The emerging relationship between PLM and Systems Engineering

Paul Nelson
PLM Systems Engineer

15 October 2015
Purdue University PLM COE Fall Meeting
Outline

- Personal Introduction
- Company Overview
- Taxonomy Level Set (syseng, model based, PLM, etc.)
- Systems Engineering Trends
- PLM Trends
- Systems Engineering and PLM are converging
- Conclusions and Recommended Actions
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Personal Introduction – Paul Nelson

- Two years in central Siberia
- B.S. and M.S. in MeEn at BYU (Internships at GM and Pratt & Whitney)
  - Thesis in Multi-physics simulations and visualizations and Global Product Development Course
- Boeing / Siemens PLM – ~5 years
  - St. Louis – F16/18/etc., Houston – Space Station, many other customers
- Orbital ATK – ~7 years - Promontory, Utah
  - Engineering Technology and Systems – Propulsion Systems
  - Corporate PLM Center of Excellence
- Began my career MCAD Management focused
- Quickly matured into core PDM / EBOM / Change / Document Management (CMIIP certification)
- More recently matured into Systems Engineering focus towards requirements engineering and MBSE
  (University of Utah graduate certificate in systems engineering and INCOSE CSEP certification)
- Now focused as a “PLM Systems Engineer” on orchestrating holistic PLM by working the above
  plus:
  - Manufacturing Engineering / ERP / MES tie ins
  - Simulation Process and Data Management
  - Materials and Mass Properties Management
  - ECAD and Software integrations
  - Foundational elements such as security, UI, Etc.
- Grateful for a career path that has allowed me to work big picture product development/delivery issues
- Enjoy my 5 kids, sweet wife, playing with LEGO robotics and exploring mountains
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Orbital ATK Overview

- New Global Aerospace and Defense Systems Company Established by Merger of Orbital and Alliant Techsystems in February 2015
- Leading Developer and Manufacturer of Reliable, Innovative and Affordable Products for Government and Commercial Customers
  - Launch Vehicles, Propulsion Systems and Aerospace Structures
  - Tactical Missile Products, Defense Electronics, Armament Systems and Ammunition
  - Satellites, Advanced Systems, Space Components and Technical Services
- About $4.4 Billion in Pro Forma Revenue Targeted for Calendar Year 2015
- More Than 12,000 Employees, Including 4,300 Engineers and Scientists
- Over $12 Billion in Contract Backlog With Strong Near-Term Growth Prospects
- Strong Revenue Growth, Earnings Accretion and Cash Flow Outlook
Top Customers and Revenue Composition

- **National Security**: 56%
- **NASA/Civil Government**: 26%
- **Commercial/International**: 18%

**Approximate CY 2015 Pro Forma Revenue Distribution**
Three Operating Groups and 12 Product Lines

Flight Systems Group
• Space Launch Vehicles
• Rocket Propulsion Systems
• Missile Defense Systems
• Aerospace Structures

Defense Systems Group
• Tactical Missile Products
• Defense Electronic Systems
• Armament Systems
• Ammunition and Energetics

Space Systems Group
• Commercial Satellites
• Government Satellites
• Spacecraft Components
• Space Technical Services

Approximate CY 2015 Pro Forma Revenue Distribution

Orbital ATK, Inc. - Overview July 2015
Orbital ATK defines Systems Engineering as the interdisciplinary incorporation of the following integrated elements:

- Requirements – definition, allocation, flow down, traceability
- Qualification / Verification / Validation
- System Design / System Integration
- Configuration Management
- Risk Management
- Technical Planning and Scheduling
- Technical Reviews
- Process Definition
CM and PLM Definitions

- **CM** ≡ traditional Configuration Management – serves to plan how identification, change control, status accounting, and audits will be performed on each product. Scoped to Engineering.

- **CMII** ≡ CM version 2 – Configuration Management scoped to include all information that could impact safety, security, quality, schedule, cost, profit, or the environment. Scoped to the Enterprise, not just Engineering. The goal is to keep requirements clear, concise, and valid and to accommodate change. Ultimate goal to achieve IPE and drive intervention resources to zero.

- **IPE** ≡ Integrated Process Excellence – CMII best practice processes for generic product development integrated and automated within a world class PLM framework. Resources spent on corrective action are in a state of decline and real improvements are occurring.

- **PLM** ≡ Product Lifecycle Management – Orbital ATK’s definition:
  - The application of a consistent set of processes and technology in support of the collaborative creation, management, dissemination, and use of product information across the extended enterprise from concept to end of life.
  - Consistent processes and tools allowing programs to share product information, leverage knowledge and to provide the right information at the right time to make the right decision.
  - PLM is more than a software tool; it is a business strategy.
Documented Requirements

ISO 9000:
"Document what you do; do what you document."

CMII Rule:
"A requirement is not a requirement until it is documented, validated and released."

No longer have to batch requirements into documents, but can decompose and handle requirement by requirement in a MBSE approach.
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System Engineering Trends

- Application of systems engineering
  - Applying systems engineering across industry domains
  - Applying systems engineering to policy
- Transforming systems engineering (see next chart for details)
- Maturing systems engineering foundations
  - Shoring up the theoretical foundation
  - Systems engineering body of knowledge
  - Systems theories across disciplines
- Commonly defined roles and competencies
  - The broadening role of the systems engineer
  - Consistency in essential systems engineering competencies
- Education and training
  - Building the future systems engineering workforce
  - The systems engineering curriculum
  - Lifelong learning
Five key systems engineering challenges:
1. Mission complexity is growing faster than our ability to manage it
2. System design emerges from pieces, rather than from architecture
3. Knowledge and investment are lost at project life cycle phase boundaries
4. Knowledge and investment are lost between projects
5. Technical and programmatic sides of projects are poorly coupled
   ➢ Most major system failures have resulted from failure to recognize and deal with risks

Systems Engineering Trending Improvements:
➢ Value Driven Practices
➢ Complex System Understanding
➢ Leveraging Technology for Systems Engineering Tools (e.g. MBSE)
➢ Collaborative Engineering: Integrating Teams and Organizations Across All Boundaries
➢ System Design In a System of Systems Context
➢ Architecting Systems to Address Multiple Stakeholder Viewpoints
➢ Architecting and Design of Resilient Systems
➢ Cyber Security – Securing the System
➢ Decision Support: Leveraging Information and Analysis for Effective Decision Making
➢ Virtual Engineering: Part of The Digital Revolution
   ➢ Simulation and Visualization
   ➢ Integrated Model-based Approaches
   ➢ Transforming Virtual Model to Reality
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PLM Trends

- PLM is a System of Systems (SoS) problem (or Fractal Zoom) with recurring principles/patterns

- Trends in PLM:
  - Integrate – Deeper integrations for CAx and PLM modules
  - Simplify – UIs and implementation approaches
  - Scale – 100ks to 1-10Ms
  - Broaden scope – more modules such as cost, testing, etc.
  - Closed loop product development – Architecture tied to mechanical, electrical, software design/analysis with testing in the loop
  - Specialize by industry – e.g. Aerospace and Defense template
  - Connecting Product and Production
  - Internet of things (or industry 4.0)
  - Move to Cloud
  - Big Data Analytics
  - Faster, better, cheaper
Closed Loop PLM

- **Requirements**
  - Customer
  - Regulatory
  - Manuf

- **Systems Engineering**
  - Use Case
  - Functions
  - Architecture

- **Engineering**
  - MCAD
  - ECAD
  - Software

- **Manufacturing**
  - Product Structure
  - MBOM
  - Routing

- **Physical**
  - As-Tested
  - As-Built
  - As-Maintained

Program Management, EVMS

Change, Issue, and Configuration Management

Integrated Reliability, System Safety, Maintainability, and Risk Management

Traceability and Accountability

Material and Processing

Behavioral Simulation, Design Trade off, Test, and Validation

Enterprise Reuse and Knowledge Management
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Address the System Challenges

Methods

Systems Engineering

Product Development, Engineering, System Safety, Mission Assurance, and Manufacturing

PLM Bridges Gaps

People

Business, Vendor, and Technical Project Management

Process

Information Technology

Tools
PS PLM IPT (Integrated Product Team)

**ERP System Owner** – Steven Busby / Jim Beck
**PLM System Owner** – Paul Nelson / Jon Jarrett / Kent Hechty
**MES System Owner** – Chuck Goodin / Kathy Philpot
**Quality System Owner** – Kaylene Sullivan / Sarah Hiza

**Configuration Management** – Angie Harbert / Jon Jarrett
**Material and Processing** – Larry Robison / Michael Killpack*
**Information Technology** – Matt McNeal / Taryn Salmon

**Future Functions to Add:**
Test, Facilities, Maintenance, Disposal, Environmental Services, EICO/Security, ATK University, PES, Research and Development Labs, As Built, As Maintained, etc.

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**KEY:**
- Function
- IPT SME
- Management Sponsor

**Design Engineering**
- Nathan Holyoak
- Fred Perkins

**Project Engineering**
- Scott Eaker
- Luke Whipple
- Tom Kelley / Dave Starrett

**Master Schedule**
- Matt Jeppsen
- Richard Hawkes

**Systems Engineering**
- Michael Lamoreaux
- Ben Goldberg*

**Program Management**
- Invite to Jeff Vosburgh
- Charlie Precourt

**Business Development**
- Brian Allen*
- Erik Gross

**Analysis**
- Brett Verhoef
- Vicki Call

**EBOM**
- Mary Lavery
- Angie Harbert

**MBOM**
- Steven Busby
- Richard Hawkes

**Mfg Planning**
- Chuck Goodin
- Kathy Philpot

**Quality Control**
- Kaylene Sullivan
- Sarah Hiza

**Safety & Mission Assurance**
- Peter Reed
- Dan Pulleyyn / Janica Cheney

**Test**
- Ben Bodrero
- ?

**As Built**
- Tommy Stokes or replacement?

**As Maintained**
- ?

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* Technical Fellow
Cross Reference Functional Interactions

- PS PLM IPT is working to identify major interaction points / major handoffs
- Help ensure process improvement investments address largest disconnects
PS PLM IPT (Integrated Product Team)

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- ?

* Technical Fellow
Model Based Plan

- Manufacturing
- Analysis
- Inspection
- Production
- 2D Draw
- Tooling

3D Model
### 3D Modeling Return On Investment

The 100% is a benchmark line to measure from

<table>
<thead>
<tr>
<th>Controlled 2D</th>
<th>Aux</th>
<th>2D</th>
<th>3D</th>
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<td><strong>2D Drawing Only</strong></td>
<td>100%</td>
<td>2D</td>
<td>100%</td>
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<tr>
<td><strong>Integration</strong></td>
<td>10%</td>
<td>100%</td>
<td>300%</td>
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<tr>
<td>• Vehicle Profile Drawing</td>
<td>10%</td>
<td>100%</td>
<td>300%</td>
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<tr>
<td>• Layout Drawing</td>
<td>10%</td>
<td>100%</td>
<td>300%</td>
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<tr>
<td>• Harness Layout Drawing</td>
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<td>• IICD’s</td>
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<td>100%</td>
<td>300%</td>
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<tr>
<td><strong>Manufacturing</strong></td>
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<td>80%</td>
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<tr>
<td>• CNC</td>
<td>0%</td>
<td>80%</td>
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<tr>
<td>• Mfg. Instructions</td>
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<td>80%</td>
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<tr>
<td><strong>Quality/Inspection</strong></td>
<td>0%</td>
<td>80%</td>
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<tr>
<td>• CMM</td>
<td>0%</td>
<td>80%</td>
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<tr>
<td>• Inspection Plan</td>
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<td><strong>Total</strong></td>
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### Controlled 2D and 3D

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<th>3D</th>
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</thead>
<tbody>
<tr>
<td><strong>Drafting</strong></td>
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<td>2D</td>
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<tr>
<td><strong>Integration</strong></td>
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<td>2D</td>
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<tr>
<td>• Inspection Plan</td>
<td>0%</td>
<td>2D</td>
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<tr>
<td><strong>Total</strong></td>
<td>200%</td>
<td>2D</td>
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<tr>
<td><strong>190%</strong></td>
<td>40%</td>
<td>2D</td>
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</table>

### Controlled 3D

<table>
<thead>
<tr>
<th>3D Annotated Model</th>
<th>2D</th>
<th>3D</th>
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</thead>
<tbody>
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<td><strong>Drafting</strong></td>
<td>150%</td>
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<tr>
<td><strong>Integration</strong></td>
<td>0%</td>
<td>2D</td>
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<tr>
<td><strong>Manufacturing</strong></td>
<td>20%</td>
<td>2D</td>
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<tr>
<td>• CNC</td>
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<tr>
<td>• Inspection Plan</td>
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<td>2D</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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<td>2D</td>
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<tr>
<td><strong>40%</strong></td>
<td>150%</td>
<td>2D</td>
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### ROI Summary
- The biggest productivity gains come with 3D models (even with 2D drawings)
- Companies have been slower to adopt 3D annotation (PMI) because it offers modest gains over associated drawings. It is however an area where gains can be realized.

**3D models can yield a 600% cost savings over 2D drawings**
Example: Benefits on the Ares – SLS Avionics

Making it work and work well with models

- Virtual prototype
- Electronic CAD and mechanical CAD
- All the information was stored on each model
The prototype used to verify the routing was significantly less expensive
Rapid Learning Cycles – Agile Scrum/Sprints for Engineering
Communication is difficult because systems don’t talk to each other – instead relying on human intervention.
Requirement Flow Through Design

System Requirements → Design Driven Requirements → Design → Requirement Validation → System Requirements

- Requirement Validation
- Design
- Requirement Validation

Passes all
Passes all w/ info
Fails w/ warning
Fails critical (error)
Systems Engineering and PLM are Converging

- PLM and systems engineering are the same problem from different vantage points
- PLM = tools and business strategy vantage point
- Systems engineering = process and methodology vantage point
- Marry people, process, tools, and methods and it is powerful
  - e.g. Rubik’s cube/LEGO Robot
- Key Systems Engineering method is an NxN coupling matrix
  - Let’s look at the interactions between systems engineering and PLM
### Technical Processes

<table>
<thead>
<tr>
<th>Category</th>
<th>General PLM Solution Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements Engineering</td>
<td></td>
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<tr>
<td>Stakeholder Needs &amp; Requirements Definition Process</td>
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<tr>
<td>Architecture / Design Development</td>
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<tr>
<td>Design Definition Process</td>
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<tr>
<td>System Requirements Definition Process</td>
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<td>Architecture Definition Process</td>
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<td>System Analysis Process</td>
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<td>Implementation Process</td>
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<tr>
<td>Qualification, Verification, and Validation Process</td>
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<td>Transition Process</td>
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<tr>
<td>Operation Process</td>
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<td>Maintenance Process</td>
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<tr>
<td>Disposal Process</td>
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### Technical Management Processes

<table>
<thead>
<tr>
<th>Category</th>
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<tbody>
<tr>
<td>Technical Planning</td>
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<tr>
<td>Technical Effect Assessment</td>
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<td>Risk and Opportunity Management</td>
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<tr>
<td>Baseline Control / Configuration Management Process</td>
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<td>Information Management Process</td>
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<td>Measurement Process</td>
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<td>Quality Assurance Process</td>
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### Agreement Processes

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<thead>
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<tbody>
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<td>Acquisition Process</td>
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<tr>
<td>Supply Process</td>
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<tr>
<td>Process Definition</td>
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<td>Life Cycle Model Management Process</td>
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<td>Infrastructure Management Process</td>
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<td>Portfolio Management Process</td>
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<td>Human Resource Management Process</td>
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<td>Quality Management Process</td>
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<td>Knowledge Management Process</td>
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### Organizational Project-Enabling Processes

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<tbody>
<tr>
<td>Affordability / Cost-Effectiveness / Lifecycle Cost Analysis</td>
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<tr>
<td>Electromagnetic Compatibility</td>
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<tr>
<td>Environmental Engineering / Impact Analysis</td>
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<td>Interoperability Analysis</td>
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<td>Logistics Engineering</td>
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<td>Manufacturing and Productability Analysis</td>
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<td>Mass Properties Engineering</td>
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<tr>
<td>Reliability, Availability, and Maintainability</td>
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<td>Radiation Engineering</td>
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<td>System Safety Engineering</td>
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<td>System Security Engineering</td>
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<tr>
<td>Training Needs Analysis</td>
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<tr>
<td>Usability Analysis / Human Systems Integration</td>
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<td>Value Engineering</td>
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### Specialty Engineering

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<td>Modeling and Simulation</td>
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<td>Model-Based Systems Engineering</td>
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<td>Function-Based Systems Engineering Method</td>
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<td>Obeya-Chinri Systems Engineering Method</td>
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<tr>
<td>Prototyping</td>
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<td>Interface Management</td>
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<td>Integrated Product and Process Development</td>
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<td>Lean Systems Engineering</td>
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### Other Cross Cutting Systems Engineering Methods

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### Only Most Urgent Interactions Identified

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<thead>
<tr>
<th>Vendor Capability, but not core PLM</th>
<th>Production PLM Capability</th>
<th>No Fill = Little to no core PLM Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>INCOSE Certification Emphasis</td>
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### Technical Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Business or Mission Analysis Process</th>
<th>Requirements Engineering</th>
<th>System Integration</th>
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<tbody>
<tr>
<td>Architecture/Design Development</td>
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<td>Maintenance Process</td>
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<td>Disposal Process</td>
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### Technical Management Processes

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### Agreement Processes

| Process                                      | Acquisition Process                | Supply Process               | |
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### Organizational Project-Enabling Processes

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### Specialty Engineering

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### Other Cuts: Systems Engineering

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### General PLM Solution Categories

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| Key Features                  | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition |
|-------------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
|                               |                      |                       |                     |                     |                     |                     |                       |                     |                     |                     |                             |                   |                     |                             |                     |                     |                     |

<p>| Key Features                  | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition | Business Intelligence | Activity Recognition |
|-------------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
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<tr>
<th>Expert</th>
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<tbody>
<tr>
<td>Nate Hartman (computer graphics)</td>
<td>MBD and minimum information model</td>
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<tr>
<td>Tom Brush (Business)</td>
<td>Supply chain and PLM integration</td>
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<td>Michael Witt (Library Science)</td>
<td>LOTAR</td>
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<tr>
<td>Mihaela Vorvoreanu (computer graphics)</td>
<td>UI/UX and PLM Implementation</td>
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<tr>
<td>Elisa Bertino (CS)</td>
<td>Cyber Security and PLM</td>
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<tr>
<td>Dan Delaurentis (Aero Eng.)</td>
<td>MBSE and PLM</td>
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Outline

- Personal Introduction
- Company Overview
- Taxonomy Level Set (syseng, model based, PLM, etc.)
- Systems Engineering Trends
- PLM Trends
- Systems Engineering and PLM are converging
- Conclusions and Recommended Actions
Q: Is there an emerging relationship between PLM and Systems Engineering?
A: Yes, my company role as a PLM Systems Engineer is proof of that; the NxN matrix just reviewed also articulates this relationship.

However, we have only just started to scratch the surface and there is a great deal of work ahead; we need to get all interactions green.

Orbital ATK defines Systems Engineering as the interdisciplinary incorporation of the following integrated elements:
- Requirements – definition, allocation, flow down, traceability
- Qualification / Verification / Validation
- System Design / System Integration
- Configuration Management
- Risk Management
- Technical Planning and Scheduling
- Technical Reviews
- Process Definition
Recommendations for Research

- Don’t lose focus on delivering the holistic system
  - While taking on new scope and tackling systems engineering and PLM interactions it is important to not degrade in areas that are strong today
  - Continue to optimize subsystems, but spend more time on how they impact the whole
  - Don’t just think technical, but cost and schedule too
  - Focus on interactions – herein lies the major risk and payback opportunity
  - It is time to take the system level problem out of the “too hard pile”

- Provide students challenging projects and research that address system needs

- Research and methods to help mitigate key Systems of Systems (SoS) risks for PLM/Systems Engineering:
  - System elements operate independently
  - System elements have different life cycles
  - The initial requirements are likely to be ambiguous
  - Complexity is a major issue
  - Management can overshadow engineering
  - Fuzzy boundaries cause confusion
  - SoS engineering is never finished
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