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Model Based Enterprise (MBE)

The 2017 RAM Training Summit

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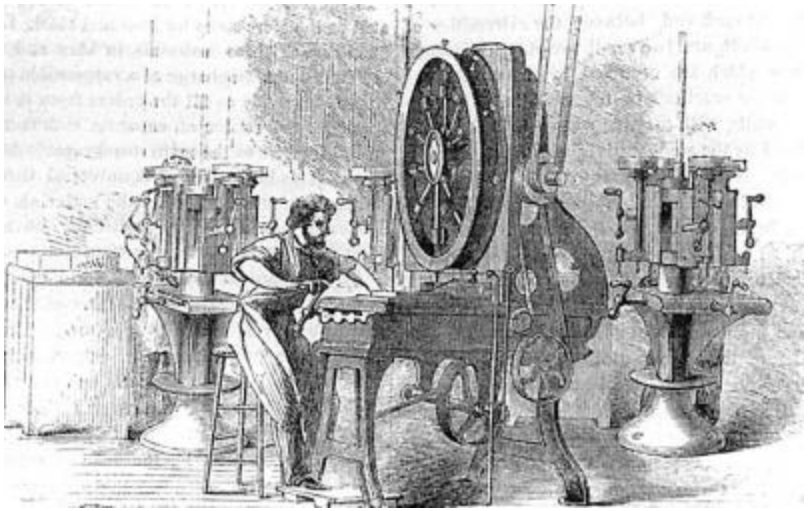
Manufacturing Data History

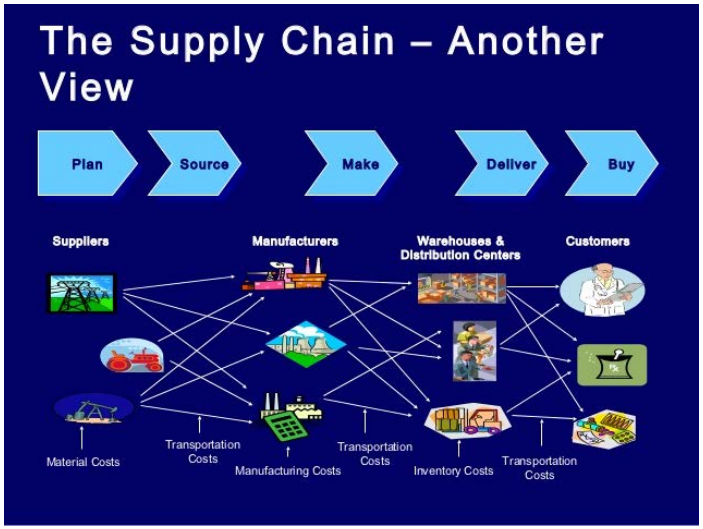


Antebellum Era of Manufacturing

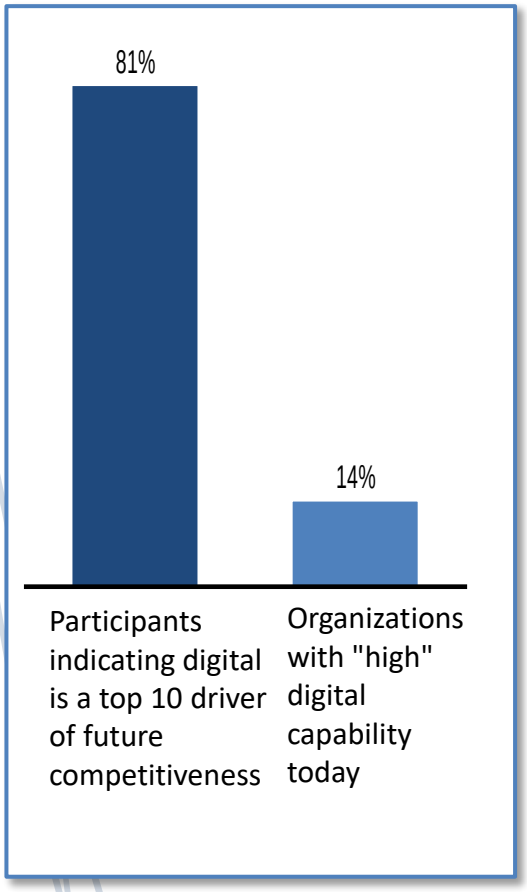
Mass Production

- Most engineering and manufacturing activities relied on 2 Dimensional (2D) drawings in hardcopy or digital form

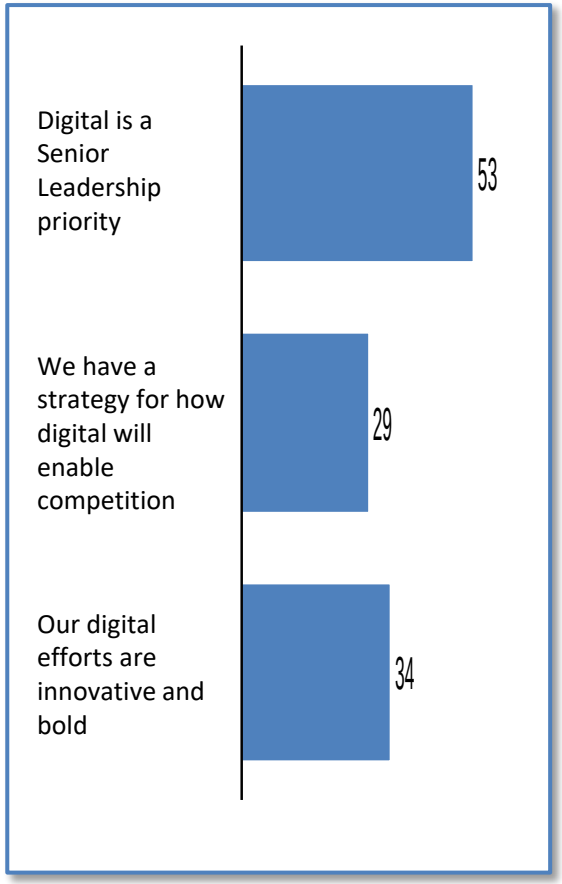
- Today, it is possible to perform most engineering functions using data models.



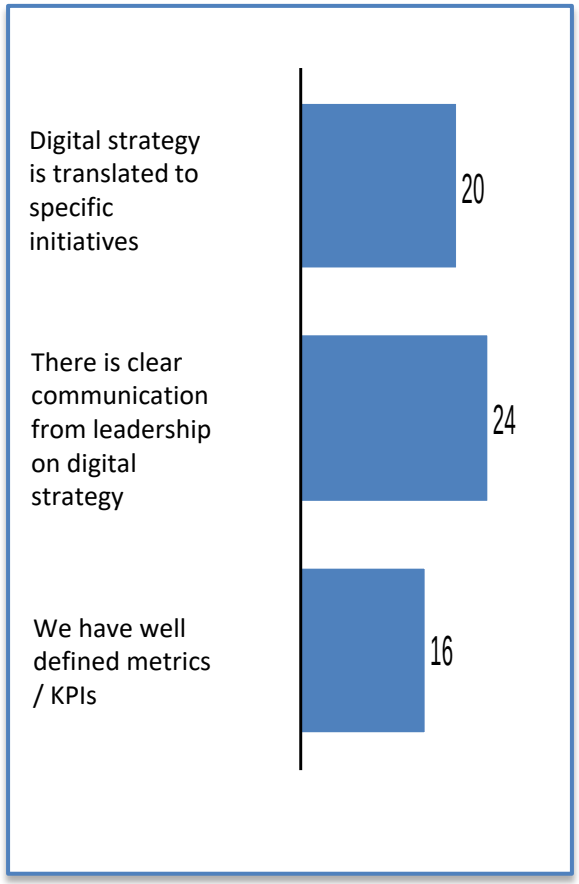
Despite the recognition of importance for digital design and manufacturing, most participants believe their organizations lack capability



Majority of senior leaders agree that digital is a priority, but few have a clear bold vision and strategy



Translating strategy to clear action is a clear gap in a majority of organizations



SOURCE: McKinsey survey, >200 responses from subject matter experts, industry leaders

The Digital Thread

- Digital models carry a significant amount of the data and information needed in digital manufacturing.
- Connected digital information is termed the “Digital Thread.”
- Integrates and connects Model-Based “x” components across enterprises.
- The digital thread describes data flows between engineering, manufacturing, business processes, sustainment and throughout supply chains.
- The digital thread is a way for different systems to access and process on the same set of digital data.

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Get Off The 'Hamster Wheel' & Fix Readiness: AMC Commander

BREAKING DEFENSE

By SYDNEY J. FREEDBERG JR.
on November 01, 2017 at 1:37 PM

- If readiness for major combat operations is really the service's No. 1 priority, Army officials have to be ready to pay for it – even in areas where they once let considerations of cost efficiency trump combat effectiveness. The changes range from issuing more spare parts so units can train harder to upgrading equipment cached in Army Prepositioned Stocks, to **buying data rights from contractors**.

- Even after tough negotiations, though, "intellectual property, rightly so, should cost some money," Perna said. "**The up-front (cost) is significant**," he said, **but it will allow greater savings over the life of a program** by increasing competition for spare parts, maintenance, and upgrades.

- Owning data rights will also improve readiness, Perna said, at least for frontline equipment that must go places that contractor service representatives can't. In 15 years in Iraq and Afghanistan, he said, the Army became dependent on contractor personnel to do even routine maintenance. That worked in warzones where soldiers [were] regular[ly] returning to large, fixed Forward Operating Bases where civilians could work in safety.

- In a war against an advanced "near peer" adversary like Russia, however, big bases will be easy targets for long-range rockets, and troops will have to keep constantly on the move, as Gen. Milley himself has said. Troops will have to leave the civilian contractors behind and keep their gear in working order themselves. To do that properly, **they need full access to the technical data**.

https://breakingdefense.com/2017/11/get-off-the-hamster-wheel-fix-readiness-amc-commander/

Models

- A model is
  - A representation or idealization of the structure, behavior, operation, or other characteristics of a real-world system.
  - 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.
  - Core to MBE is the integration of descriptive models with computational models.

Models (2)

- Early CAD models were meant only for human viewing.
- Today, CAD models can be directly understood by other engineering software applications.
- A product model used in manufacturing is a container of the nominal geometry and any additional information needed for production and support.
- Product Manufacturing Information (PMI), may include geometric dimensions and tolerances (GD&T), material specifications, component lists, process specifications, and inspection requirements.

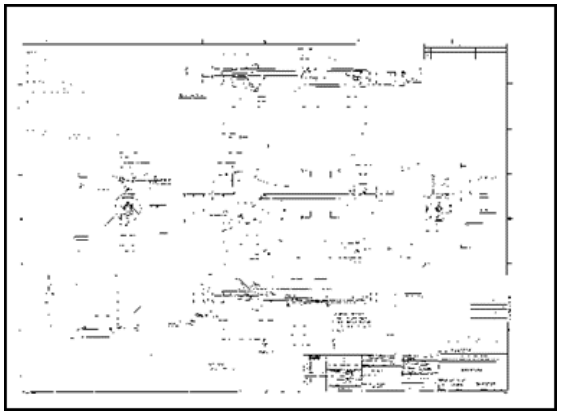
(Lubell, J., Chen, K., Frechette, S., Horst, J, & Huang, P., 2012)

What is the Model Based Enterprise?

A Model-Based Enterprise (MBE) is:

"an integrated and collaborative environment, founded on 3D product definition shared across the enterprise, enabling rapid, seamless, and affordable deployment of products from concept to disposal."[1]

From



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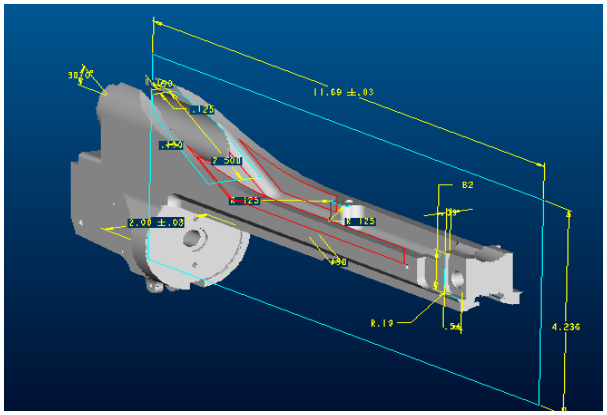


1 - A Summary Report on the Model-Based Enterprise Capability Index and Guidebook Workshop. National Institute of Standards & Technology (NIST). http://dx.doi.org/10.6028/NIST.AMS.100-1

What is the Model Based Enterprise? (2)

- A Model-Based capable organization operates under a single source of truth: the product model.
- The model could be an annotated computer-aided design (CAD) model or a systems model defined in SysML.
- An organization operating under these conditions could eliminate the inefficiencies and opportunities for errors of recreating “silo-ed” drawings.
- A study showed that a MBE approach results potentially in a 75% average reduction in cycle-time over a drawing-based approach.

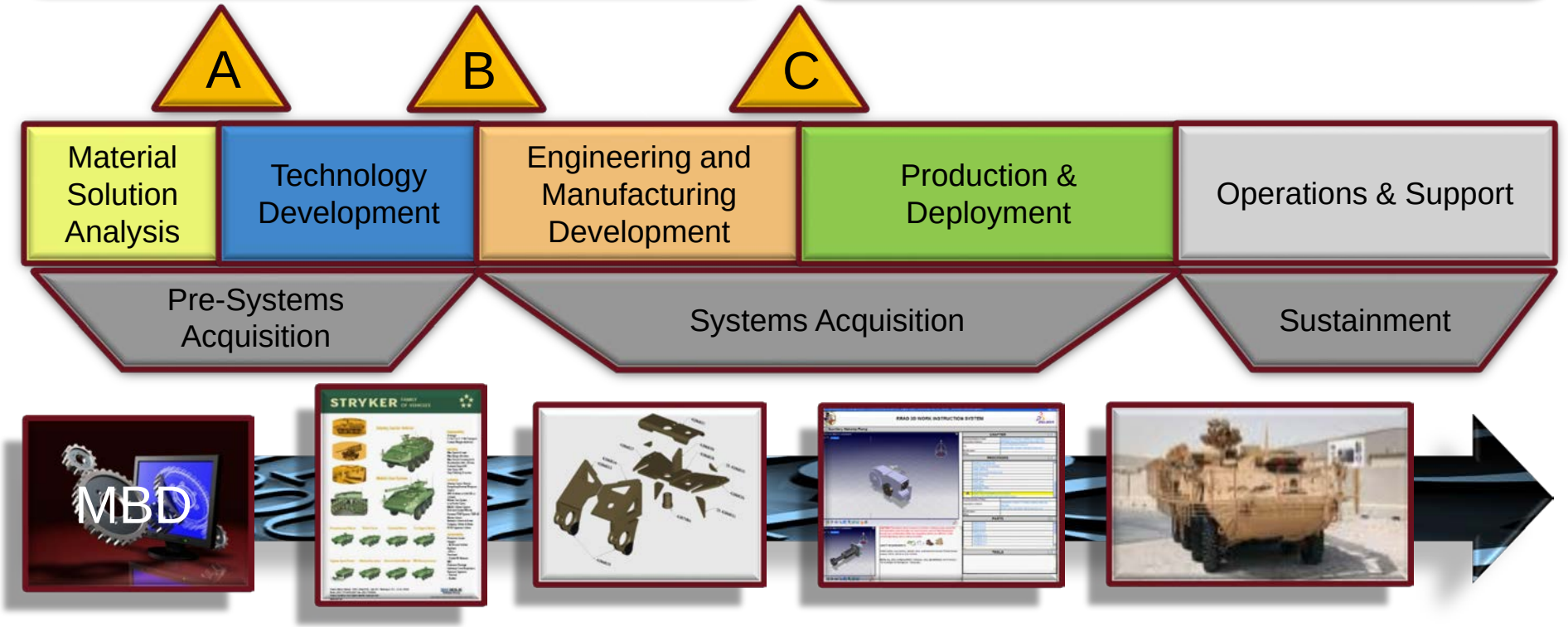
  (Hedberg Jr, Lubell, Fischer, Maggiano, & Barnard Feeney, 2016).
- In addition to bringing products to market quicker and cheaper, an additional benefit of MBE is the ability to potentially reduce the cost of supporting and maintaining the product throughout its life.

  (Model Based Enterprise, 2014)

What is the Model Based Enterprise? (3)

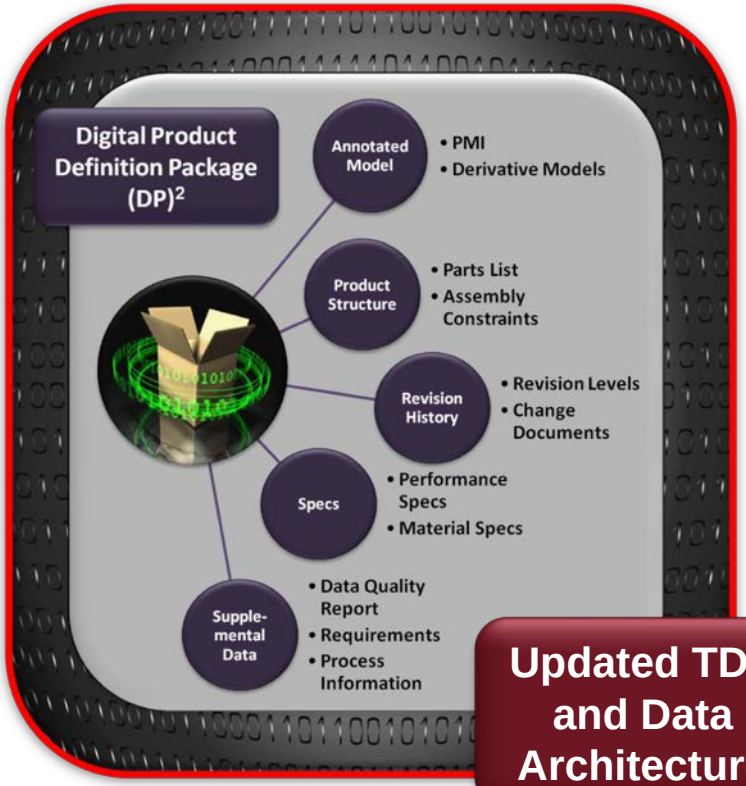
The Model Based Definition (MBDf) is created at the beginning of the lifecycle then reused throughout the enterprise, thus creating the Model Based Enterprise (MBE)

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



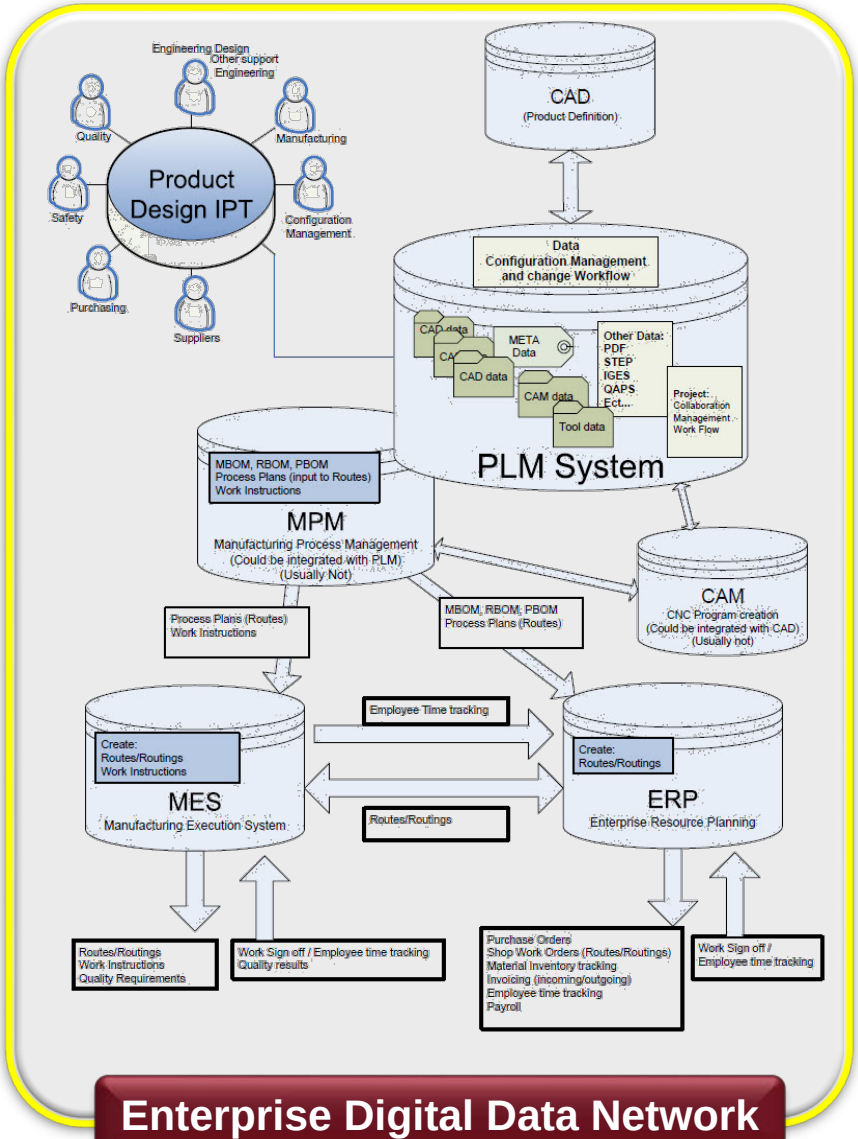
MBDf is the core of the Digital Thread and MBE is the fabric in which it is woven

Connected Digital Thread



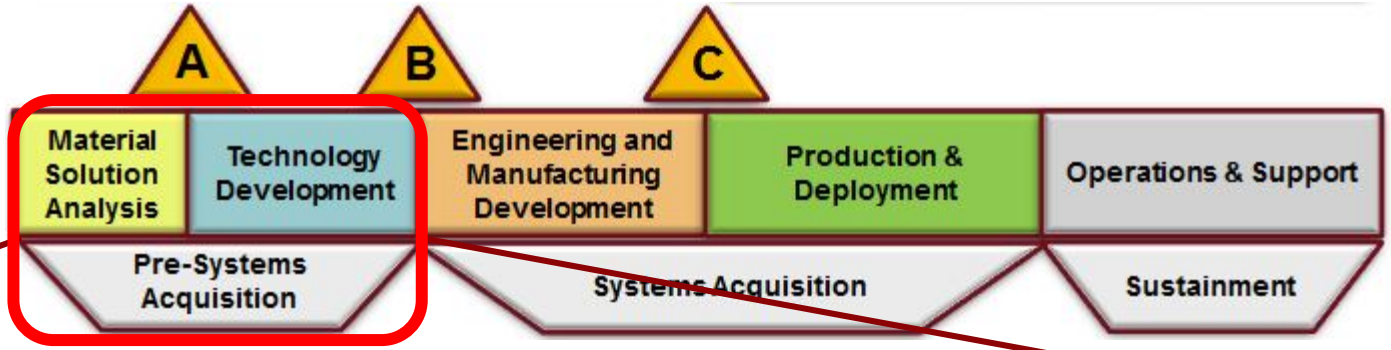
Updated TDP and Data Architecture

MBE Level 4: Model Based Definition With Data Management



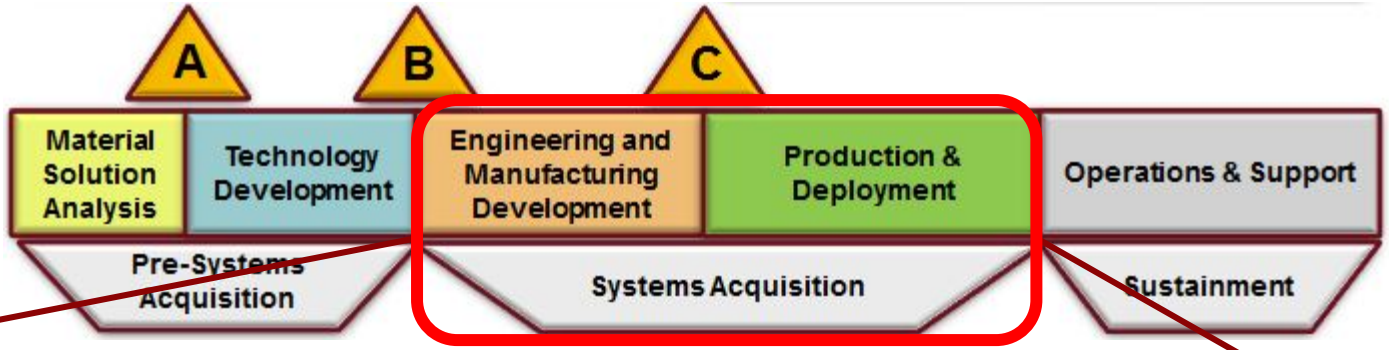
Enterprise Digital Data Network

MBE Enables Faster Pre-Systems Acquisition



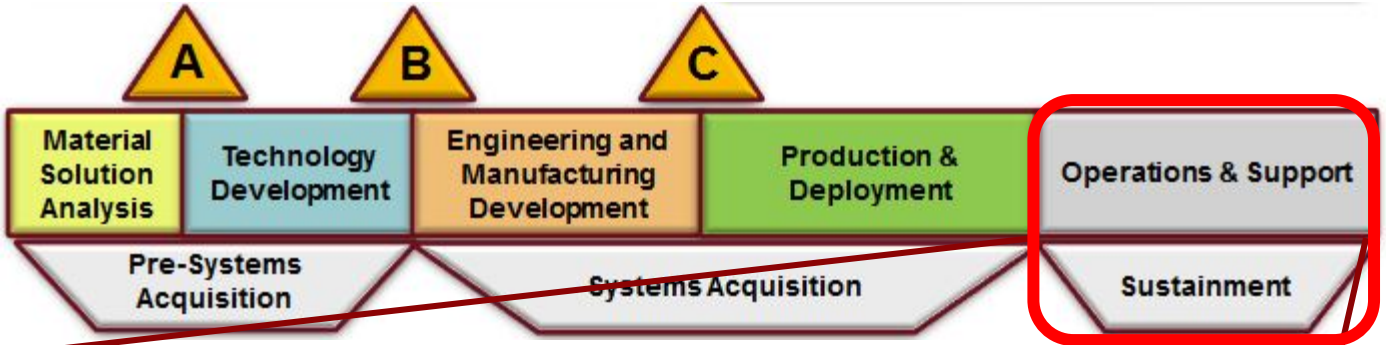
Digital Master	Reuse	Data Management
Minimal Annotation Models	Trade Studies	Initial PLM Structure
3D PDF for Supply Chain Collaboration	Analysis	Design Baselines
Initial Validation of Model Quality	Structured TDPs $(DP)^2$	Virtual Design Reviews

MBE Enables Acquisition of Digital System Data



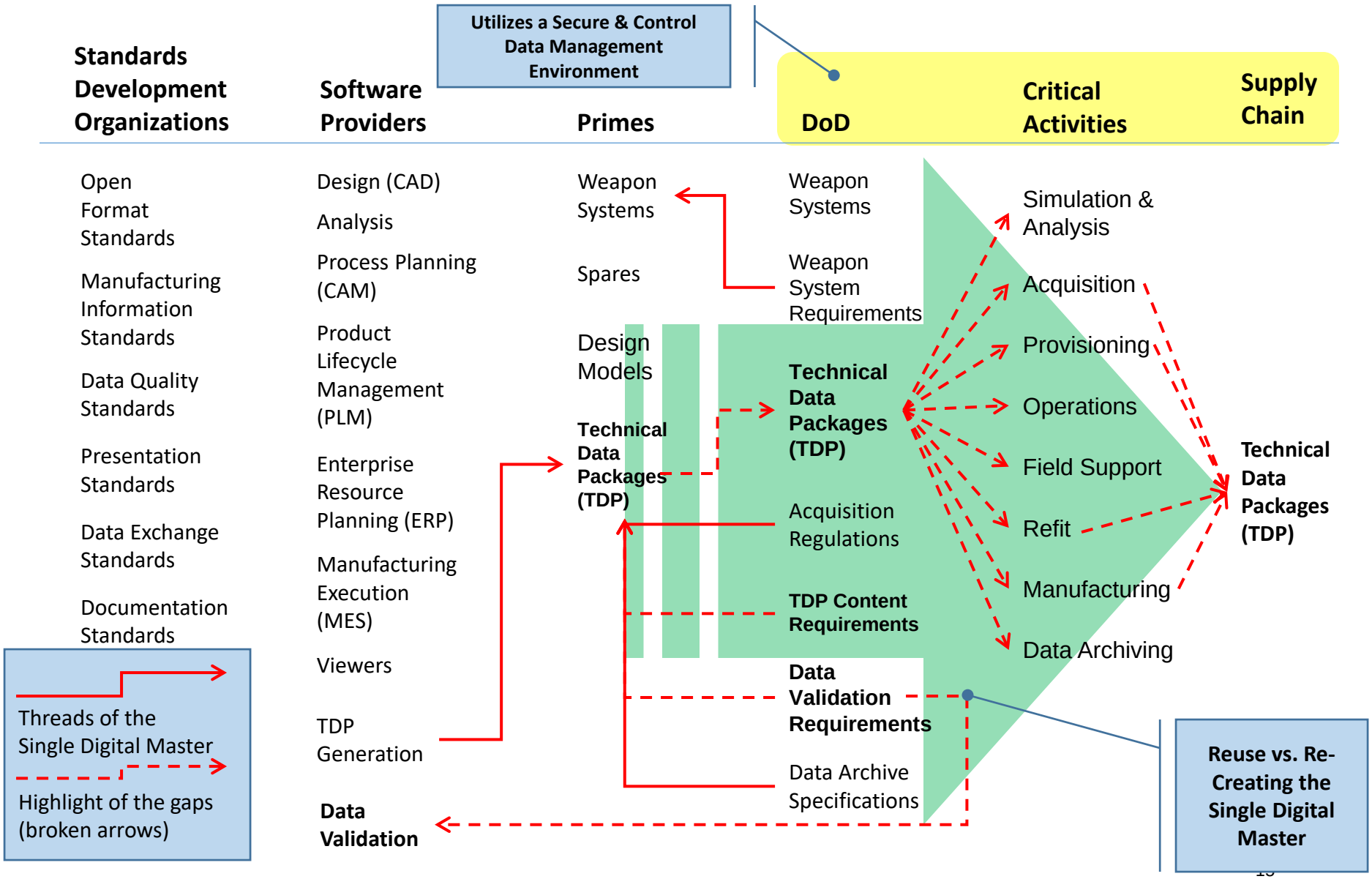
Digital Master	Reuse	Data Management
Partial to Full Annotation Models	Requirements Analysis	Electronic Configuration Management
3D PDF for Non-CAD Collaboration	Production Planning	Secure Enterprise Access
Validation of Model Quality	Discreet Event Simulation	Data Exchange

MBE Enables Effective Support and Sustainment



Digital Master	Reuse	Data Management
Full Digital Technical Data Package	Tech Publications	Efficient Access to TDP
3D PDF for Archival and Non-CAD	Refit and Reman Planning	Electronic Change Control
High Data Quality for Ease of Reuse	Trouble Shooting	BOM Exchange with ERP

TDP Workflow utilizing MBE



Design and Engineering Analysis

- ***Model-Based Definition (MBDf)****: The authoritative digital data set based on a 3D geometric model that defines the end item requirements for a product.*
- ***Model-Based Design (MBD)****: Act of creating the model-based definition (product).*
- ***Model-Based Engineering (MBEng)****: The act of evaluating the design intent of a product utilizing a digital data set.*
- How Models are used:
  - Models will be used from conceptual design to detail design for Analysis of Alternatives, and costing.
  - Additionally, models are used by the analysis community to ensure designs perform to the requirements.
- Issues:
  - There is not acceptable bi-directional communication of the models between engineering and system requirements (i.e. the verification/validation/certification process.)

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Model Base Definition (MBDf)
Model Base Enterprise (MBE)

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

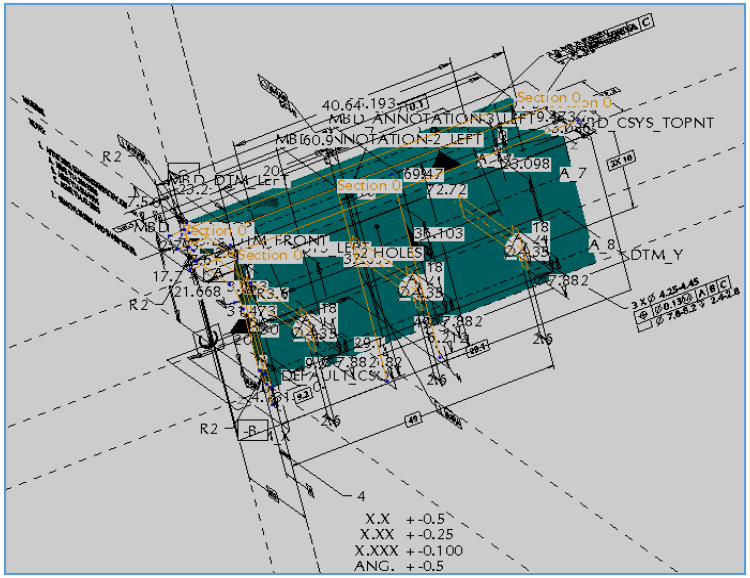
MBD → Concept → Design → Production → Sustainment → End Of Life

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

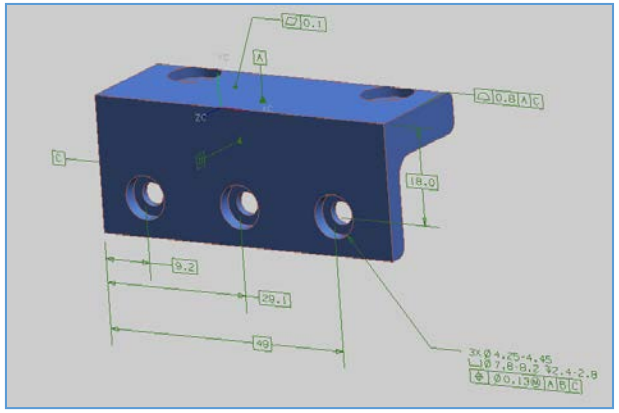
Example of Challenges: MBDf Schema

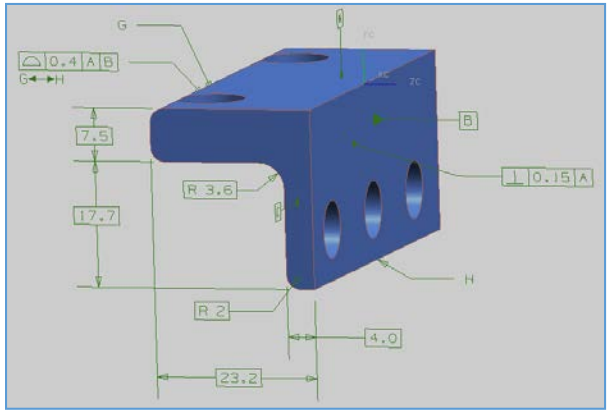
In order to effectively use MBDf, CAD file organization methods are required.

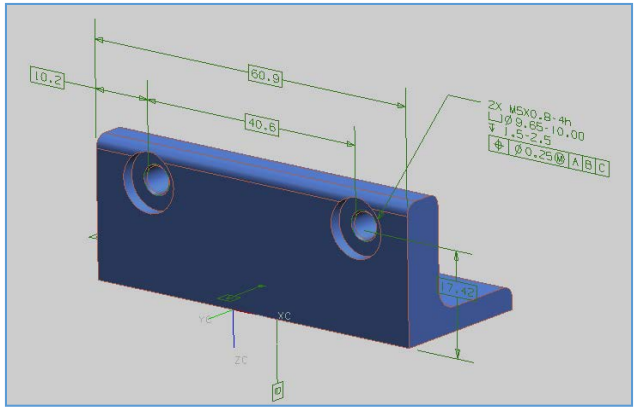
CAD File Fur ball



MBDf Schema applied to “Tame” the Fur ball







Manufacturing

- ***Model-Based Manufacturing (MBM)****: uses the model created by the Model-Based Design (MBD) process. It reuses not only the geometric representation of the product contained within the MBDf, but also much of the text or metadata stored there as well. This eliminates the traditional process of manually recreating this data to establish the process definition used to produce a product.*

- ***Model-Based Manufacturing (MBM)****: an environment [that] the Design Data can be consumed by the value stream to plan, produce, fabricate, assemble, inspect and certify, [and] maintain and sustain parts and assemblies to meet requirements.*

- How Models are used:
  - The largest use of models in manufacturing is for planning. Below is a list of activities that the subject-matter experts identified.
    - CNC programming
    - Assembly / sequencing
    - Converting eBOMs to mBOMs
    - Tooling and fixturing
    - Visualizing manufacturing processes
    - Creating 2D drawings for the shop floor (if necessary)
    - Generating work instructions
    - Manufacturability analysis
    - Manufacturing resource consumption
    - Manufacturing costing

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Manufacturing

- Issues:
  - 2 areas of concern: technical and social.
  - Combined, these issues highlight socio-technical barriers to adopting full model-based processes.
  - The most significant issue identified with models was in relation to notes in the product definition.
  - The engineering notes included in drawings and models are not in a standard format (e.g., semantics, syntax).
  - The note data is often in ASCII text that is not machine interpretable for meaning (semantics). This means that the production flow and work instructions require manual (human) interpretation, verification, and creation.
  - Socio-technical refers to the interaction between human behaviors and infrastructure.

Technical Issues:

- mechanical side of the standard (interpretation and definition of standard)
- interoperability
- data formats proprietary and version
- validation tools for interoperability,
- cyber security
- large scale visualization
- standards are good for different levels of fidelity/applicability

Cultural Issues:

- designers need to adhere to minimal standards
- lack of knowledge while designing (problem even in 2d)
- design 2D in a 3D environment
- risk tolerance
- supply chain – don't share information with supply chain
- varying degrees of stakeholder maturity
- value of a model

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Systems Engineering

- ***Model Based Systems Engineering (MBSE)***:*"The formalized application of modeling to support system requirement, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases."* [INCOSE Vision 2020]

- How Models are used:
  - There is a broad set of many different models, just shy of design models, but are not considered definition models. This has led to two contrary views:
    - A single system [architecture] model is the hub for all models – drives "single source of truth"
    - Federated, heterogeneous mesh of models – truth is a consistent set of models
  - When it comes to using the data, the SMEs agree that classic data exchange does not work. The users are not trying to move the data, but more so are concerned with moving and understanding relationships between data objects, which is the most important aspect.
  - Models are used to decompose performance requirements from high to low levels.
  - Models also help with conducting impact analysis, such as how changes at low levels affect higher level performance. Models also help with knowledge capture and reuse.

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Systems Engineering

- Issues:
  - There are several different data formats in existence, which leads to interoperability problems.
  - Data-format diversity is healthy at the enterprise level because it enables more resilience against threats.
  - Models are proliferating and complexity is ever increasing.
  - No one model has all the information that everyone needs to make the required decisions.
  - Data-interoperability formats should be tool-neutral and process-independent to be resilient and adapt to change.
  - Sunk costs, or past investments, often inhibit an organization's willingness to transform and move to more robust model-based approaches.

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Sustainment

- ***Model Based Sustainment (MBSu)****:The use of models in the segment of the lifecycle where the product is operational with the major concerns being maintenance, configuration management of the product and spare parts, repairs, engineering changes to the product, and logistics.*

- How Models are used:
  - The product-model data must contain the information necessary to generate output products and the data needed to perform scheduled and unscheduled maintenance, repairs, configuration management of spare parts, and engineering changes to the product.
  - Model data is currently being used much the way engineering drawings have been used in the past, in terms of sustainment.
  - Engineering Teams use model data to support the in-service engineering tasks for the systems they support: repair design, validation of models for manufacturing, design of tooling, mishap investigations, and review/development of design changes.
  - Manufacturing typically uses validated models from the Engineering Teams as input to NC Programming/Additive Manufacturing and on to the actual manufacturing process.
  - Output products in the form of technical manuals, work instructions, and training artifacts are generated from the product model during the sustainment phase.

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Sustainment Issues

- Concern over design definition being maintained through the lifecycle.
- Errors to dimensioning and tolerances are introduced when translating between formats.
- Latent defects in models that remain undiscovered for years.
- Poor Configuration Management practices that allow design definition to be changed without documentation.
- Downstream consumers (Artisans/Workers) are comfortable and familiar with 2D drawings.
- No enterprise strategy for the utilization of IT to support MBE and Product Lifecycle Management (PLM)/Product Data Management (PDM) business processes.
- No agreed upon enterprise strategy on what MBE and PLM/PDM business processes are and who in the organization has cognizance over them, creating variances and inefficiencies in how product data (model data specifically) is managed, resulting in the proliferation of stand-alone/stove piped and misaligned IT systems that are not affordable, or sustainable, creating a chaotic environment (a free for all).
- Systems and Programs with adequate funding are doing their own thing in response because there is a void of guidance, and seemingly no appetite to enforce the guidance that currently exists.

Testing and Evaluation

- Need input from SMEs

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Quality

- ***Model-Based Quality (MBQ)**: the conformance of the physical product and process to the requirements of digital product definitions and process specifications using measurement planning, execution, and evaluation in combination with three-dimensional (3D) annotated models and associated data.*

- How Models are used:
  - Models today are only used for “reference” in the Quality community.
  - The contractually binding format is still a 2D “static” drawing.
  - Drawings are still considered the “master” data – the key communication protocol between the design, engineering, and the supply chain.
  - Many organizations will request 3D model data as a reference in case reading the drawing becomes a problem, but all agreed that reading the 3D model data without validating it back to the drawing creates a significant risk for quality escapes. Rarely do the session participants receive 3D models with PMI included.

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Quality Issues

- Several socio-technical barriers exist with achieving a complete, clear, and unambiguous representation and presentation of the product definition and its associated processes.
  - Little to no semantic PMI representation in models today (technical)
  - Lack of understanding between representation and presentation PMI (social)
  - Context and behavior of product requirement is missing from product definition (Technical)
  - No, or weak, standard for designating priority of characteristics (Technical)
    - Definitions for representation and presentation will be included with the upcoming release of the standard Y14.41.1 (Model-based Definition – Model Organization) by the American Society of Mechanical Engineers (ASME).
  - Business process; acquisition can't handle MBE yet (Social)
  - Lack of Product Data Quality (PDQ), Verification &Validation processes and understanding (Technical and Social)

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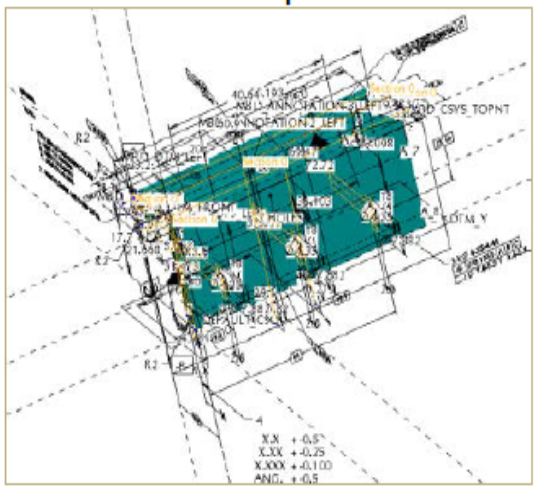
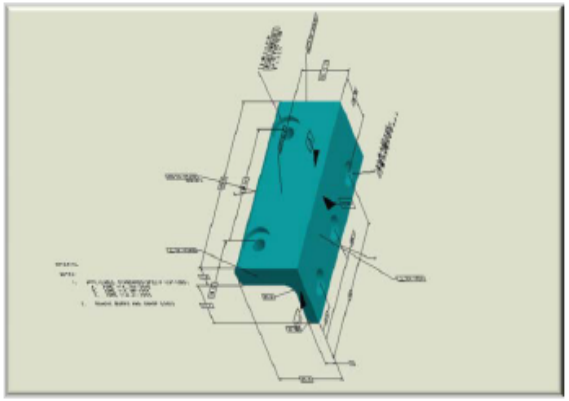
In order to effectively use MBD,CAD file organization methods are required.

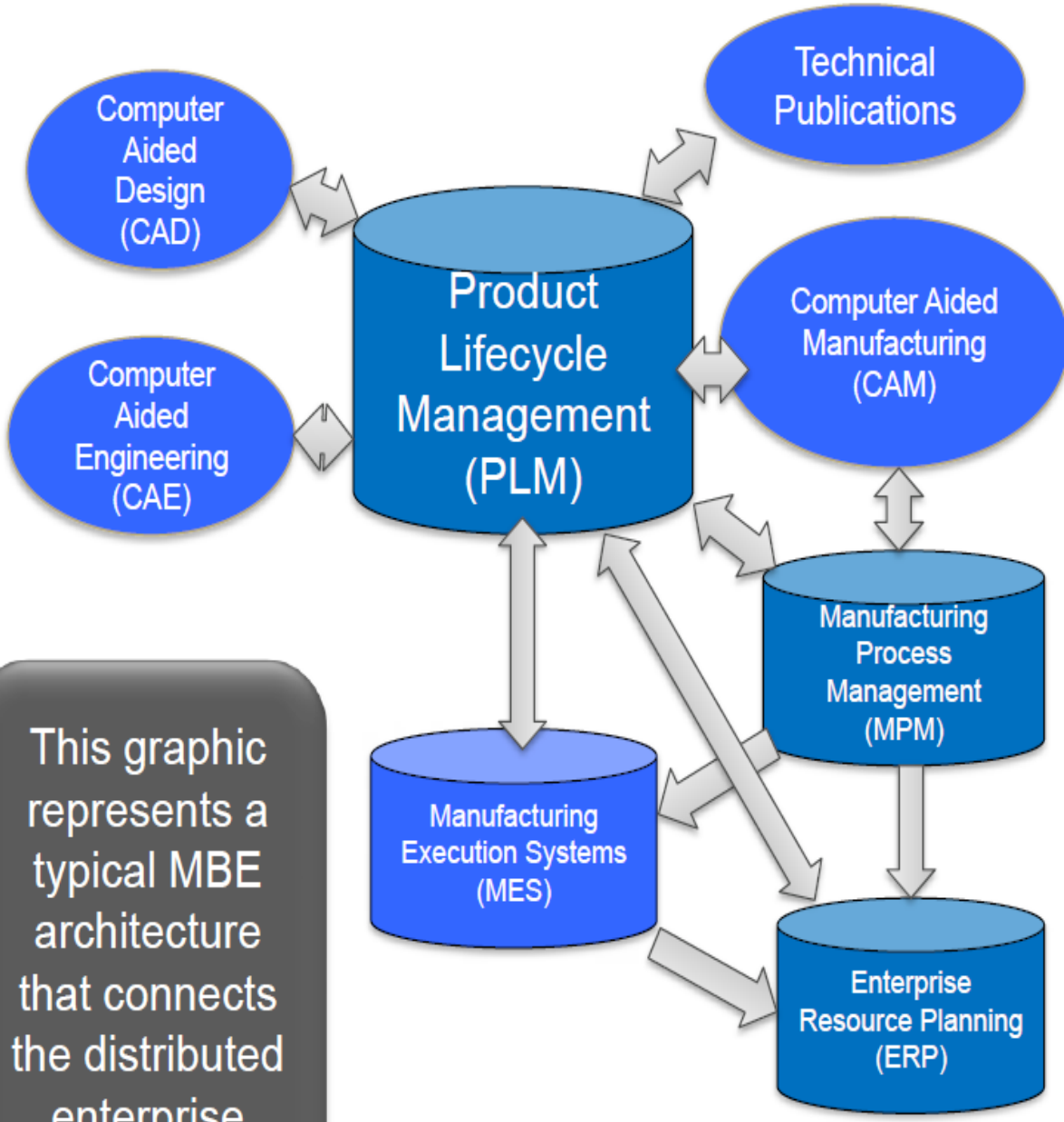


CAD File Fur ball



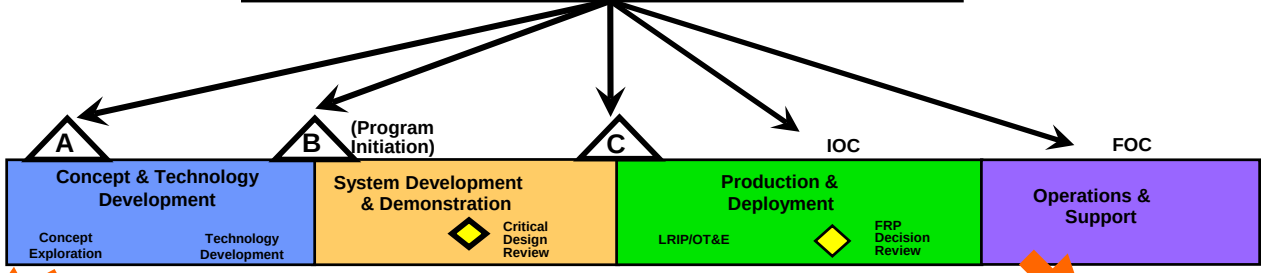
MBD Schema applied to "Tame" the Fur ball

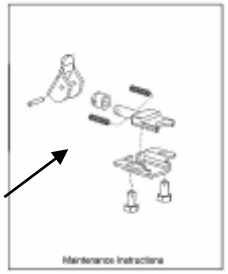
This graphic represents a typical MBE architecture that connects the distributed enterprise



3D Tech Data Usage in the Lifecycle

MODEL BASED ENGINEERING
Benefits throughout lifecycle





Concept Exploration

Build virtual parts and assemblies in the computer

Explore multiple design alternatives

Infinite viewpoints and exploded views of assemblies

Virtual Reality Simulation

Reduces analysis and simulation time

Create rapid prototypes

System Development

Better and faster engineering analysis

Stress analysis

Mechanism design

Interference fit

Tolerance stack-up

Fatigue analysis

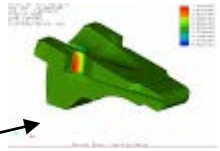
Design optimization

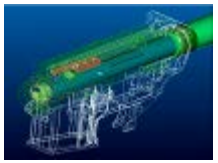
Improved interface with other systems

Automated generation and update of line drawings

Automated bill of material

Generate near perfect TDP





Sustainment

Technical manual development

Maintenance training

Faster design upgrades

Less time to update drawings

Increase competition in re-procurement

Save money on spare part purchases and completive re-buys

Better and faster problem analysis

Production and Deployment

Faster and better manufacturing (reduced ALT & PLT)

Process Planning

Assembly Planning

Reduced TDP interpretation errors.

Tooling design

Models used to generate CNC codes

Investment casting

Mold Design

Sheetmetal Design

Routed Systems, Piping and Cabling Design

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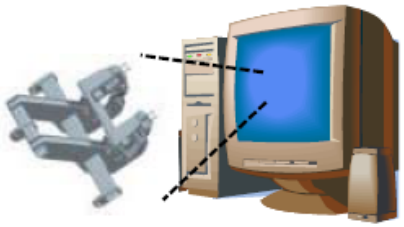
The Model Based Enterprise as a "Single Digital Thread"

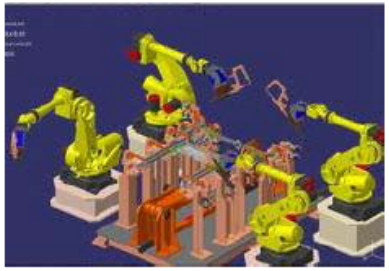
1 Digital Definition



Specs, E-BOM, M-BOM

- Integrate product design and Mfg process applications (dynamic BOMs)
- 3D Tech Data Packages

2 Digital Manufacturing



Simulated IED robotic welding

- Virtual manufacturing process design and simulation
- Digital environment for design and validation
- 3D models enable direct NC programming
- 3D work instructions

3

CAM, Data Mgmt, Work Flow, Fixtures, Factory Layout, Work Instructions

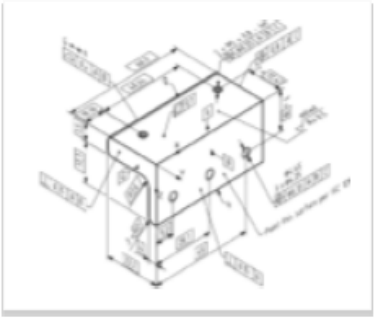
Actual IED Robotic Welding

4

- Virtual environment produces real world execution
- Digital design and mfg knowledge can be shared across organic base and industry

Hardware integration, delivery to customer

5 Digital Sustainment



- 3D TDP used for sustainment (Spares, Tech Manuals, etc.)

Benefits

- Integrate design and mfg processes, reducing costs
- Shorten time-to-field for new/ revised products
- Increase quality of production process design
- Improve collaboration with stakeholders
- Real-time configuration management processes
- Increase efficiency of spare parts procurement

RAM and MBE

- Out of date information
  - Issues with not having access to the most current information, even during the conceptual design phase for RAM considerations.
  - With MBE and PLM this would allow the use of true concurrent engineering and allow the RAM team access to the most relevant design data throughout the lifecycle.

- Reuse vs Re-creation
  - Just like CAE many RAM activities require the information in the model to be recreated.
  - With a digital and annotated model this can be minimized.
  - Model definition can be added to by the RAM group (animation, producibility items, notes, etc.) then cycled back seamlessly to the other users.
  - This would be facilitate a feedback loop where everyone can have a say in the design.

- True digital threads
  - Not only is the design model data captured in a MBE, but all the supporting digital elements as well.
  - This means that everyone can see the effects their data has on the ecosystem, while at the same time managing all of their simulation, analysis and notes for future use.
  - All securely managed by the appropriate system (PLM, ERP, MES, etc.)

The Question

Is the DoD/Government going to be involved in Defense System Design, Development, Realization, Use, Sustainment, and Disposal in the future?

- If the answer is no then we will simply contract out all system development and sustainment functions.
- But, if the answer is yes, then we must prepare for the tsunami of 3D data and digitalized technical and business processes coming.

The Current State of MBE Capabilities

- A focus on geometric related information with no associativity.
- Multiple CAD/CAM environments in the supply chain.
- Lack of Interoperability among different systems.
- Most operations are in different degrees of ‘silo’ effect.
- Supply chain collaboration is manual at best.
- There is a lack of in-depth model exchange validation capability.

Future State of MBE Capability (What is needed)

- More than just replacing drawing type information exchange to include design intent and context.
- Robust interoperability among disciplines and organizations.
- Responsive and adaptive to the changing market place and technology.
- Improved product life cycle time and costs.
- A building block for accelerating the maturation of the full MBDf schema and communications across silos.

Key factors required to implement MBE

- A functioning enterprise Product Data Management (ePDM) system.
- Documented business processes to guide MBE tool selection and configuration.
- Policy regarding the acquisition, contracting and use of 3D MBDf.
- Consistent leadership emphasis to affect cultural change, and digital product data management (including fully annotated 3D models).
- MBE tools and processes must be common, but can be tailored to each organization and site based on mission.
- This will not be achieved through chance and random application, it will take a strategic plan to guide and manage the initiative and subsequent culture change.

- Reality
  - MBE has not achieved the level of urgency of other activities and issues within Program Management functions.
  - A concerted effort must be brought to bear on this issue to continue to provide superior service to customers.
  - Even if the PMO wanted to implement MBE they don't have the personnel or skill sets.

Project Approach

- Develop the vision of MBE for a typical PMO and the Army support organizations engaged with a weapon system.
- Document the data processes within a PMO and the support functions that support the PMO.
- Develop a scenario of a typical PMO with MBE capability.
- Create the Business Case for the implementation of MBE at a typical PMO.
- Establish a framework for the implementation of MBE capability.

Additionally,

- Develop requirements for an Army Organic Industrial Base (OIB) MBE solution.
- Coordinate and demonstrate alignment of the Army OIB MBE requirements with the Lifecycle Product Data Management requirements.
- Identify and catalog standards related to Model Based Enterprise.

A Systems Engineering Approach to MBE Capability

- "For RDECOM overall, we must have a robust PLM/PDM to help us with more than just manufacturing. We need to tie into the logistics and provisioning folks also." Quote from ePDM representative
- Document and Understand Current State
- Clearly Stated Problem Definition
  - Document and Describe Concept of Operations
- Identify ALL stakeholders
  - Identify Stakeholder Needs and System Desires
- Develop a set of Requirements
- Identify Gaps between Current Capability and System Requirements

So what?????

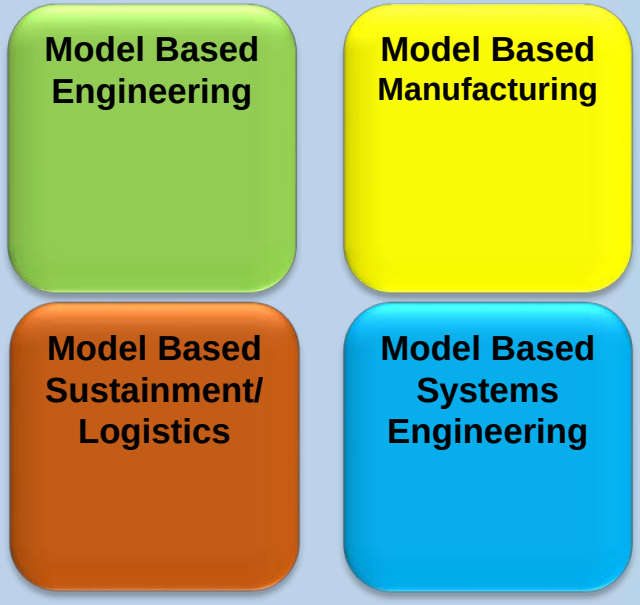
- We develop a strategy and framework for implementation of MBE capability in Program Management Offices and the Organic Industrial Base of the Army.
- How do we actually implement?
- How do you provide the skill sets?

Model Based Enterprise Capability Center

PM/Government

- Point Solutions
- Solving Today's Problem Focus
- Process Based

Model Based Enterprise Capability Center (MBECC)



Institutes DMDII/Centers of Excellence

- Industry, Academia, Government, Working Together
- Enterprise Level Solutions
- Technology Based

Foundational Standards

- Focus on Users and the Processes in Government PM Shops
- Overcome Culture
- Feedback Loop from Institute Developments in the Digital Thread
- Improve MB Capability in Government Organizations

Two Functions of the MBECC

- On the PMO side of the MBECC
  - Reimbursable Subject Matter Experts available to assist PMO personnel
  - Business processes
  - Engineering processes
  - Workflow
  - Digital processes

- On the Outreach side of the MBECC
  - Problems encountered during a PMO implementation are developed and solutions solicited
  - CRADA type relationship with academia to stay abreast of current and future capabilities
  - Research teams for use by MBECC to resolve specific and general issues encountered

Model Based Enterprise Capability Center

Model Based Engineering

- Design
- Planning
- Virtual Evaluation
- Prototype
- Tests
- Simulation

+MB Definition for Design and Development

Model Based Enterprise Capability Center (MBECC)

- **Model Based Manufacturing**
- **Model Based Sustainment/ Logistics**
- **Model Based Systems Engineering**

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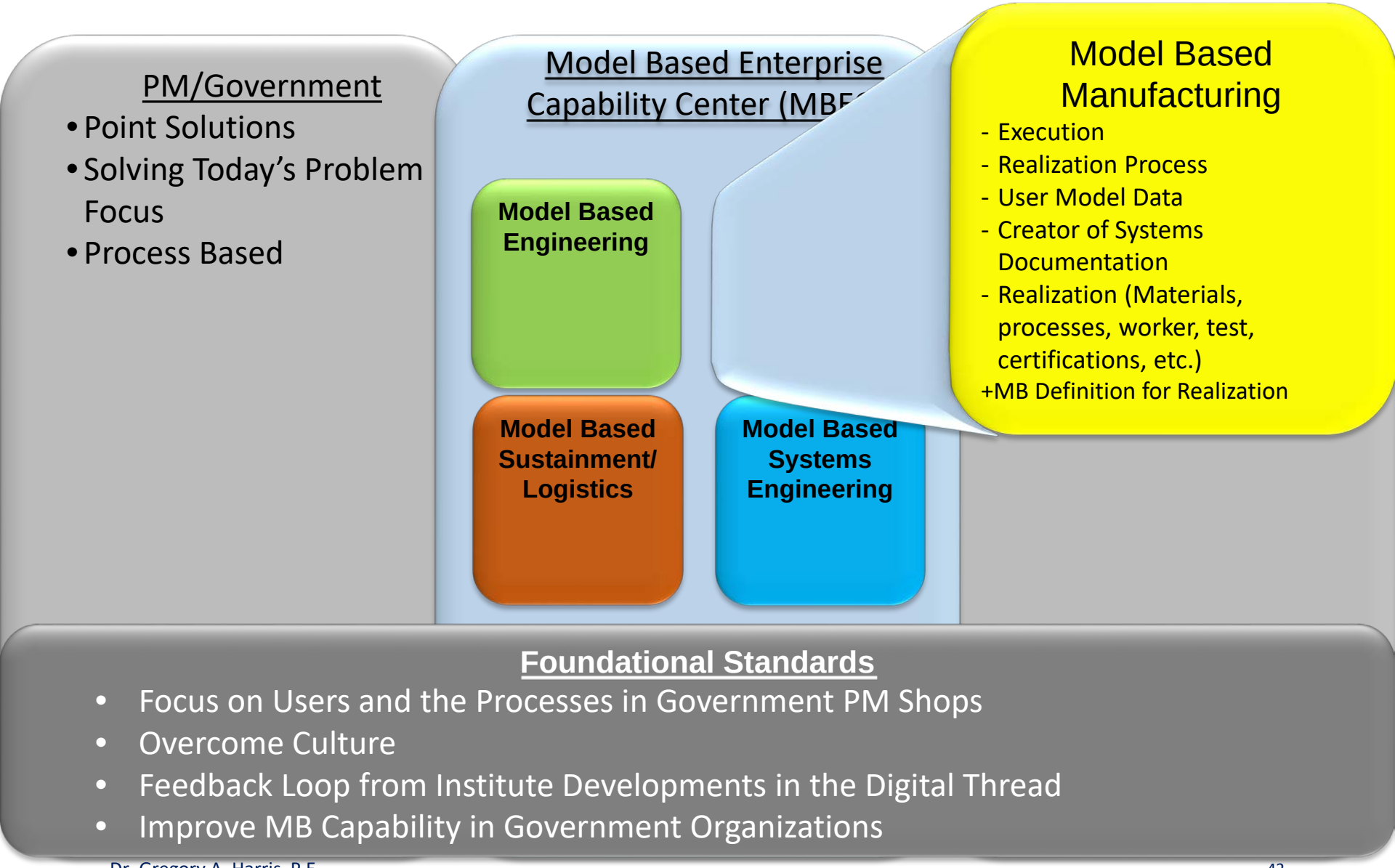
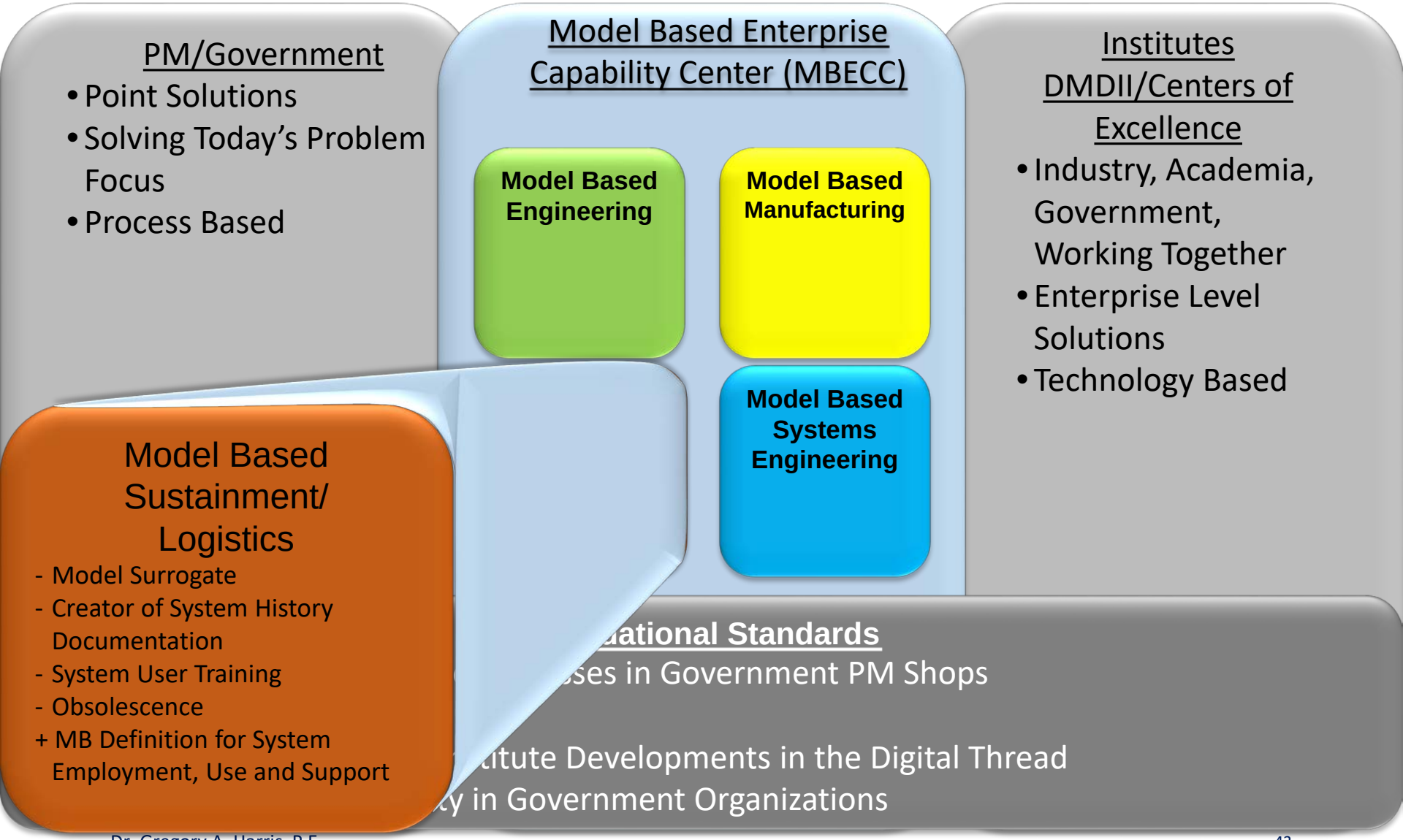
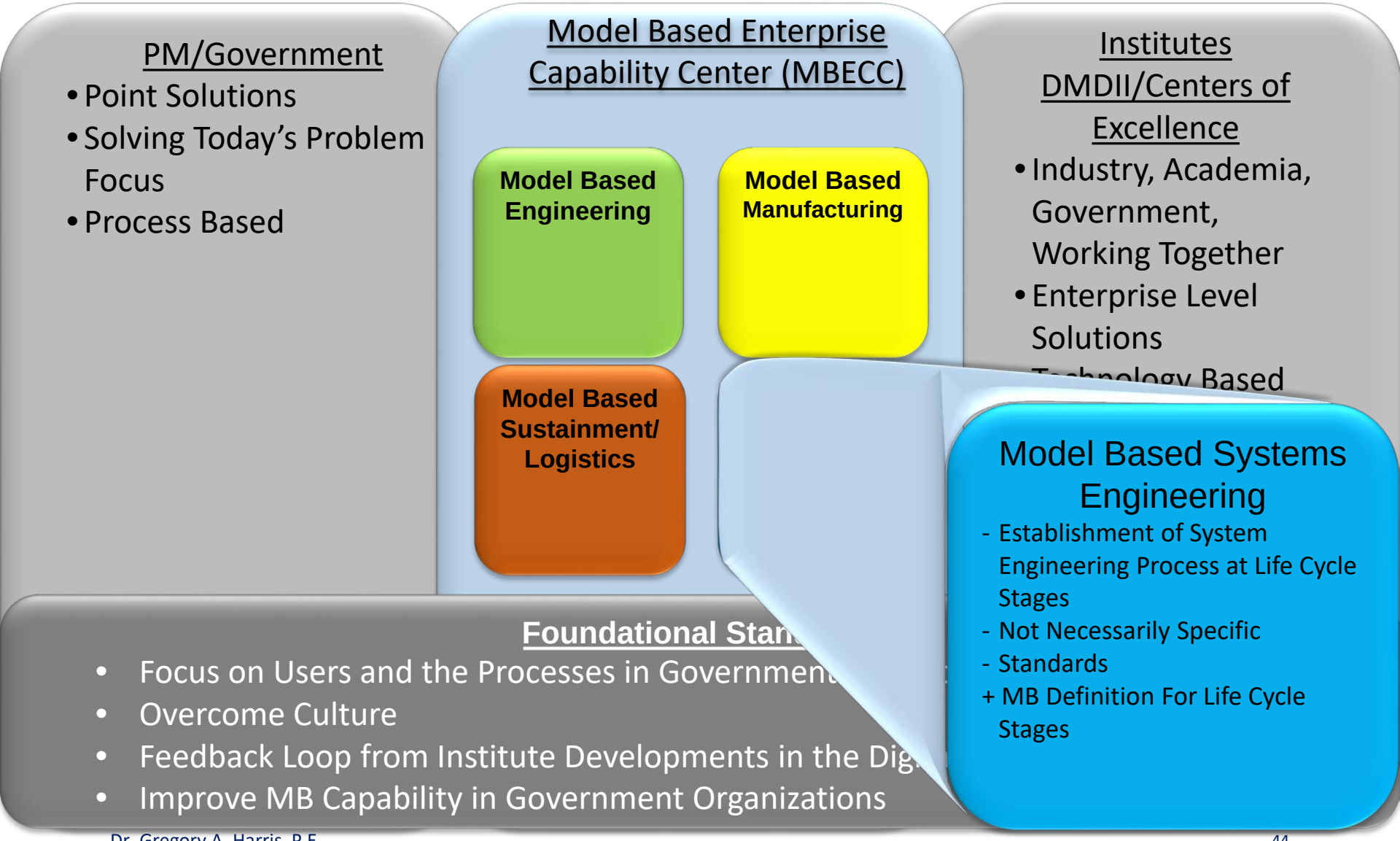
Model Based Enterprise Capability Center



Model Based Enterprise Capability Center



Model Based Enterprise Capability Center



Model Based Enterprise Capability Center

- The MBECC should be government owned and government managed and operated.
- PMOs will come to the realization that MBE is a necessary capability at different rates.
- SMEs are placed in PMOs when they come to the realization the capability is needed and paid for by the PMO.
- Subject Matter Experts can be government employees and contractors.
- The general Issues and Strategy Document is currently under development and will be delivered by the end of October 2017.

Summary

- The world of product and process data is changing at a rate faster than most large organizations can keep up.
- New initiatives such as the Digital Manufacturing and Design Innovation Institute (DMDII) are developing solutions to many of the gaps and issues that have hindered the manufacturing industry from accessing the power of the completed the Digital Thread.
- The Army's industry partners have managed to stay abreast of the movement toward a digital manufacturing environment, but the Department of Defense (DoD) and component branches and agencies have not able to maintain the level of investment necessary to develop the same understanding and capability of their industry partners.

Summary

- This can be attributed to the reality that the need to work with models has not reached the level of urgency that other issues in the development and fielding of DoD systems achieve in the day-to-day activities of these programs.
- However, there is a genuine issue that the inability to perform required functions using models is going to cause in the very near future.
- Some DoD industrial partners have indicated that they no longer intend to provide 2 dimensional (2D) drawings as a deliverable on contracts but instead will be delivering 3 dimensional (3D) CAD models.
- Most Army organizations currently do not possess the capability to receive and utilize 3D models to perform the functions for which they are responsible.
- To achieve the level of proficiency necessary to support the warfighter, a strategy for the use of the MBE tools and a methodology is needed.