Final Definitive Engineering Master
  - Manufacturing Engineering extract for:
    - FAIR
    - IPC
    - CMM Program
    - SPC and Process Excellence

CAD Models - Can one size fit all?

- As built or in-process Manufacturing dimensions don’t always match Design Model
- Design models must be built with Stress Analysis and Manufacturing in mind
  - Analysis doesn’t like included Blends and Radii in the CAD Model
  - CNC programmers and Quality Engineers do!

Populated CAD Models

- Design Perspective



- Dimensions
- Tolerances
- GD&T
- Datums
- …

Populated CAD Models

- Manufacturing Perspective

- Casting Pads
- Primary Datum
- Secondary Datum
- Tertiary Datum

Populated CAD Models

- 3D Scanning Perspective

- Optical or Scanning CMM
- Point Cloud Data
- Is it valid?
- Density?
- Standards?

Populated CAD Models – Points to Consider

Optical Scanning

- How do we make decisions when using point cloud data?
- How do we define the “right” number of points?
- Qualification of the Optical Based Inspection Standard
- Industry Lack of Optical Based Inspection Standard
- VDI/VDE are still a CMM Based Spec.

Rolls-Royce

Populated CAD Models – Points to Consider

Models

- Complete/Released
  - Design
  - Stages of Manufacture
  - Dimensionally Toleranced
  - Validated for all uses
- Configuration Management
  - Naming Convention
  - Feature Identifications
  - Revision Control
  - Model Ownership
- Knowledge Capture and Management
  - Standard Features
  - Standard Processes

GD&T

- What Level Imbedded
- Stack up and tolerance checks
- Repeated Features

Rolls-Royce

Agenda

- Mission and Vision
- Challenges in Our Industry & Supply Chain Risk
- DMSC Value of Information Exchange Standards
- CAV
- Improving first article inspection in a model centric environment
- The Importance of FAI
- Using Tools to improve AS9102 Compliance
- QMS Pilot Project
- Business process mitigates against successful FAI for Many Weapons Systems

Quality Planning/Processes; Our Key to Success

Mission and Vision

Our Vision

Powered by Innovation, Guided by Integrity, We Help Our Customers Achieve Their Most Challenging Goals

Our Values

- *Do What's Right*
- *Respect Others*
- *Perform With Excellence*

Our Mission

To Provide Superior Weapon Systems and Advanced Technologies that Protect Our Warfighters

Fundamental Business Principle

Our Business is Not the Objective … It is the Result

Performance Is Our Objective

Peoples Lives are At Stake….

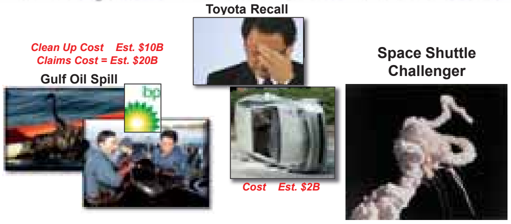
Toyota Recall

Clean Up Cost Est. $10B
Claims Cost = Est. $20B

Gulf Oil Spill

Cost Est. $2B

Space Shuttle Challenger



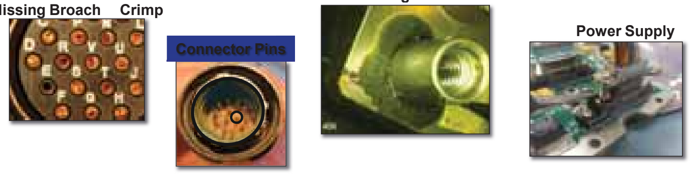
IMPACTS

- Loss of Reputation
- Financial Loss
- Product Performance
- Product Recall
- Loss of Business

Missing Broach Crimp

Plating Issue

Power Supply



A Great First Article Inspection Can Catch Mistakes

Supply Chain Quality Risks

Risks

- Domestic and International Economy
- 2nd and 3rd Tier Supplier Performance
- Government Policy Changes
- International Trade Regulations
- Increased GIDEP Notifications

Quality Pressures

- Supply Chain, 2nd & 3rd Tier
- Experienced Talent
- Supplier Value Stream
- Fixed Price
- Non Traditional Quality is Less Tangible
- Technical Challenges

Various Quality Strategies

- Development
- Production
- Life Cycle
- Subcontracts
- Distributors
- COTS/MOTS
- Service
- Software
- Hardware
- Labs

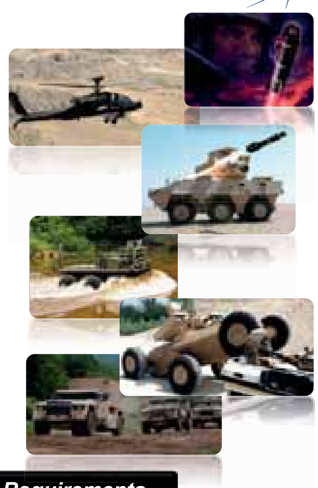
CAV & FAI Critical to Success

99.99% Success Rate Is Unacceptable

CAV

•Characteristic Accountability & Verification (CAV) – a process used to ensure that all Critical and Major characteristics are defined and accounted for in the product technical data package and manufacturing and quality plans, and to ensure that manufacturing planning includes controls adequate to ensure continued conformance of these characteristics.

•All Components shall be subjected to First Article Inspection in accordance with AS9102. Those with Critical and/or Major Characteristics shall be subjected to recurring First Article Inspections. Critical or Major characteristic inspection shall be performed at the lowest possible component level that allows adequate inspection of the Critical or Major characteristic.



What Are The Requirements

Top Product Definition Issues

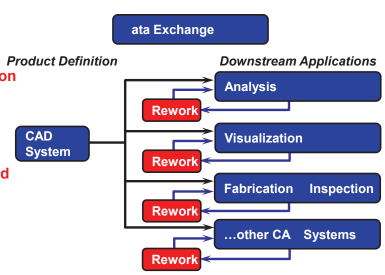
•CAD data (including GD&T) does not flow seamlessly to downstream processes when components are not from same vendor.

•GD&T data is not associated with individual features of the part (the CAD model) which makes it impossible to automate inspection process programming. If GD&T information is expressed as annotations in CAD files or as notes on drawings, it is not available to automated computer processes that can use it.

•It is difficult if not impossible to know if a vendor truly supports a standard as advertised. When a vendor claims that its product conforms to a standard, there is often no means of certifying that the product actually does conform to the standard as claimed. There continues to be divergence in the use and interpretation of GD&T standards both within the U.S. and at the international level. Some major companies have adopted internal variations in the way that they interpret and apply the standards. It is believed that this practice will result interoperability problems in the near future. The standards effort must be international, involving multiple government standards organizations.

•Crosscutting Issue: There are currently no "consensus" approaches to the interconnection of components/systems. The "big picture" needs to be defined before unified efforts can be developed to solve this important problem. There is no shared vision between vendors and users for interoperability

Top Inspection Process Definition Issues



•The lack of comprehensive non-shape information available from the product

•Definition model – CAD tolerance data, material properties, optical properties, etc.

•The lack of a standard mechanism to capture and exchange knowledge – including

•Methods, practices, and rules.

•The lack of resource definition from the product definition model or elsewhere – such

•As inspection equipment capability, capacity, available configuration, performance,

•Measurement uncertainty, etc.

•Does DMIS support all measuring devices?

•The macro-to-multiple-micro planning interface is not well defined.

Benefits of Model Centric

•&Shorten Design Cycle Improve Quality by Eliminating Parallel Data Paths
- – Avoid conflicts between model and drawing
  - • Minimize risks associated with data re-creation
  - • Minimize costs by facilitating data reuse
- – No need to recreate model dimensions to capture design intent
- – Enable design activities to better collaborate through sharing models
- – Enable the future management of key characteristics (per AS9100) and their relationships to product definition data

•&Enhance Downstream Data Sharing via Configuration Managed Models
- – Enhance Visualization
  - • Model use in Documentation
- –& Streamline simulation to optimize the total product design throughout the life-cycle
  - •& Manufacturing Engineering and our suppliers fabricate and Inspect from model data

• Competitive Industry Requirement
- –& Leverage efficiencies related to the use of standards for data exchange and electronic data transfer throughout our supply chain

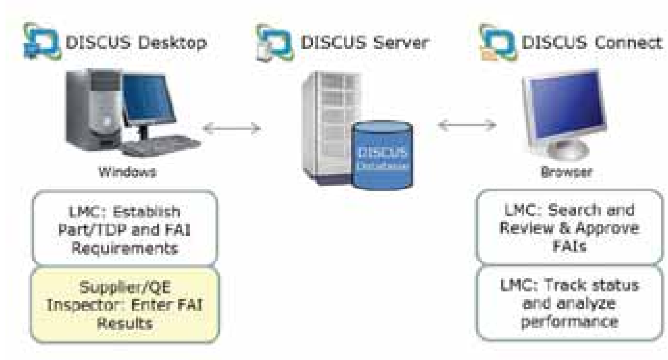
Why the FAI is so important

- Customer requirement
- Reassurance that we are compliant to specifications
- & Repeatable process
- & Parts are built correctly
- & Assure the shop/supplier is capable

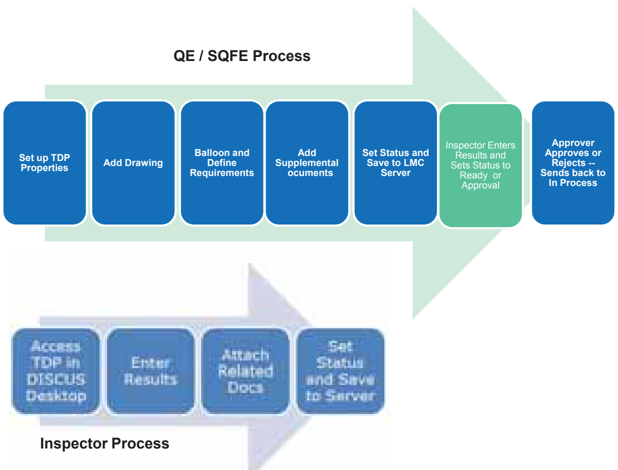
What You Need to Perform FAI

- Knowledge of FAI Process
- Work Instructions/Planning for part (SAP)
- BOM/Parts List
- FAI Checklist
- & Vaulted Drawing and all engineering requirements

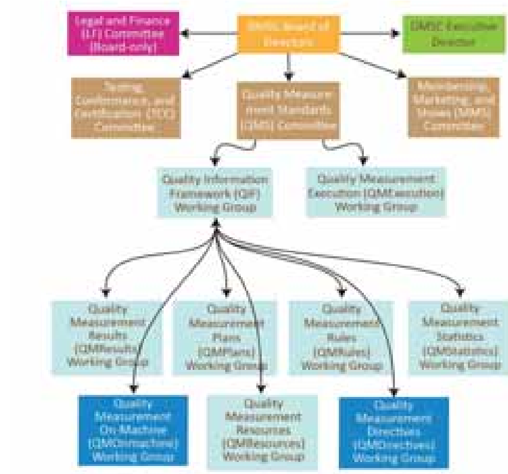
New DISCUS Process



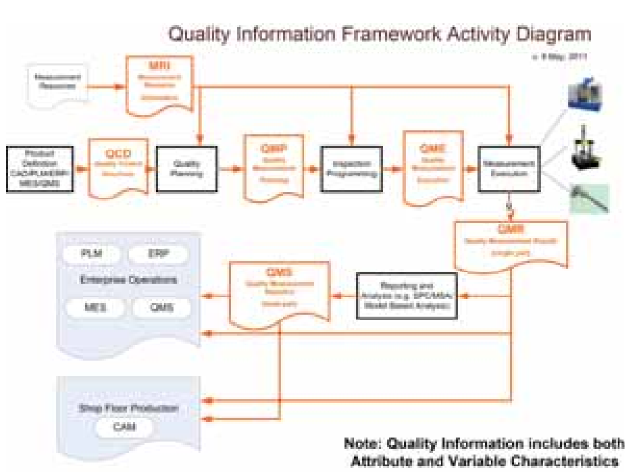
TDP Process

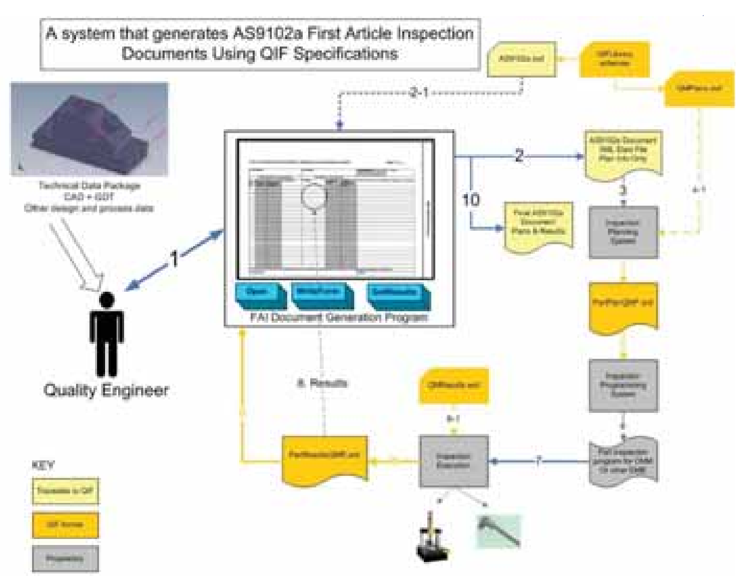


DMSC Organization

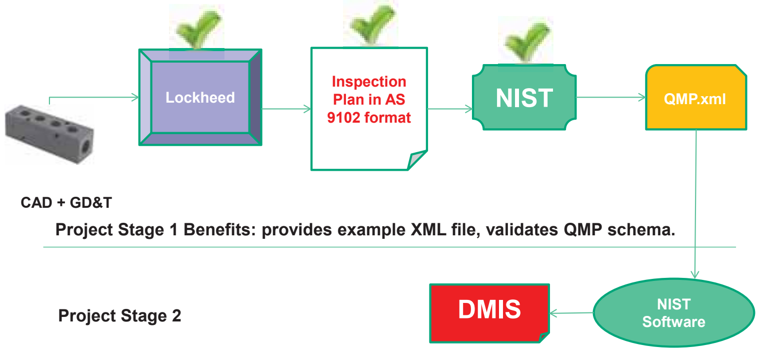


QIF Activity Model





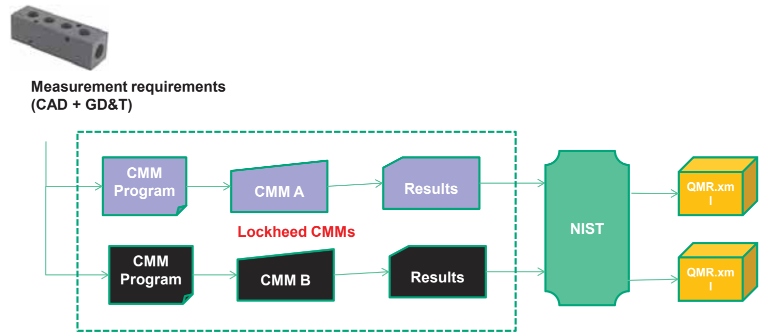
QMS Pilot Project (NIST-LMC)



Quality Measurement Planning Pilot Project

Hypothetical Stage 3: A measurement planning solution provider may export QMP from its planning software. This stage is only doable when the first two stages are successful and attract interest from Lockheed management level and vendors.

QMS Pilot Project (NIST-LMC)



Quality Measurement Results Pilot Project

Project Stage 1: Benefits: validate QMR schema; provides example QMR files; demonstrates interoperability of QMR.

Hypothetical Stage 2: A CMM software vendor may generate/convert measurement results in QMR. This stage is only doable when the first stage is successful and attracts interest from Lockheed management and a vendor.

In Summary

Automation Improves Our Success

- Customer Expectations
- Complexity of Industry and Risks
- Result of Failure is Severe
- MFC Expectations

Product Definition and Requirements are Vital

Protecting the Customer's Interest

MULTI METRICS, INC.
Machine Part Geometry Management

MBD
The Key to Intelligent GD&T

MBE-TDP Summit Conference
Gaithersburg MD 2011-12-13

Bill Tandler

A *Smart*GD&T™ Presentation

MULTI METRICS, INC.
Machine Part Geometry Management

or

MULTI METRICS, INC.
Machine Part Geometry Management

MBD
The Key to Intelligent GD&T
and
Intelligent GD&T
The Key to functional MBD

MULTI METRICS, INC.
Machine Part Geometry Management
*Smart*GD&T

Presentation Overview

1. Objectives
2. MBD and its Promises
3. GD&T and its Promises
4. An Example: "Decorative" versus "Functional" GD&T
5. An ~~Exam~~ple: "Functional" GD&T and Metrology !
6. Conclusions

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Objectives

1. Review MBD and GD&T to assess their promises.

2. Present ideas for helping them fulfill their promises.

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Review & Assessment of
MBD

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Machine Part Geometry Management
*Smart*GD&T
MBE + MBD

1) What is MBD? Among many other things . .

A computational environment which creates a truly functional connection between the 3D features of a machine part and the tolerance zones defined by GD&T to limit their imperfection.

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Machine Part Geometry Management
*Smart*GD&T
MBE + MBD

2) What is MBD for? Among many other things . .

To enable the intelligent application of GD&T controls in the 3D model space, and their intelligent transfer to largely automated downstream processes.

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Machine Part Geometry Management
*Smart*GD&T
MBE + MBD

3) What are MBD's promises?

1. To vastly improve the ability of mechanical engineers to produce fault tolerant, functional designs right from the get-go.
2. To largely automate the Tolerance Stack-Up Analysis process.
3. To completely automate coordinate metrology.

*Smart*GD&T&
MBE + MBD&

4)&Does MBD fulfill its promises?

At this point, only to a very limited extent !

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MBE + MBD

5) What limits the ability of MBD to fulfill its promises?

1.&The continuing inadequacy of, and confusion surrounding certain Y14.5 and ISO 1101 definitions of GD&T concepts, tools and rules, makes **fully comprehensive** MBD implementation **impossible** at this juncture.

Very sad !

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MBE + MBD

5)&What limits the ability of MBD to fulfill its promises?

2.&In spite of recognizing its benefits, widespread confusion caused by the complexity of GD&T, leads many potential users to simply avoid it and certainly to fail to even wonder if GD&T "encoding" could ever be intelligently supported.

*Smart*GD&T
MBE + MBD

5)&What limits the ability of MBD to fulfill its promises?

3.&The messy maze (**FUR BALL**) of GD&T callouts which commonly swarm around MBD enhanced 3D models causes even pro-GD&T users to still prefer the 2D drawing environment, thus further limiting interest in MBD systems.

*Smart*GD&T
MBE + MBD

5)&What limits the ability of MBD to fulfill its promises?

4.&The still **limited intelligence** of current MBD products, and their **less than brilliant ergonomics**, leads to further reductions in enduser interest and demand.

*Smart*GD&T
MBE + MBD

5)&What limits the ability of MBD to fulfill its promises?

5. Limited enduser demand for intelligent GD&T encoding leads to limited interest on the part of CAD companies to invest in their refinement, leaving MBD still far from being able to fulfill its promises.

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MBE + MBD

6) What's the impact of MBD's Failure to fulfill its promises?

1. Continued mis-use of GD&T in the 2 D drawing environment.
2. Low enduser demand for MBD due to ignorance of its potential and therefore low incentive for developers to invest in its refinement.

Oh BAD ! So SAD ! Makes one terribly MAD !

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MBE + MBD

7) How can MBD be made to fulfill its promises?

1. By cleaning up the foundations of GD&T to enable intelligent MBD implementation.
2. By moving forward with the development of a truly smart, highly ergonomic MBD based GD&T encoding engine, in the absolute certainty of payback when the champagne hits the fan.

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Review & Assessment of

GD&T

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What is GD&T ?

Many people think of GD&T as

Grim, **D**epressing **T**roublesome

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and a fine way to waste a

Great **D**eal of **T**ime

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But others find GD&T

Grand, **D**elicious **T**antalizing

*Smart*GD&T

and in fact the . . .

Greatest **D**esign **T**ool

ever !

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GD&T

is therefore all about

managing imperfect geometry

perfectly!

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And without

GD&T

all

Tolerance Stack-Up Analysis

Coordinate Metrology

are meaningless

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Purpose of GD&T

Most people would say . . .

The main purpose of GD&T is to communicate Design intent **unambiguously** to manufacturing and inspection !

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Purpose of GD&T

but in fact . . .

The primary purpose of GD&T, is to ensure that **what** we communicate is **worth** communicating, namely represents manufacturable, assemblable and operational parts.

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In greater detail . . .

Definition of GD&T

GD&T is a symbolic language for

1. **researching**
2. **refining** and
3. **encoding**

the **functions** of each feature of a part and for maximizing the **fault tolerance** of a Design,

in order - through **decoding** - to

1. **guarantee assemblability** through truly functional, Tolerance Stack-Up Analysis
2. **reduce manufacturing cost** by setting precise, achievable objectives
3. turn **inspection** into a **scientific process**

How is GD&T used in **Design**?

1. For **researching** the functional interaction between mating product components during early design stages,
2. For **refining** the geometry of certain features in order to maximize the fault tolerance of a design,
3. For **guaranteeing** the assemblability of in spec mating parts through tolerance stack-up analysis, and
4. For **encoding** the functions of each feature of a part in absolutely unambiguous terms to specify its geometric requirements for manufacturing and inspection.

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How is GD&T used in **Manufacturing**?

GD&T does not specify manufacturing **PROCESSES** **!**

It merely specifies manufacturing **OBJECTIVES**, and serves only to guide the selection and management of manufacturing processes.

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How is GD&T used in **Inspection**?

GD&T does not specify inspection **OBJECTIVES** **!**

It specifies inspection **PROCESSES** in their entirety.

Without GD&T, metrology, and therefore effective assessment of **end product quality** and **manufacturing process quality** are simply impossible

*Smart*GD&T&

3)&What are GD&T's Promises?

1.&To guarantee absolutely reliable **tolerance stack-up analysis** on which to base acceptance or revision of the code.&

2.&To guarantee absolutely reliable **communication** of **design intent**, to enable manufacturing to make it right the first time.

3.&To enable absolutely reliable, **fully automatic** coordinate metrology.

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4)&Does GD&T fulfill Promises?

Almost, but with great difficulty !

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5)&Why does GD&T fail to fulfill its Promises?

1.&Due to the difficulty of mastering its **necessary complexity**, namely the complexity of its code which enables it to deal effectively with the complexity of imperfect real geometry.

2.&Due to the continuing **imprecision** of certain concepts, tools and rules defined in the ASME Y14.5 and ISO 1101 Standards.

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6) What's the impact of GD&T's failure to fulfill its promises?

Huge wastes of time struggling to **interpret** GD&T **decorated** drawings and the the cost of getting it wrong.

Reduced interest on the part of users and developers **in perfecting MBD**, the only hope we have for reliably managing and partially or completely automating:

1. The GD&T encoding process.
2. Tolerance stack-up analysis.
3. Inspection processes.

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7) How can GD&T be enabled to fulfill its promises?

1.&By being reduced to crystalline sets of concepts, tools, rules, processes and best practices in refined & versions of the current Standards – or – for example as captured in the heuristics of ***Smart*GD&T™ *Technology*** !

2.&By then being empowered by intelligent, ergonomic implementation in the world of MBD.

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"Decorative" versus "Functional"

GD&T

"Decorative" versus "Functional"

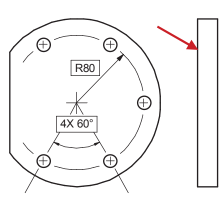
GD&T

Encoding the functions of the Features of a

Flat Edged Vacuum Flange

Functional Objectives

1) One face of the flange shall be flat within 0.01mm to create a reliable vacuum seal with an O-ring in a mating flange.



"Decorative" versus "Functional"

GD&T

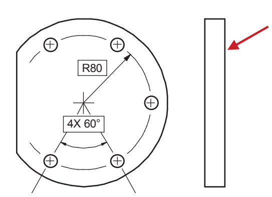
Encoding the functions of the Features of a

Flat Edged Vacuum Flange

Functional Objectives

1)& One face of the flange shall be flat within 0.01mm to create a reliable vacuum seal with an O-ring in a mating flange.

2) The opposing face shall be located within 1mm but parallel to the first within 0.1mm.



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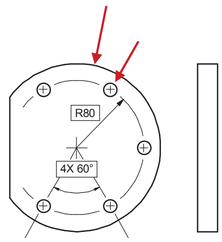
1)& One face of the flange shall be flat within 0.01mm to create a reliable vacuum seal with an O-ring in a mating flange.

2)& The opposing face shall be located within 1mm but parallel to the first within 0.1mm.

3) The bolt hole pattern shall be loosely centered in the flange but otherwise tightly controlled to serve as a locating feature.



“Decorative” versus “Functional”

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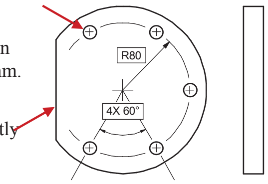
2)& The opposing face shall be located within 1mm but parallel to the first within 0.1mm.

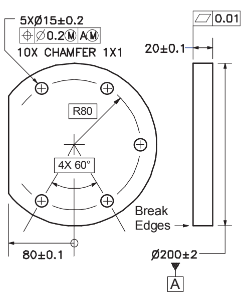
3) The bolt hole pattern shall be loosely centered in the flange but otherwise tightly controlled to serve as a locating feature.

4)& The left hand edge of the flange shall be tightly controlled relative to the bolt pattern to reliably align and locate a mating part.



“Decorative” versus “Functional”

GD&T

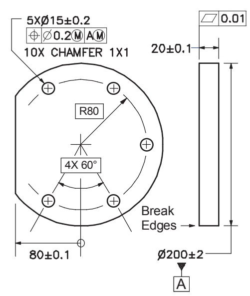


First cut !
How are we doing?

“Decorative” versus “Functional”

GD&T

The
“decorated”
Drawing

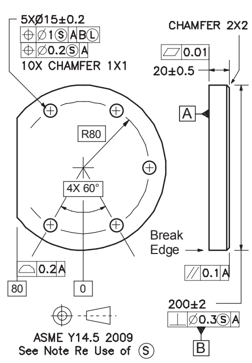


1. Part symmetry should have been broken but was not.
2. Thickness tolerance was made tighter than necessarily to control parallelism.
3. Datum Feature A is non-functional for the purpose assigned to it.
4. The Tolerance Zone Size modifier (M) on Position does not encode the location function of the bolt pattern.
5. The control on the flat edge in no way represents the required constraints.

“Decorative” versus “Functional”

GD&T

Second cut !
How are we doing?

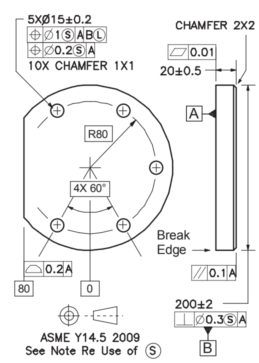


“Decorative” versus “Functional”

GD&T

The
“functional”
Drawing

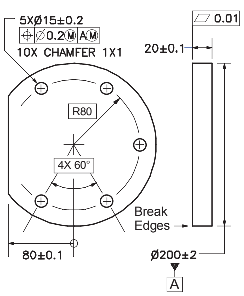
1. The symmetry is broken.
2. The thickness is controlled loosely and the flatness and parallelism of the faces independently and functionally.
3. A Y14.5 Standard is referenced and the projection preference is specified.
4. The Datum Features are functional.
5. The bolt hole pattern and the flat edge are controlled in a manner to fully represent their functions in a highly fault tolerant way.



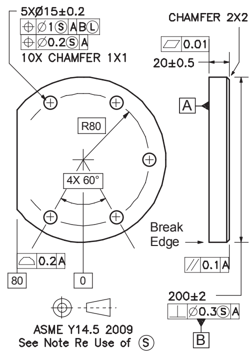
"Decorative" versus "Functional"

GD&T

"decorated"



"functional"



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MBD + "Functional" GD&T

Complete Automation

of the

Coordinate Metrology Process

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An Example of Coordinate Metrology Process Automation

Based on

InnovMetric Inc.'s

PolyWorks Inspector™ V12

A Multi Metrics, Inc.

Smart*GD&T™ *Technology

Licensee

MULTI METRICS, INC.

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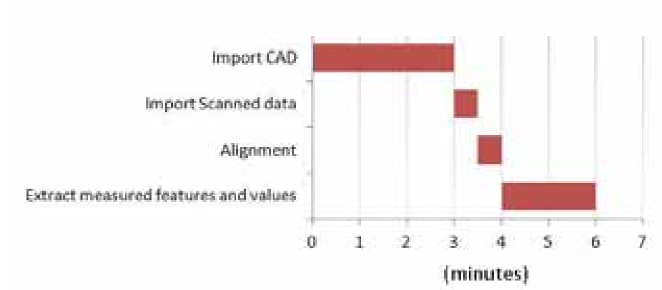
PolyWorks Inspector
Process Steps and Timing

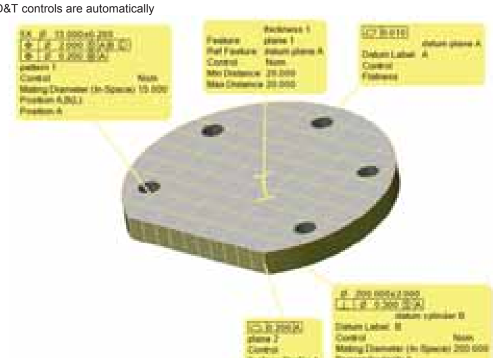


PolyWorks

Flat Edged Flange Inspection

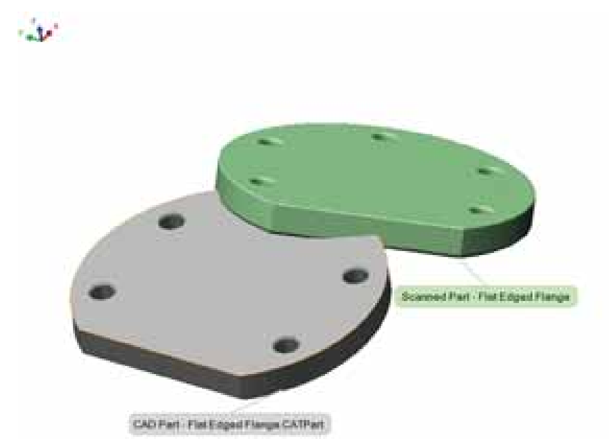
Report Author:
Date: 12/1/2011

1. Import CAD model.
The features and the GD&T controls are automatically imported.

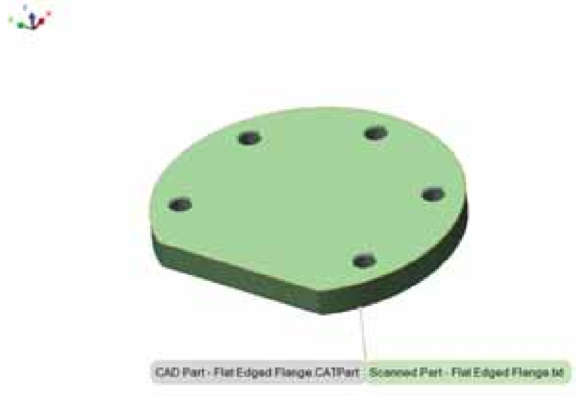


Organization: A company	**Part name:** Scanned Part Flat Edged Flange
Operator: Whoever	**Part number:** 123-456
E-mail: whoever@acompany.com	**Device:** Laser scanner

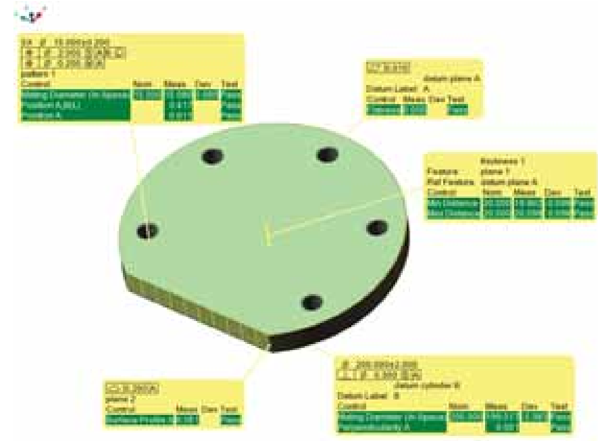
2. Import scanned data



3. Align the scanned data to the CAD model



4. Extract measured features.



5. Inspection results

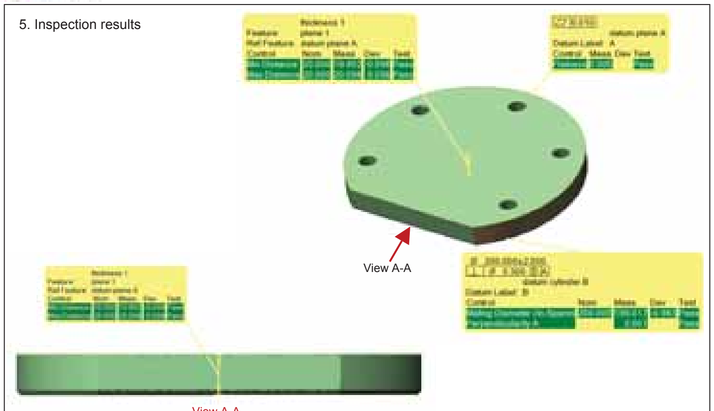


Table Type **Feature**

Name	Control	Nominal	Measured	Tol+	Tol-	TZ Size	Deviation	Test
h ckness 1	M n s ance	20.000	19.902	1.000	1 000		0 098	Pass
h ckness 1	Max stance	20.000	20.098	1.000	1 000		0.098	Pass
da um p ane A	Fla ness		0.005			0.010		Pass
da um cy nde B	Ma ng ame e n-Space)	200.000	199.017	2.000	2 000		0 983	Pass
da um cy nde B	Perpend cu ari y A		0.001			0.300		Pass

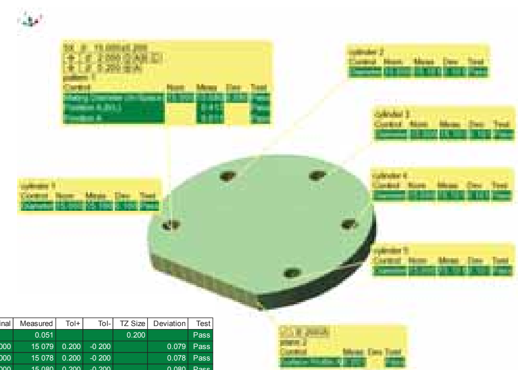


Table Type **Feature**

Name	Control	Nominal	Measured	Tol+	Tol-	TZ Size	Deviation	Test
p ane 2	Su ace Pro e A		0.051			0.200		Pass
patte n 1	Ma ng ame e n-Space)	15 000	15 079	0.200	-0 200		0.079	Pass
patte n 1	Ma ng ame e n-Space)	15 000	15 078	0.200	-0 200		0.078	Pass
patte n 1	Ma ng ame e n-Space)	15 000	15 080	0.200	-0 200		0.080	Pass
patte n 1	Ma ng ame e n-Space)	15 000	15 079	0.200	-0 200		0.079	Pass
patte n 1	Ma ng ame e n-Space)	15 000	15 078	0.200	-0 200		0.078	Pass
patte n 1	Pos on A,B(L		0.417			2.000		Pass
patte n 1	Pos on A,B(L		0.376			2.000		Pass
patte n 1	Pos on A,B(L		0.326			2.000		Pass
patte n 1	Pos on A,B(L		0.320			2.000		Pass
patte n 1	Pos on A,B(L		0.367			2.000		Pass
patte n 1	Pos tion A		0.011			0.200		Pass
patte n 1	Pos tion A		0.010			0.200		Pass
patte n 1	Pos tion A		0.010			0.200		Pass
patte n 1	Pos tion A		0.010			0.200		Pass
patte n 1	Pos tion A		0.010			0.200		Pass

MULTI METRICS, INC.
Machine Part Geometry Management

What is *Smart*GD&T ?

***Smart*GD&T** is a **rule-based**, process driven approach to either the ASME Y14.5M 1994 or ISO 1101 standard, which makes it possible to "**encode**" and "**decode**", rather than "interpret" GD&T, and get it right the first time.

MULTI METRICS, INC.
Machine Part Geometry Management

Conclusions

1. GD&T is the ultimate tool to enable useful MBD.
2. MBD is the ultimate tool to enable functional GD&T.

3. It is time to clean up the ISO and ASME GD&T Standards.
4. It is time to start investing in heavily MBD development.

MULTI METRICS, INC.

Thank you !

Bill Tandler

bill@multimetrics.com

Menlo Park, CA

3D Technical Data Package Validation Demo

Paul Huang, ARL
Simon Frechette, NIST
Roy Whittenburg, UTRS

Date: 11/01/2011

Agenda

- Project Overview
- The Demo
  - –Model Creation
  - –PLM Check In
  - –Derivative Creation
- Conclusions
  - –Questions?

Project Overview

- Project Overview
- Demo:
  - Model Creation
  - PLM Check In
  - Derivative Creation
- Conclusions

The Project

- Objective: To provide a process to Verify and Validate that the Data Quality of the 3D TDP is sufficient for manufacture
- The Team: A multi service and industry set of subject matter experts
  - Government:
    - Army
    - Navy
    - NIST
    - DLA
  - Industry:
    - ITI TranscenData
    - Elysium
    - PTC
    - BAE Systems
    - Boeing
    - Jotney
    - Vistagy
    - Anark
    - I-Cubed
    - Tetra4D

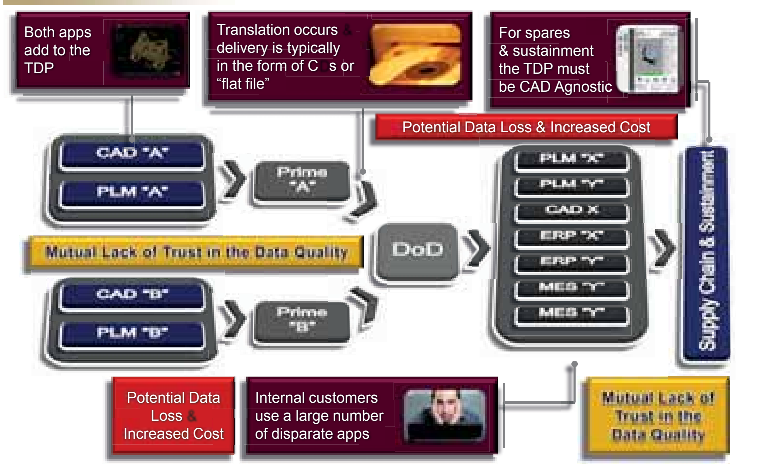
The Need

- Since the DoD is inherently 2D and drawing based there is no method of verifying the quality of the 3D data they receive
- As a result the prevailing view is that the data is not reliable for use by in the non design portions of the lifecycle
- &When used it is often translated into a new format possible introducing more errors
- All of this has fostered an inherent distrust of the data that could be reused in the lifecycle thus driving up cost and time to mission

Without Verification & Validation there is no trust

RDECOM

The Enterprise Driver

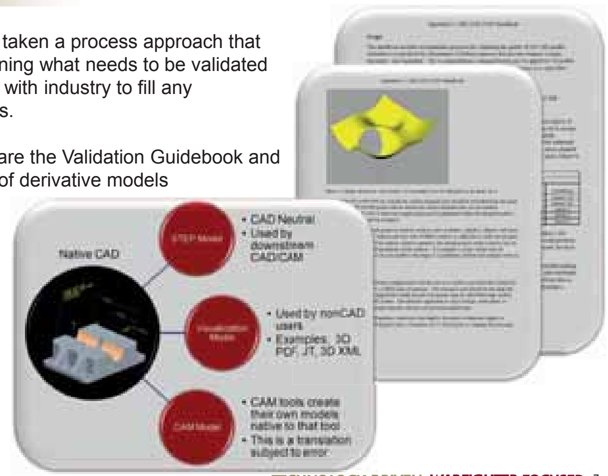


RDECOM

The Approach

The team have taken a process approach that focuses on defining what needs to be validated and then works with industry to fill any technology gaps.

Two examples are the Validation Guidebook and the verification of derivative models



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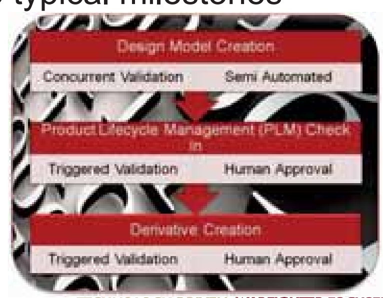
Demo

- Project Overview
- Demo:
  - Model Creation
  - PLM Check In
  - Derivative Creation
- Conclusions

RDECOM

Demo Framework

- What follows is a demonstration of how validation tools could be inserted into the typical Model Process
- It centers on three typical milestones
- We will follow a data set through this process



RDECOM

Model Creation

- Project Overview
- Demo:
  - Model Creation
  - PLM Check In
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- Conclusions

RDECOM

The Milestone

- As the name states the Model Creation milestone covers the act of building the model
- This is further broken down into segments, each of which has its own validation point
- These checks can and should be done multiple times or interactively before a step is completed in order to catch the problem when it is the easiest to fix, early…

Early Error Detection = Reduced Time Cost

Typical Modeling Process &

Primary Feature Creation
Initial Geometric Checks | Integrated Tool

Secondary Feature Creation
Initial Geometric Checks | Integrated Tool &

Tertiary Feature Creation
Initial Geometric Checks | Integrated Tool &

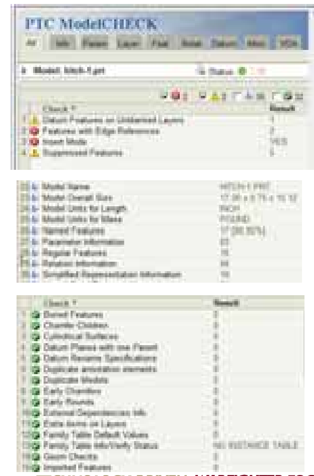
Initial Cleanup &
Full Geometric Checks | Integrated Tool

Documentation
Format Checks | Manual | Integrated Tool

Final Modeler Review
Full Checks | Manual | Offline Tool &

Interactive Quality Reporting

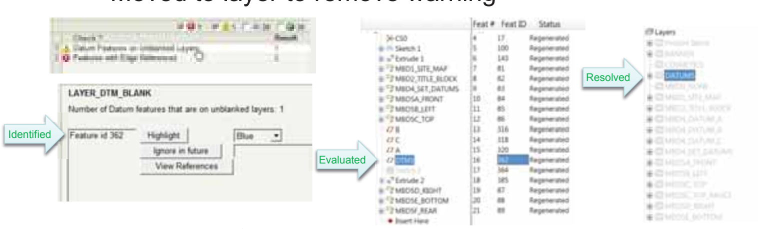
- Results Example
  - – Errors
  - – Warnings
  - – Information
  - – Pass
- Most errors can be identified early and fixed on the fly
- Process:
  - > Identify > Evaluate >Display & Resolve



Images provided by PTC

Enforcement of Organizational Rules

- Besides Geometry and Design checks, & organizational or schema rules can be enforced
- Example: Datum Features should be Blanked on Layers
  - Identified by feature number &
  - Moved to layer to remove warning

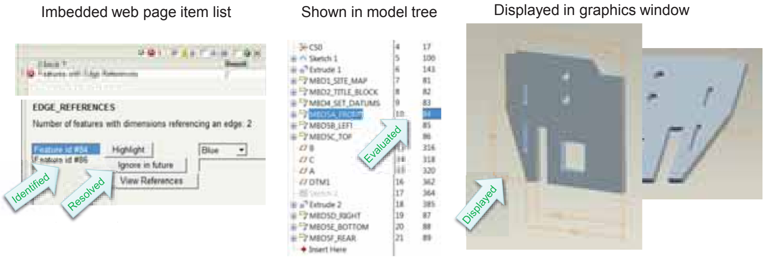


Images provided by PTC

Reuse Quality Checks

- Issues that can effect the reuse of the model are also checked
- & Feature with Edge References. issue for child geometric features

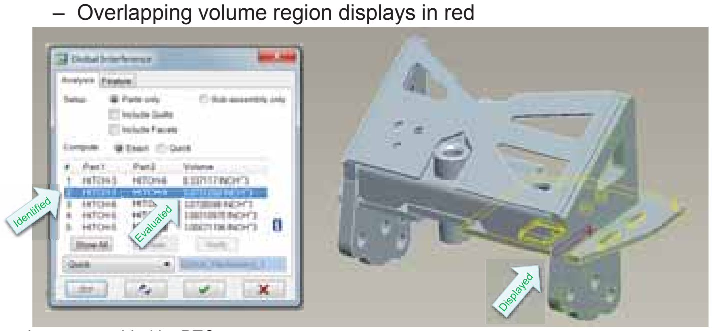
Imbedded web page item list | Shown in model tree | Displayed in graphics window



Images provided by PTC

Assemblies Can Be Checked Too

- Example: Directs designer to run interference check
  - Software finds 5 interferences with volumes
  - Interfering parts are outlined in yellow & green
  - Overlapping volume region displays in red



Images provided by PTC

PLM Check In

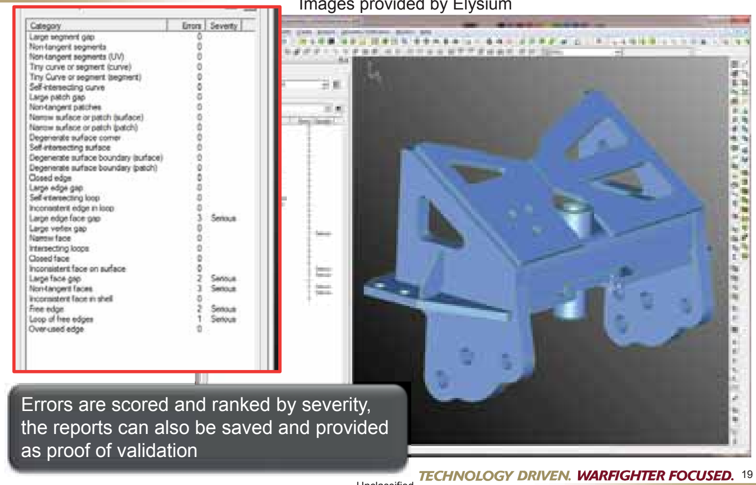
- Project Overview
- Demo:
  - Model Creation
  - PLM Check In
  - Derivative Creation
- Conclusions

The Milestone

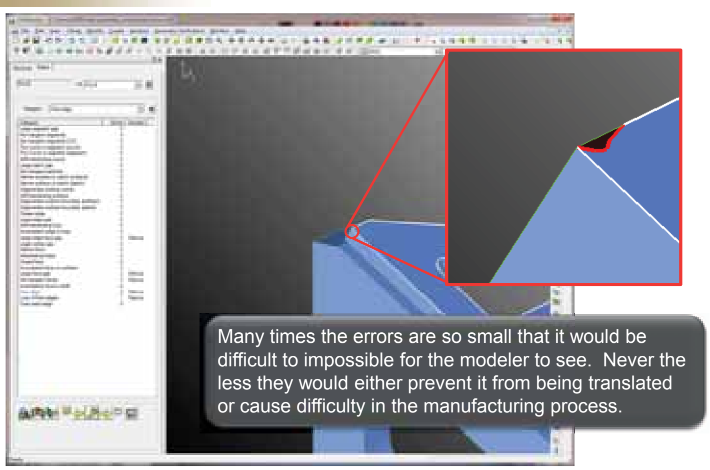
- Once a model has been created it is typically placed or “checked in” to a Product Lifecycle Management (PLM) tool
- At this point a series of checks are run verifying its quality
- If the model does not pass these checks it is not allowed to enter the repository
- At this point it is ready to be shared with others in either a released or unreleased state

Models Are Scored And Reports Saved

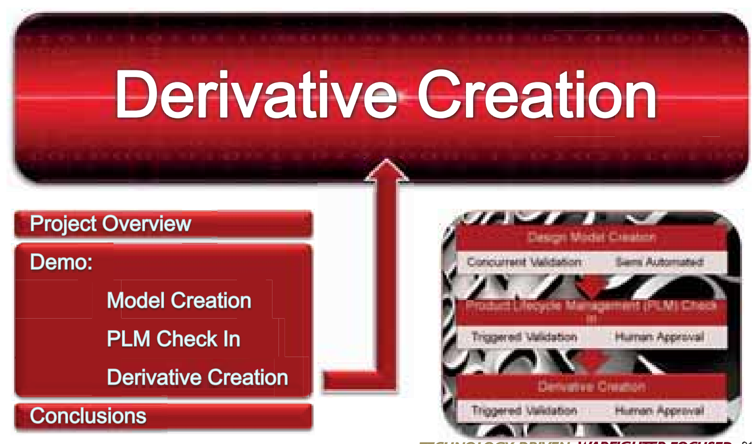
Images provided by Elysium



Full Data Quality Checks Are Run



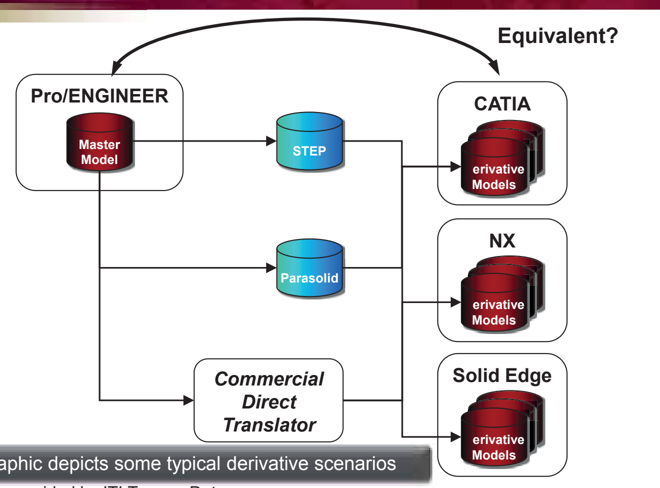
Images provided by Elysium



The Milestone

- Once released to downstream customers and often before that, every model will eventually be translated into another format for consumption
- The translated model is called a derivative
- This derivative must be validated just like the original
- But in addition to checking for normal quality errors it must be checked to make sure it does not deviate from the original

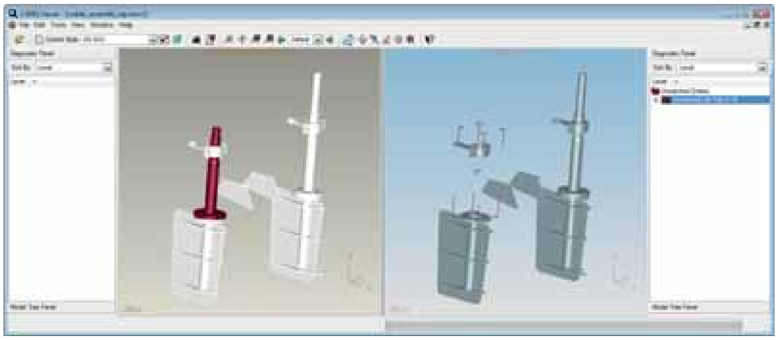
Translation Validation Testing



This graphic depicts some typical derivative scenarios

Images provided by ITI TrancenData

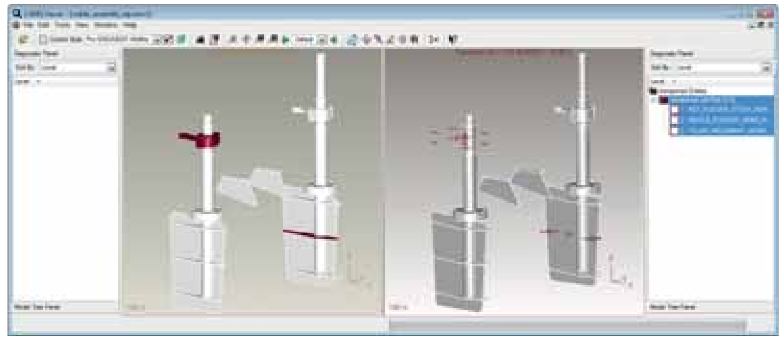
RDECOM Geometry Validation Example



During direct translation from ProE to NX the highlighted part was lost

Images provided by ITI TrancenData

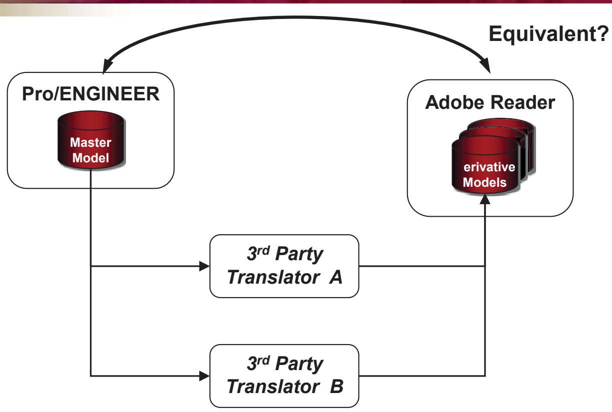
RDECOM Geometry Validation Example



During Parasolid translation from ProE to Solid Edge the highlighted parts were lost

Images provided by ITI TrancenData

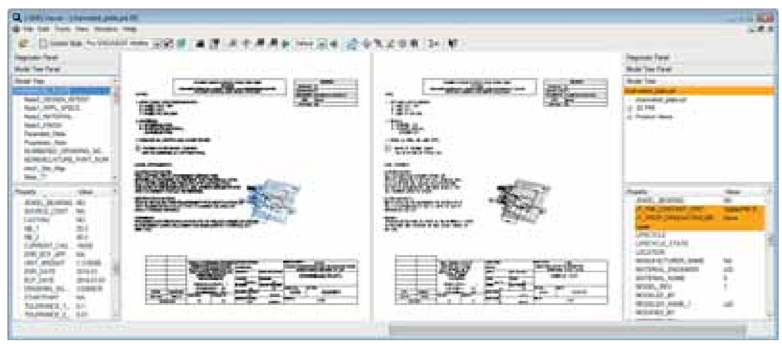
RDECOM PMI Translation Validation Testing



A growing use case is the translation to Adobe 3D PDF. At this point we will also address the Product Manufacturing Information quality

Images provided by ITI TrancenData

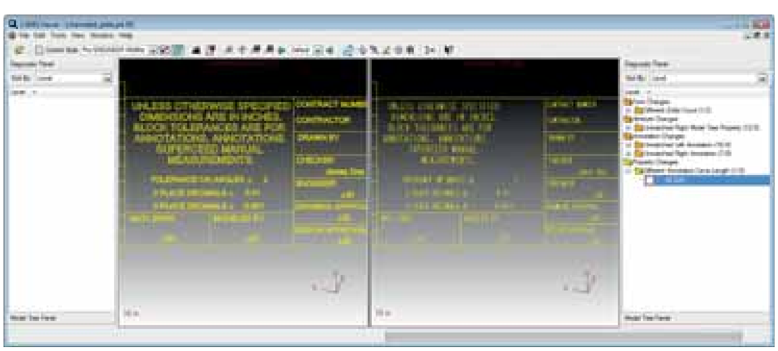
RDECOM Model Attributes Validation Example



During export from ProE to 3D PDF confusing attributes were added to the model

Images provided by ITI TrancenData

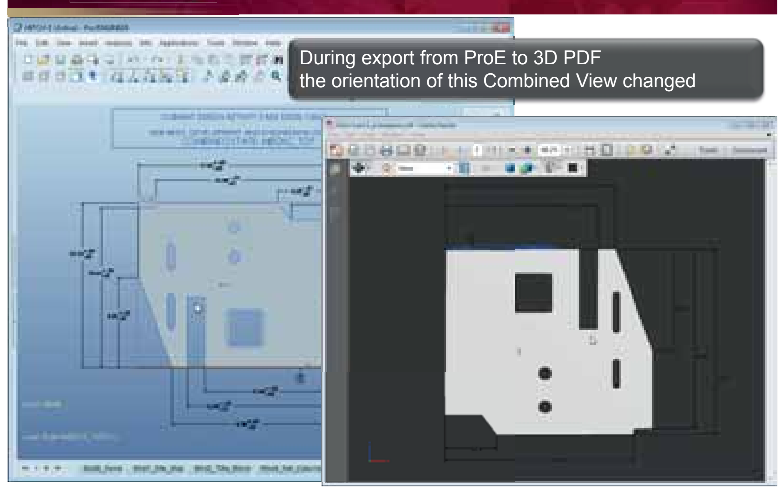
RDECOM PMI Font Validation Example



During export from ProE to 3D PDF the text font in this title block changed

Images provided by ITI TrancenData

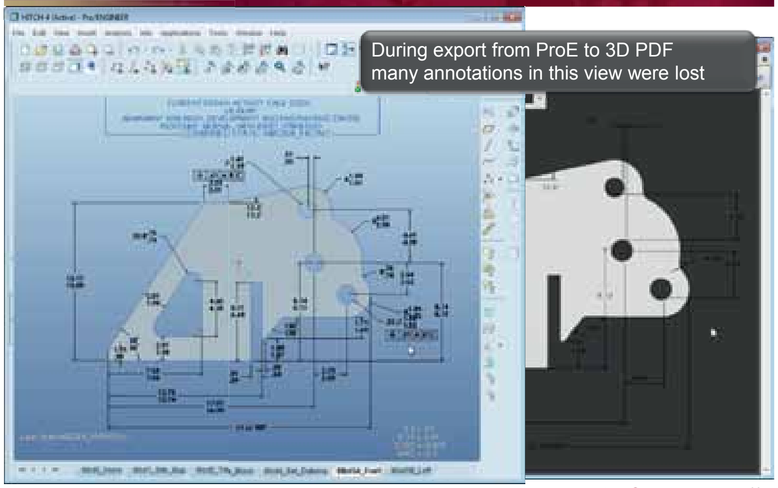
RDECOM PMI Combined View Validation



During export from ProE to 3D PDF the orientation of this Combined View changed

Images provided by ITI TrancenData

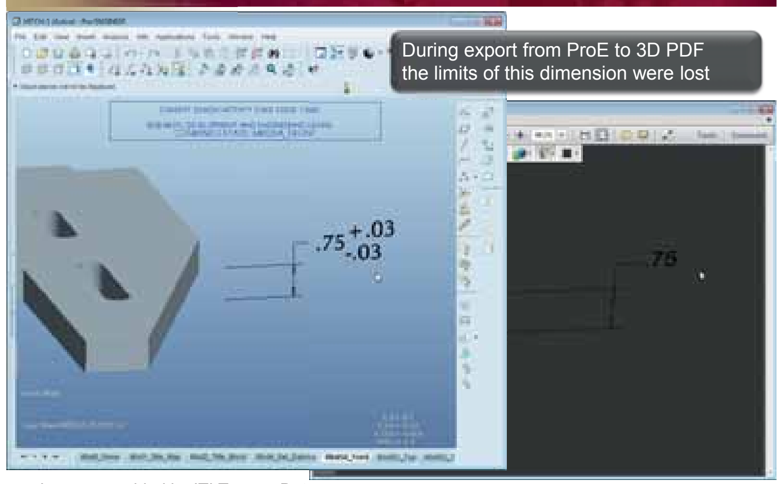
PMI Annotation Validation



During export from ProE to 3D PDF many annotations in this view were lost

Images provided by ITI TrancenData

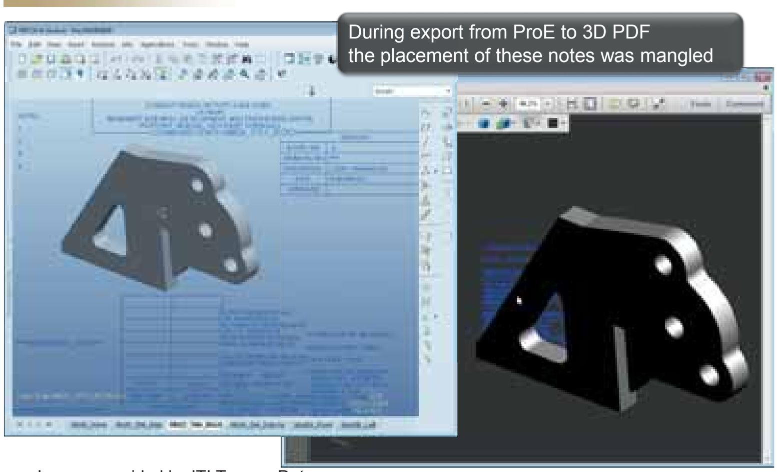
PMI Dimension Validation



During export from ProE to 3D PDF the limits of this dimension were lost

Images provided by ITI TrancenData

PMI Note Placement Validation



During export from ProE to 3D PDF the placement of these notes was mangled

Images provided by ITI TrancenData

Conclusions

- Project Overview
- Demo:
  - Model Creation
  - PLM Check In
  - Derivative Creation
- Conclusions

Wrapping It All Up

- Validation and Verification (V&V) needs to occur at many points in the lifecycle of a model
- &Derivative V&V is at least as important as that of the native model
- It is a combination of automation and human in the loop process
- Its end goal is to increase the model data quality and thus increase the trust of consumers of the model

Customer Supplier Interoperability

Building the Digital Thread

Reducing new product introduction time and cost through more effective collaboration

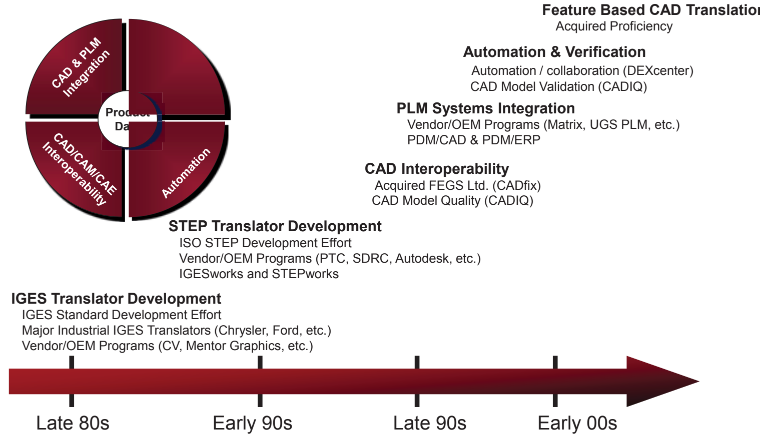
John Gray
ITI Transcen ata
December 14, 2011

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited. Case Number 88ABW-2011-5822."

International TechneGroup, Inc. (ITI)

- Background
  - Founded in 1983 by Dr. Jason Lemon
  - Privately held
  - Headquarters – Cincinnati, OH
- Global Presence
  - North America
  - Europe
  - Asia Pacific
- Business Offerings
  - Engineering Process Improvement Consulting (CP/PD™)
  - Analysis, Simulation, Test and Reliability Engineering Services
  - Product Data Integration & Interoperability (TranscenData Business)

ITI TranscenData History



"A billion here, a billion there and pretty soon you're talking real money."

– Attributed to the late Senator Everett Dirksen

- Senator Dirksen was referencing the US budget and how relatively small items in the budget ($1B < .03% of US budget) can add up to great costs
- Interoperability is similar
  - No one has an explicit "interoperability" budget. Rather interoperability costs are spread throughout other operating costs and are incurred with every technical data exchange.
  - –&An individual exchange is not unreasonably expensive (maybe an hour, a few hours, or even a few days)
  - When a program lasts 40+ years and includes more than 4 million exchanges, **the hidden "interoperability" costs can easily exceed $1 B**
  - –&**A modest savings of just ½ hour per interoperability exchange can save 12,000 person years and $200 M in labor costs alone**

Interoperability: A $ 1 Billion + Problem

- Interoperability Cost Analysis of the U. S. Automotive Supply Chain

NIST, US Department of Commerce, March 1999

"Interoperability is the ability to communicate product data across different production activities. It is essential to the productivity and competitiveness of many industries because efficient design and manufacturing require the coordination of many different participants and processes that rely on a digital representation of the product."

"This study estimates that imperfect interoperability imposes at least $1 billion per year on the members of the U.S. automotive supply chain."

- Today's DoD annual imperfect interoperability costs likely exceed $2B

Why Is Interoperability Important?

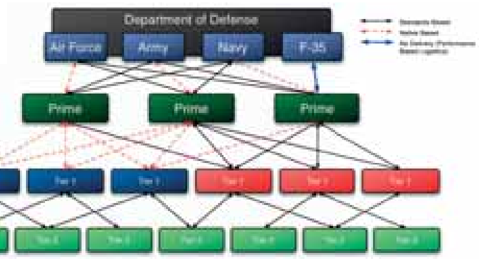
- Drivers for Government / Defense
  - Reducing both development and sustainment costs
  - Deploying systems for use in the field sooner
  - Improved reliability during operation
  - Complying with new MIL STD 31000 initiative for MBD exchanges
- Strategies for success depend on collaboration and interoperability
  - Leverage supply chain
    - •&Use best resources effectively
      - Focus on core competencies
      - Rely on partners for their competencies and cost effectiveness
  - Eliminate inefficiencies
    - Shorten cycles and cost by eliminating non-value added work
  - Innovation
    - Focus resources on better designs
  - Quality
    - Reduce / eliminate mistakes to contain development and sustainment costs
  - Incorporate additional MBD requirements
    - More complete and readily usable technical data exchanges
    - Validated
    - Visualization

Exploring Solutions For Improved Interoperability

- Customer / Supplier Interoperability During Collaborative Design (CSI)
  - Solution addressing AFRL BAA: 08-08-PKM
    Air Force Research Laboratory
    Defense Manufacturing Science & Technology (MS&T)
    High Performance Manufacturing: Model Based Enterprise

ITI International TechneGroup Incorporated
LOCKHEED MARTIN
Honeywell
Rockwell Collins
PDES, Inc.
ATI

CSI Overview



POC: Steven Turek
937.904.4957
steven.turek@wpafb.af.mil
Contractor: ATI

DoD Problem:

Lack of defined data exchange format requirements between suppliers and customers generate significant hidden costs for weapons systems

Approach:

- Capture, validate and test "data-contract" requirements by assessing the requirements, evaluating the highest priority requirements, and developing prototype solutions for the most critical requirements
- Using the DEXcenter, ITI will develop CSI modules, to include contract mapping tools, and software libraries
- Conduct a demonstration to highlight the savings achieved through automation and develop a commercialization plan

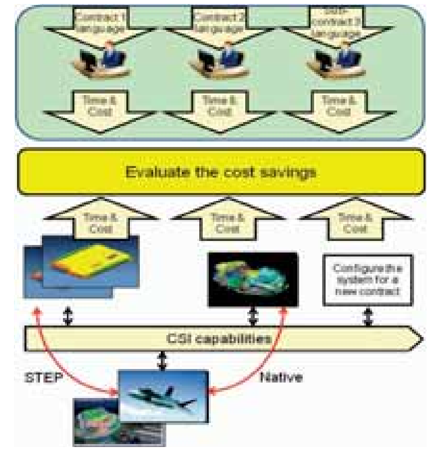
Warfighter Benefits:

Reduced costs and higher quality data. Improvements in business practices will be seen in:

- Less cost to deliver products to the warfighter by eliminating non-value added data manipulation tasks and elimination in errors introduced in the manual manipulation of the data
- Less time for new capabilities to reach the warfighter because of streamlined processes through the supply chain during early product development phases
- Cost savings are estimated to be over $35 million per major program

Focus of program

- **Review** "data contract" language and current methodologies used by industry to support contract requirements or negotiate changes to contract requirements
- **Analyze** failures (unable to comply or cost prohibitive to comply) in the process to support "data contracts"
- **Prioritize** these failures in terms of frequency of occurrence and impact if the failure occurs as well as the cost impact
- **Identify** processes that can be automated to improve compliance with "data contracts"
- **Demonstrate** some of these automation capabilities and the associated savings if deployed in the industrial base

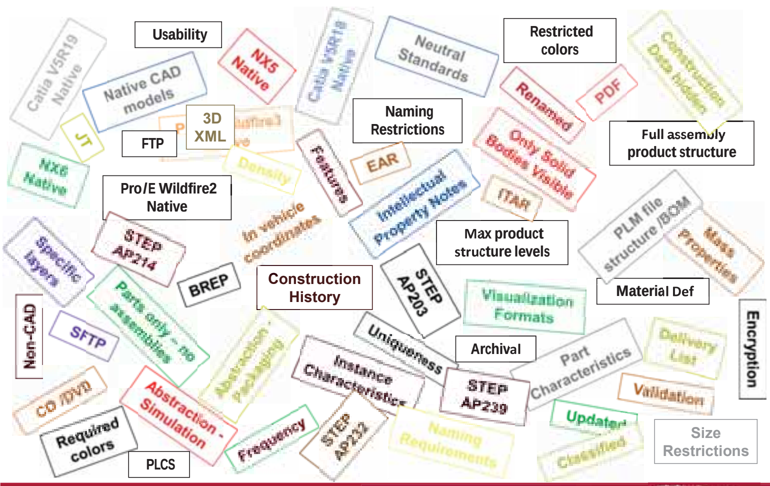


Example contract language and non-value added tasks in organizing and reformatting data

Aerospace (an OEM's requirement to suppliers)	Defense-Army (a customers requirements to the prime contractor)	Automotive (an OEM's requirement to suppliers)
▪ **CATIA V5** shall be used for 3D Solid Model ▪ No assembly constraints shall be active ▪ Red and orange colored geometry is not to be used ▪ Individual files sizes to be less than 30 MB ▪ All parts to be SolidM ▪ No hidden/no show elements ▪ Provide separate file with interface points and vectors ▪ Files must be in engine coordinates ▪ Provide list of differences/changes since last transmittal	▪ Layers shall be named in accordance with the naming convention in ProE per xxxx Modeling STD 100T Rev G (26 pages of rules). ▪ The contractor shall provide a 3D Solid Model in **Pro/Engineer, Version Wildfire 3**, **Intralink 9.0-PDM and 9.0 Intralink 3.4** of all new parts. ▪ If the proposed change is adding a new part for which a drawing or solid model does not exist, the Contractor shall provide a solid model and 2D drawing of the entire affected assembly/installation with their package.	3D CAD models must be **AutoCAD**: ▪have geometry positioned relative to supplied origin (X0,Y0,Z0). ▪be created in accordance with 3D Level of Detail CAD Modeling. ▪use the layer key styles, system definitions and routing preferences contained within the supplied AutoCAD template. ▪have a maximum of 50 layers for additional bespoke model space objects. ▪use supplied custom fittings catalogue. ▪use the default names for structural member styles. ▪be saved showing a 'Top' (Plan) view of the geometry. ▪be saved on the Model Space tab.

Deviations from optimal internal operations (inside customers, suppliers or prime contractors) cause delays, rework, changes, increased cost and inefficient use of staffing resources

Example Contract Requirements



F-35

The F-35 program has been used in CSI because it is typical of large, complex DoD programs.

Examples of CAD data interoperability issues and potential cost impacts:

- Lockheed Martin Aero attempted to enforce CATIA V4 model delivery on **F-35** SDRL's
  - Response to bids by several suppliers showed an impact in excess of $1M for some suppliers – contract clause not invoked.
  - Alternative approach – use STEP and/or take native models and convert at LM Aero
  - Early design activity resulted in several hundred models being exchanged/year
- Lockheed Martin Aero heritage program impacts
  - & Several instances occurred over last 5 years on **F-16** contracts where LM Aero was required to take complex designs in NX for conversion to V4 & V5 for internal design activities (several hundred man hours for conversion/clean-up incurred)
  - **F-22** Tooling task requiring NX engine envelope model being converted to V4 (6 month conversion/cleanup task)

Example Problem Areas and Estimated Cost

Issue Area	Problem Description	Effort per model	Frequency of occurrences	Hours per 1000 models	$ @ $100/hr	
Automation				31000	$ 3,100,000	$ 15,250,000
	lack of automation	16	10%	1500		
	DMU process issues	16	70%	11,200		
	Store multiple models vs create on demand	8	70%	5600		
	can't translate	16	40%	6400		
	ITAR	16	10%	1500		
	non value added time	16	10%	1600		
	manual metadata reentry	2	70%	1400		
	non automated translation	18	10%	1800		
	better use of licenses	2	30%	600		
PLM Exchanges				29400	$ 2,940,000	
	DMU process issues	16	70%	11,200		
	metadata	5	10%	500		
	plm to plm product structure	16	10%	1600		
	general plm to plm	16	70%	11,200		
	maintain assemblies	16	10%	1600		
	PLM access	2	70%	1400		
	manual metadata reentry	2	70%	1400		
	manual exchange	5	10%	500		
Model Content / Structure				21750	$ 2,175,000	
	Extraneous entities	16	70%	11,200		
	renaming	5	70%	3500		
	no modeling standards	16	25%	4000		
	metadata	5	10%	500		
	change coordinates	5	10%	500		
	file naming	8	10%	800		
	specific structure	5	25%	1250		

Example Problem Areas and Estimated Cost

Reduce Model Size				18400	$ 1,840,000
	Model too large for customer	16	70%	11200	
	File size increases	16	40%	6400	
	file too large	8	10%	800	
Improve translations / quality				17900	$ 1,790,000
	Bad Translations	16	10%	1600	
	Version upgrade errors	16	10%	1600	
	can't translate	16	40%	6400	
	broken asm structure	5	70%	3500	
	maintain assemblies	16	10%	1600	
	non value added time	16	10%	1600	
	non automated translation	16	10%	1600	
Validation				8800	$ 880,000
	Bad Translations	16	10%	1600	
	Version upgrade errors	16	10%	1600	
	no validation of supplier models	16	25%	4000	
	non value added time	16	10%	1600	
Other				5750	$ 575,000
	ITAR	16	10%	1600	
	Kinematics	5	25%	1250	
	obsolence	8	10%	800	
	not all parts available	5	10%	500	
	process for adding suppliers	16	10%	1600	

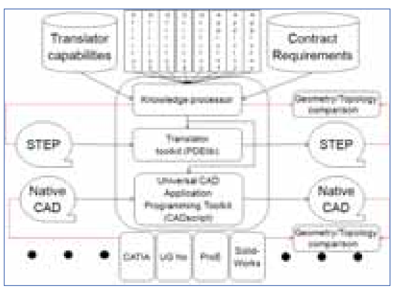
Model Based Enterprise Capability Levels

- Level 0: **Model Centric Drawings for Design and Manufacturing**
  - All activity based upon a 2D drawing package throughout lifecycle
- Level 1: **Model Based Manufacturing**
  - The 2D drawing is master but manufacturing uses natural CAD files
- Level 2: **Native CAD Based Manufacturing**
  - The 2D drawing is master but manufacturing uses native CAD files
- Level 3: **Model Based Definition**
  - The 3D annotated CAD model is the master file for the enterprise
- Level 4: **Model Based Definition With Data Management**
  - The master 3D annotated CAD model and viewable are delivered via PLM
- Level 5: **Model Based Definition With Automated Technical Data Package**
  - Full digital product definition with associated TDP is delivered via PLM
- Level 6: **MBD With Automated TDP and On Demand Enterprise Access**
  - Both the digital definition and TDP are delivered via the web in real time

Source – NIST MBE/TDP Workshop 2010

CSI Vision

- A flexible, configurable, standards based system which automates common tasks associated with Customer Supplier Interoperability
  - Easily / quickly configurable to handle different contract requirements
  - Leverages existing ITI technologies (DEXcenter, PDElib, CADscript, CADfix, CADIQ, etc)
  - Supports typical requirements like:
    - Model preparation
      - Removing / adding / hiding data
      - Organization
      - Coordinate systems
      - Renaming
      - Abstraction / simplification
      - Adding IP / ITAR notes
    - Translation
      - Neutral standards (STEP, IGES)
      - CAD Native formats
      - Visualization
    - Validation
      - Geometry, topology, PMI
    - Delivery
      - Encrypted
      - IP protection
      - ITAR controls
      - Direct (https web, sftp) or via PLM
    - Tracking / auditing



Existing Capabilities and Tools

- Standards
  - STEP AP203, AP214, AP232, AP239
  - CAD vendor STEP translator support
- ITI DEXcenter / CADIQ
  - Existing flexible, highly configurable automation framework
    - Database driven
    - Workflow engine
  - Translations with automated validation
  - Delivery
    - https, sftp, ftp
    - Security, encryption, tracking
    - Regulatory compliance
- ITI PDElib toolkit
  - Toolkit for working with standards (STEP, IGES, DXF)
  - Conversions between various formats
  - Geometry manipulation
- ITI CADscript toolkit
  - Abstracted CAD API access
  - Generalized functions which can access enabled CAD systems
  - Read data from native CAD models
  - Modify data in native CAD models
- ITI Proficiency direct Feature Based Translator
  - Translate between CAD systems while maintaining features
  - Convert 3D Model plus associated drawing to MBD PMI
- ITI CADfix
  - Direct BREP translation
  - Model healing and repair

NIST

PDES, Inc.

DEXcenter

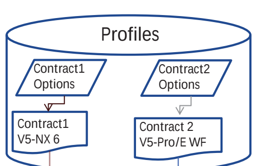
CADIQ

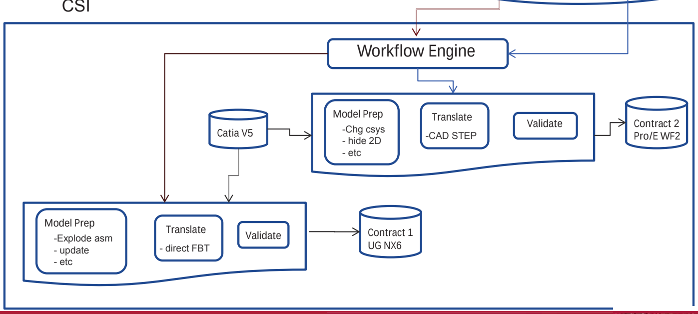
Proficiency

CADfix

Scenario With Automated System

- System components
  - Database (Unique contract options/workflows)
  - Workflow engine
  - CAD translators (CAD neutral, direct)
  - Validation software
  - Model Preparation components developed per CSI

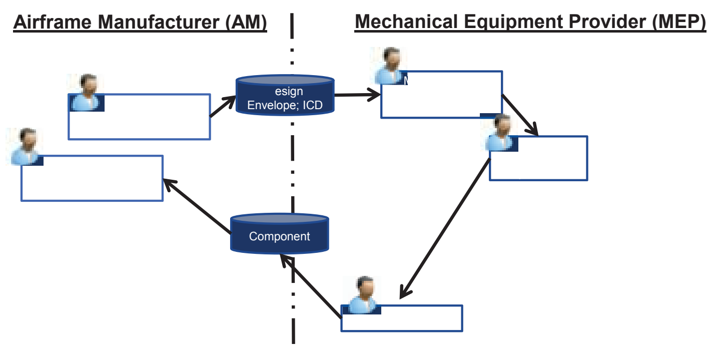




Example Demonstration Scenario (High level view)

Original Process (High Level Summary)

= Requires Human Interaction

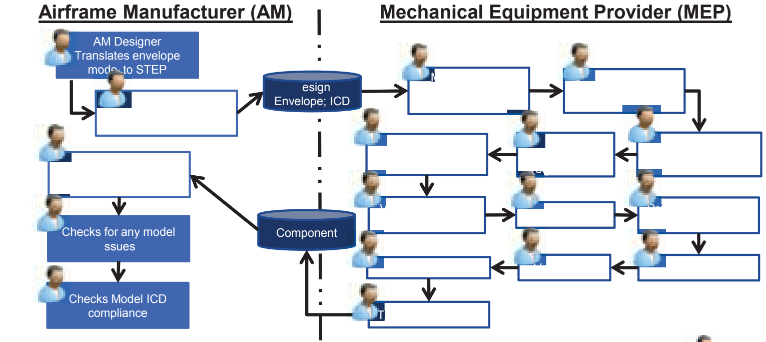


*Note: Assumes each step in the process works perfectly!

Example Demonstration Scenario (Detail view)

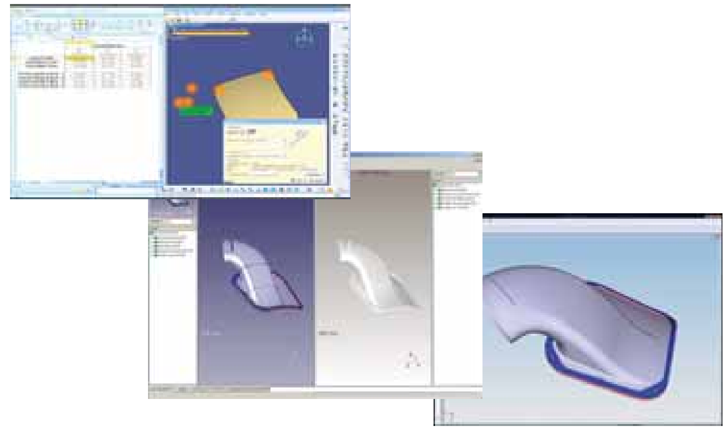
Original Process (Detailed)

= Requires Human Interaction



*Note: Assumes each step in the process works perfectly!

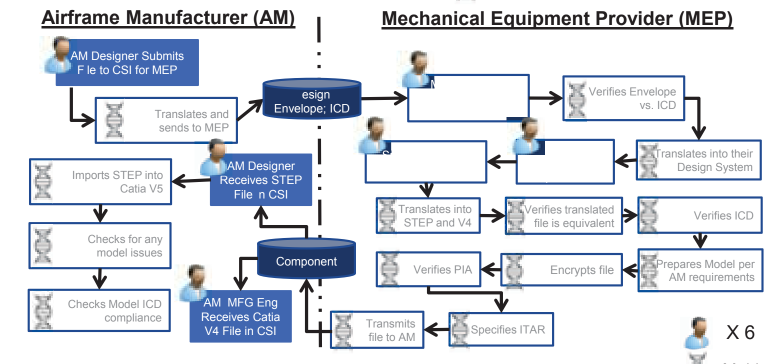
Video Demonstration of CSI developed technology
Lockheed Martin – Honeywell
Typical Data Exchange



Example Demonstration Scenario (Detail view)

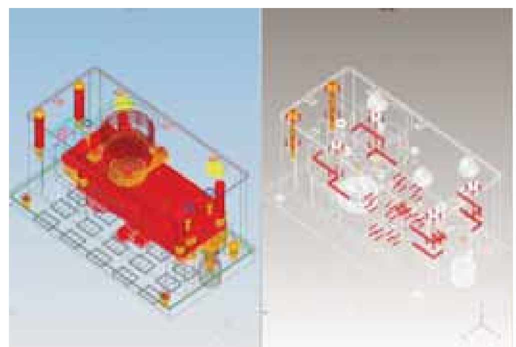
CSI PROCESS:

= Requires Human Interaction = Automated by CSI



*Note: Assumes each step in the process works perfectly!

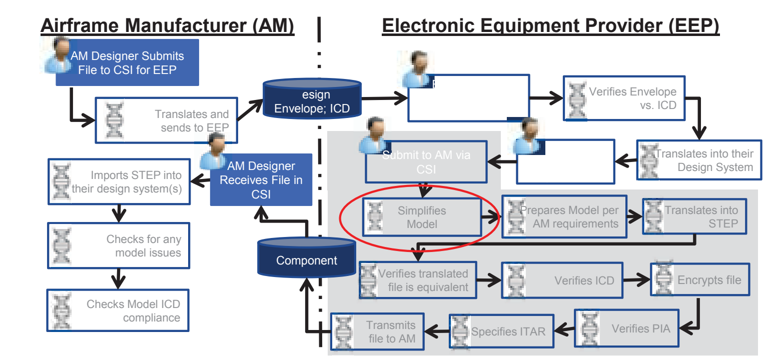
Video Demonstration of CSI developed technology
Lockheed Martin – Rockwell Collins
Model Simplification



Simplification Demonstration Scenario

CSI PROCESS

= Requires Human Interaction = Automated by CSI



*Note: Assumes each step in the process works perfectly!

*Note: Unique tasks

CSI Demonstrated Savings – Phase 1 Results

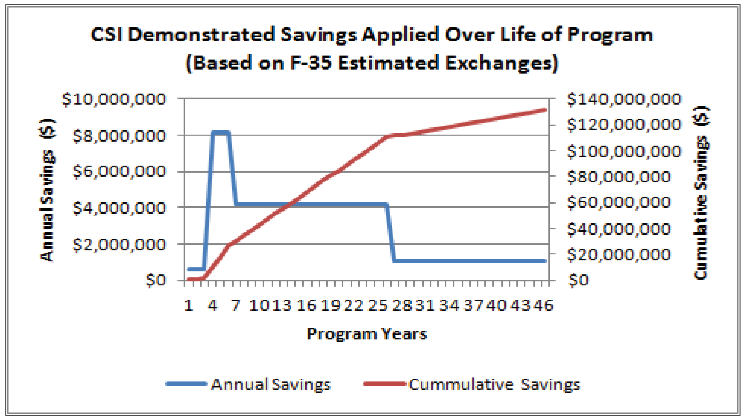
Category	Problem Description	Effort per model	Frequency of occurrences	% functionality enabled in Phase I	% Reduction
Automation/ Model Structure	Lack of automation	16	10%	75%	43%
	Store multiple models vs create on demand	8	70%	100%	
	ITAR	16	10%	100%	
	Non value added time	16	10%	75%	
	Non automated translation	16	10%	100%	
	Better use of licenses	2	90%	100%	
	Manual exchange	5	10%	100%	
	Extraneous entities	16	70%	80%	
	No modeling standards	16	25%	15%	
	Specific structure	5	25%	15%	
Visualization / Other Formats	DMU - consistent processes	16	10%	25%	29%
	DMU process issues	16	70%	25%	
	Visualization processes	5	50%	50%	
Reduce Model Size	Model too large for customer	16	70%	50%	33%
	File too large	8	10%	50%	
Improve translations / quality	Bad Translations	16	10%	50%	68%
	Can't translate	16	40%	75%	
	Broken asm structure	5	70%	75%	
	Maintain assemblies	16	10%	75%	
	Non value added time	16	10%	75%	
	Non automated translation	16	10%	100%	
Validation	Version upgrade errors	16	10%	100%	77%
	No validation of supplier models	16	25%	100%	
	Non value added time	16	10%	75%	
				TOTAL as a percentage	35%

Analysis estimates based on FMEA study

Basis for ITI estimated savings on F-35 program

- Program phases
  - Initial design
  - Detail design
  - Production
  - Support
- Number of file exchanges per month from prime to tier 1 suppliers based on phase
  - Initial design - 250
  - Detail design – 2500-4000
  - Production - 2500
  - Support – 625
- Categories of Tier 1 suppliers
  - Suppliers with design responsibility
  - Suppliers with manufacturing responsibility (build to print or build to spec)
- Transactions per file based on type of supplier:
  - Design responsibility (6 transactions)
    - 1 exchange from prime
    - 1 exchange to prime
    - 1 exchange to (2) tier-2 suppliers
    - 1 exchange from (2) tier-2 suppliers
  - Manufacturing responsibility (4 transactions)
    - 1 exchange from prime
    - 1 exchange to prime
    - 1 exchange to (1) tier-2 supplier
    - 1 exchange from (1) tier-2 supplier
- Savings per file per transaction .35 hours from CSI demonstration
- $100 per hour labor rate

CSI Demonstrated Savings (ITI generated analysis)



Savings based on functions developed in Phase 1, integrated into CSI platform and deployed throughout supply chain

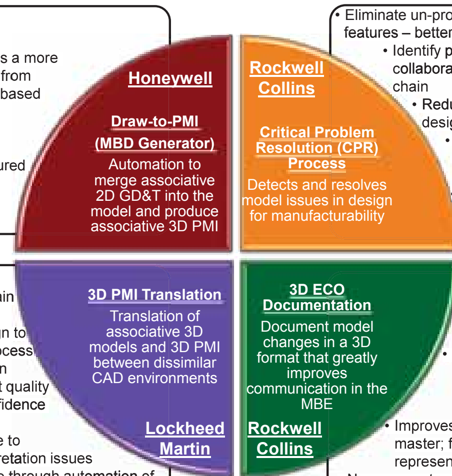
Other benefits

- Delivering systems to field quicker ($??)
- Improved reliability through a controlled, repeatable process ($??)

Accelerating MBE deployment – CSI contract addendums

Benefits
- Potentially enables a more efficient transition from drawing to model-based definition
- May provide an alternate path to translation of featured models

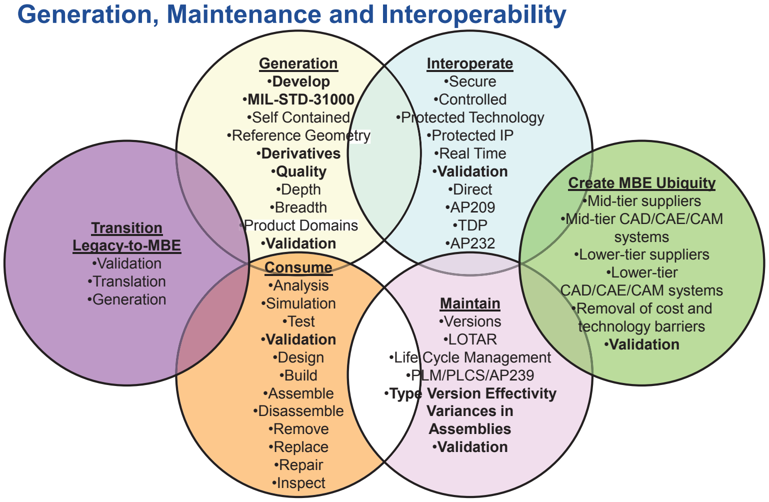
Benefits
- Eliminate un-producible features – better quality model
- Identify potential problems; collaboratively resolve with supply chain
- Reduce rework or scrap due to design escapes
- Eliminate model ambiguity that otherwise drives design revision
- Improve model translation success and designer productivity



Benefits
- Support MBE approach - maintain the digital thread
- Streamlines design to manufacturing process within supply chain
- Increased product quality due to higher confidence in data handoff
- Reduce scrap due to conversion/interpretation issues
- Reduce cycle time through automation of conversion & validation

Benefits
- Eliminates need for drawing-based documentation of design change
- Improves designer productivity (reduces time) in model/drawing revision
- Improves quality; model is explicit master; fully represents/documents change
- Necessary step toward full model based design (eliminating drawing)

CSI Team Brain Storming Concept Synthesis - MBE Model Generation, Maintenance and Interoperability



Questions?

For More Information:

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