Developing Digital Manufacturing Capability for U.S. Industry: Re-shaping the Enterprise

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SmartManufacturingSeries.com
DIGITAL ENTERPRISE, MBD AND PLM
What is a digital enterprise?

A digital enterprise changes the way people work and how they use information.
What is digital manufacturing?


Digital manufacturing is the use of an integrated, computer-based system comprised of simulation, three-dimensional (3D) [representation], analytics and various collaboration tools to create product and manufacturing process definitions simultaneously. The digital representation matches the physical product in shape, behavior, and level of fidelity.
Executives and the digital manufacturing enterprise?


The digital revolution has the potential to open new markets and level the playing field between companies due to the ability to leverage information in new ways. However, just collecting the information is not enough – you must be able to do something with it. Here are five questions executives should ask:

• How will digital disrupt my industry in the next five to ten years, and what new ecosystems will emerge?
• Where is the value for my company, and how can we maximize it?
• How close is the revolution to our factory doors, and where should I make investments in infrastructure, cybersecurity, and partnerships?
• What new capabilities, skills, and mind-sets will we need in our organization? How will we identify, recruit, and retain the right new talent?
• What should we pilot now to start capturing this value?
Ongoing industrial challenges

- Driving product lifecycle data with high fidelity representations
- Global competition
- Design/make vs. make to print (model)? → supply chain transformation
- Increasing product complexity
- Product knowledge stored with people or artifacts?
- Mobility, Collaboration, and Interfaces → the social psychology of expertise
- Securing digital product and process data through the enterprise
- Funding priorities for education focus on jobs that are not there
- Difficult to hire new workers with requisite knowledge

PURDUE
POLYTECHNIC
The next industrial revolution

Mechanization, mass production, automation, virtualization

Four Phases of Industrialization

1. **Industry 1.0**
   - End of 18th century
   - Use of water and steam power to run mechanical production facilities

2. **Industry 2.0**
   - Beginning of 20th century
   - Use of electrical power to enable work-sharing mass production

3. **Industry 3.0**
   - Early 1970s
   - Use of electronics and IT to automate production

4. **Industry 4.0**
   - Today
   - Use of cyber-physical systems to monitor, analyze, and automate business

http://saphanatutorial.com/industry-4-0/
PLM – a key element to a digital enterprise

The digital product definition forms the core of how product information is moved through this sociotechnical system.
PLM – a key element to digital enterprise

The digital product definition forms the core of how product information is moved through this sociotechnical system.

- However, still sequential
- Dynamic model re-purposing still lacking
- MBD must move beyond shape
- Lifecycle loop still not connected
Yesterday

The collaboration journey...

Communications often in serial fashion

You trusted the data because you trusted the person that generated the data

Collaboration meant face-to-face communication
The collaboration journey..

The **3D digital definition** becomes the *conduit* in a standards-based communication process.

The product *model* is the basis for a **secure, authoritative** source of product definition.

You come to *trust the process* that generates product data (because the person may be unknown).
A complete MBD supports lifecycle communication

**SHAPE**

The communications spectrum...

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Standard</th>
<th>Con Mat</th>
<th>Unit</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Internal Tension</td>
<td>ISO 1160</td>
<td>960</td>
<td>N</td>
<td>905</td>
</tr>
<tr>
<td>Density (Mass)</td>
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<td>960</td>
<td>g/cm³</td>
<td>0.11</td>
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<tr>
<td>Water Flow Rate (100%)</td>
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<td>960</td>
<td>L/s</td>
<td>0.01</td>
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<td>Net Kilometer</td>
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<td>Inside Stress at Rod</td>
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<td>Diameter of Rod</td>
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<td>Inside Diameter of Rod</td>
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</table>

**BEHAVIOR**

SHAPE BEHAVIOR

**CONTEXT**

HUMAN TO HUMAN

MACHINE TO HUMAN

HUMAN TO MACHINE

MACHINE TO MACHINE

PURDUE POLYTECHNIC
The old communications medium

The paper thread
How is the model structured?

Singular representation vs. multiple, connected representations

<table>
<thead>
<tr>
<th>Singular Representation</th>
<th>Multiple Connected Representations</th>
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<tbody>
<tr>
<td><strong>Context</strong></td>
<td><strong>Shape</strong></td>
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<td>• geometry</td>
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<td>• in use</td>
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<td></td>
<td>• retirement</td>
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</tbody>
</table>
MBD and Systems Engineering

Two different engineering tribes

Systems Engineers

Masters of the abstract

Product Designers

Masters of the tangible
MBD and Systems Engineering

The evolution of representations

Evolution of PLM to date

Geometry

Behavior

Context

Virtual environment based

CAD based

Drawing based

Next step for PLM

Next step for SE

Evolution of SE to date

Document based

Diagram based

Behavior

Structure

Requirements

Specifications

Interface requirements

System design

Analysis & Trade-off

Test plans

Lifecycle based

MBD and Systems Engineering
MBD and Systems Engineering

MBD, Systems engineering, and big data decision making

• Big Data and Data Analytics
  – State-of-art methods to help make sense of generated data
  – In line with INCOSE SE Vision 2025* vision of “Leveraging Technology for SE Tools”
  – Current parametric solvers limited in scope and application** to potential bigger SE picture

• Can we exploit state-of-art in analytics to aid in turning large volume of MBSE outputs into useful information?

*INCOSE Systems Engineering Vision 2025 June 2014
**Approximation Analytics for Model-Based Systems Engineering – Vitech Corporation 2014
Insigh Webinar
MBD and Materials & Process Characterization

Reduce the need for trial-and-error approaches

Models and analysis replace costly experimental iterations to optimize the manufacturing process and component performance

MBD and Materials & Process Characterization

Reduce the need for trial-and-error approaches

Models and analysis replace costly experimental iterations to optimize the manufacturing process and component performance

To Be – Goal

Application of physics-based modeling tools can reduce overall cost and time to complete system design

MBD and Materials & Process Characterization

Physics-based modeling

- Through surrogate meta-models create tools that can be used to inform decisions, in real time, for shop floor use.
The new communications medium

The digital thread

For many people, it is a matter of whether they are an author or a consumer. MBD is fundamental to the future of digital manufacturing but it is more than a proxy for a drawing.
MBD and the Digital Twin

MODEL-BASED DEFINITION
Multiple Connected Representations

- **Shape**
  - geometry
  - topology
  - logic
  - constraints

- **Behavior**
  - materials
  - process
  - dim./tol.
  - physics

- **Context**
  - assembly
  - machining
  - in use
  - retirement

DIGITAL TWIN

- Product Line
  - Model 1
  - Model 2
  - Model N

- Subsystem
- Component

Temporal, lifecycle-based levels of a model-based definition

MBD + IT architecture + Connectivity

Purdue Polytechnic
Clearing up some vocabulary...

- A **model-based enterprise** (MBE) is an **environment**. It is an organization that has transformed itself to leverage model-based information in its various activities and decision-making processes. In this environment, the model serves as a dynamic artifact that used by various authors and consumers of information for their respective tasks. The MBE embraces feedback from the various lifecycle stages to improve the model representation for the creation of subsequent products and product iterations. People working within the enterprise have an enlightened view of digital product information that can be leveraged in their daily work.

- **Model-based** (MBx) Model-based engineering, model-based manufacturing (MBm), model-based sustainment (MBs), and any other model-based [fill in the blank] (MBx) are categories of **activity** within the model-based enterprise. Any of these activities (and the people in them) use digital product data to represent shape, behavioral, and contextual information carried by the model-based definition to execute their functional role. Model-based activities are conducted by relying on the predictive and archival capabilities of the model, by relying on its high levels of fidelity to physical object or system.

- A **model-based definition** (MBD) is a **thing**. It is a digital representation (artifact) of an object or system. It is representative of the physical object or system and all of its attributes, and is used to communicate information within various MBx activities in a model-based enterprise. The MBD is rich in information – shape, behavior, and context – and it travels the information architecture within an enterprise (including its extended supply chain and customers), providing input to the various authors and consumers who need it. The model-based definition is analogous to the **digital twin**, although most people today do not think of it in such broad view. And the **digital thread** is the combination of the MBD and the IT architecture that connects the various functional areas of the model-based enterprise.
The digital twin to enable modern enterprises

MBD relevance is often matter of whether you are an **author** or a **consumer**.

- **Context**
- **Behavior**
- **Geometry**
  - Drawing based
  - CAD based
  - MBx based
  - Virtual environment based
  - Lifecycle based

Increased sophistication in digital representations and their fidelity to the physical world.
The Problem

• Virtual assembly and VSA are powerful tools: when processes and methods are specified, they can validate feasibility

• They cannot directly help the designer however in dividing up the tolerances on a product into the tolerances on components (budget tolerance problem):
  – Tolerances that are too tight drive up manufacturing costs (excessively precise manufacturing processes)
  – Tolerances that are too loose may be caught by VSA – in production these will result in scrap

• Information does not flow well *upstream* in the product lifecycle to inform design and planning.
Enabling a Digital Twin

- Data needs to be in a usable form to allow queries and interoperability.
- A prerequisite to updating component/fleet information is the ability to access data when needed.

Images from Tuegel, AFRL, ADT 101: Introduction to the Airframe Digital Twin Concept, 88ABW-2013-2396, 23 May 2013
Enabling a Digital Twin

1. Measure physical data
2. Collect and Organize Data
3. Create As-builds
4. Present As-builds

Data

Information

Process

How to define the “controlling” virtual product?
Create a comprehensive, product-centric view of the product across time and geography.
Physical product and the virtual mirror

By comparing digital product data to the physical performance of the object, variation can be tracked and used to inform design of next-generation products or to develop predictive modeling and validation schemes for existing products.
Variation Simulation Analysis

Unit Operations
- Milling
- Drilling
- Composite Layup
- and so forth...

VSA: Can predict the quality outcome for an assembled component given knowledge of the distributional characteristics of the components input to assembly (assembly and joining also have distributions)

Assembly and Joining

Assembled Product

Distributions of Quality Characteristics for Various Manufacturing Processes

LSL | USL

Quality Characteristic of Product

 nghỉ
Analysis vs. Budgeting

VSA Problem: Variation Stack-up

Analysis: complicated but well defined

Statistical Distributions

Individual Components

Tolerances on Components

Design Problem: Tolerance Budgeting

Design: complicated and open-ended

Assembled Product

Tolerance On Product
Variation Stack-up and Budgeting

Unit Operations
- Milling
- Drilling
- Composite Layup

Manufacturing
- Assembly and Joining
- Assembled Product
- Assembled Product Quality

Product Model
- Virtual and Physical
- Geometry / Topology
- Process for Producing
- Behavior in the Lifecycle

Component Specifications

Product Specification
Supply chain challenges (historical)
Supply chain challenges (historical)

Tier 2

Tier 1

CAE Data & Tools

OEM
Engr Simulations:
Structural
CFD
Electrical
...

Manufacturing (Quality & Cost)
The digital enterprise supply chain

Leveraging supplier and process data to ensure capacity

Customer
- Feedback
- Close the loop

Validation and Testing/QC
- Digital validation & verification
- Accuracy and fidelity

Fleet Management and Utilization
- Delivery verification
- Monitoring and adjustment

Production Floor Integration
- Intelligent, integrated equipment
- Predictive capacity

Raw Materials
- Traceability
- Usage

Collection and Integration of Data

Capability across the enterprise

Digital Product Data

Adapted from Kinnet, J. Creating a Digital Supply Chain: Monsanto’s Journey, October 2015.
A new world…

Source: Gartner 2016 Hype Cycles

- By 2018, 20% of all business content will be authored by machines
- By 2018, more than 3 million workers globally will be supervised by a "roboboss"
- By 2020, more than 35 billion things will be connected to the Internet
- The growing range of 3D-printable materials will drive a compound annual growth rate of 64.1% by 2019

Source: Gartner Analysis
... and the accompanying educational revolution

Mechanization, mass production, automation, virtualization

Education 1.0
Apprenticeship
Up through the early 19th Century. Characterized by studying the Master, and focused on specific customer needs. Difficult to reproduce.

Education 2.0
Manual Arts
Through the 19th and beginning of the 20th centuries. Focused on work and tools of the day. Discussion of a formal discipline began.

Education 3.0
Industrial Arts
Beginning to middle of the 20th centuries. Included a focus on breadth of topics to develop technological literacy, but clinging to its vocational roots. Focused on putting students to work.

Education 4.0
Technology Education & the Designed World Today.
Characterized by national movements and formal curriculum standards. The design process and its use as a problem solving method is central.

Regardless of the era, the educational revolution connected to manufacturing has always had a focus on the tools and techniques of the day, and on the making of something. However, the incumbent workforce was left unattended in this model.
The proportions on the education continuum

Engineering Science

- TRL 1
- TRL 2
- TRL 3

Engineering Practice

- TRL 4
- TRL 5
- TRL 6
- TRL 7
- TRL 8
- TRL 9

Technical Career Education

Engineering Science (BS, MS, PhD)
Preparing a workforce for the digital enterprise

- Adaptable skills
- Problem solving skills
- Data interpretation skills
- Promote work experience in school
- Enhanced marketing
- Manage talent like a supply chain
- Re-do HR
- Foster professional development
- Experiential development
- Skill standards and competencies
- MBD, MBE, and PLM
Nathan W. Hartman

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