Integrating Sustainment Throughout the Model-Based Enterprise

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AGENDA

Model-Based X where “X” = Sustainment

Digital Tapestry and Shared Data Perspectives

Industry 4.0 for Sustainment and A/V/MR

Digital Data for Additive Manufacturing for Sustainment

Agility and Affordability Challenge and Acquisition Approach

CASE FOR MODEL-BASED "X" WHERE X = SUSTAINMENT

"Product-Focused O&S Should-Cost Opportunities

Early, Upfront Investment in Reliability, Maintainability and Supportability. Often, the greatest opportunities to save costs are manifested well before a weapon system is produced and deployed. Giving due consideration to reliability and maintainability and electing to pursue thoughtful trade decisions in the design affords the opportunity to reap tremendous life-cycle cost (LCC) savings. We like to talk about "upfront and early" since, **notionally, 80 percent of O&S costs are determined during design development."**

AFFORDABILITY: TOTAL OWNERSHIP COST FOCUS

O&S Cost Management Guidebook – February

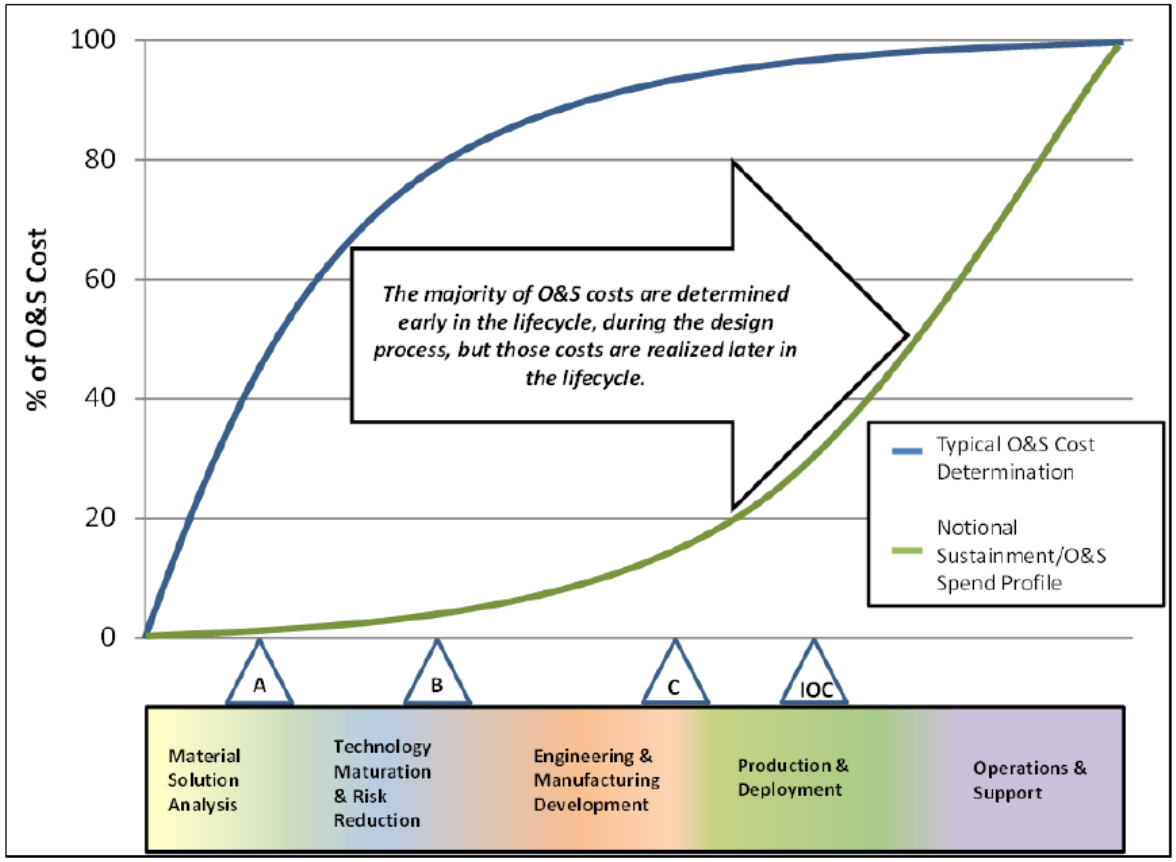
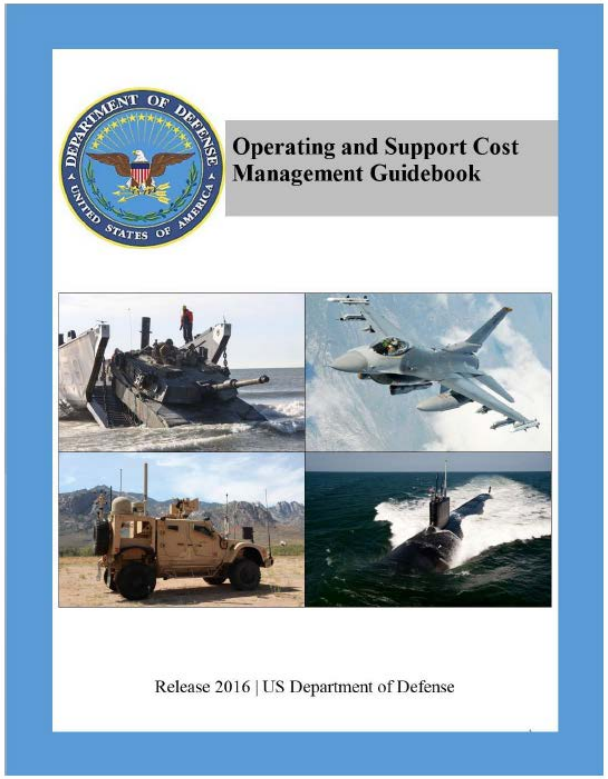


Figure 4 – Time delay between decisions effecting O&S cost and the realization of those costs



"Operating and support (O&S) costs historically account for approximately 70 percent of a weapon system's total life-cycle cost", GAO-18-678, Sept. 2018, p. 1.

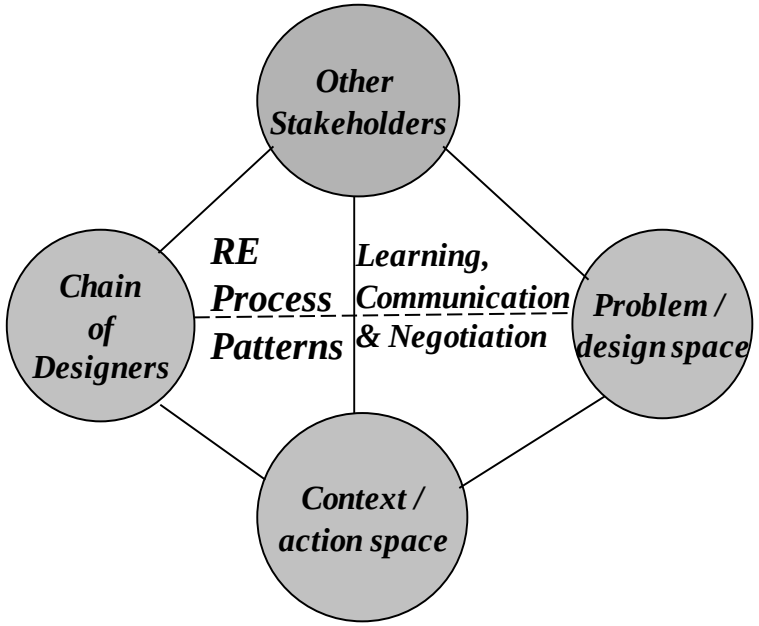
CONTEXT AND USAGE MODELING AS PART OF MBE

Gaska, “Improving Requirements Engineering (RE) to Support Cross-Discipline Collaboration on Complex Computer-Based Systems”, Thesis, Binghamton University, 1999

Understand interaction with world of operations and sustainment (O&S)

Collaborative Human Immersive Lab (CHIL) usage for design for operations and sustainment within context / world

Architecture 3D Modeling and Building Information Management



RELEVANT SOLUTIONS
IN THE REAL WORLD

DESIGNING FOR A MAINTENANCE FREE OPERATING PERIOD

"A maintenance free operating period (M-FOP) is defined as a period of time (or appropriate units) during which a system is both operational and is able to carry out its required function(s) without maintenance activities and without encountering failures". (Hockley, "Maintenance Free Periods of Operation – The Holy Grail?", RTO-MP-AVT-144, p 23-3.)

Design up front using MFOP models with mission availability focus

Concept compared to warranties

Additional selected references:

- Mitchell, "What the Customer Wants. Maintenance-Free and Failure-Free Operating Periods to Improve Overall System Availability and Reliability", DTIC ADP010429, 2000.
- Guertin et al., "Impact of Maintenance Free Operating Period Approach to Acquisition Approaches, System Sustainment, and Cost", NPS-LM-13-005, Jan. 2013.

GOVERNMENT MANDATE EVOLUTION

2. Achieve Dominant Capabilities While Controlling Lifecycle Costs

System of Systems Approach: Primary and Enabling Systems

Apply Affordable System for Operational Effectiveness (ASOE) model

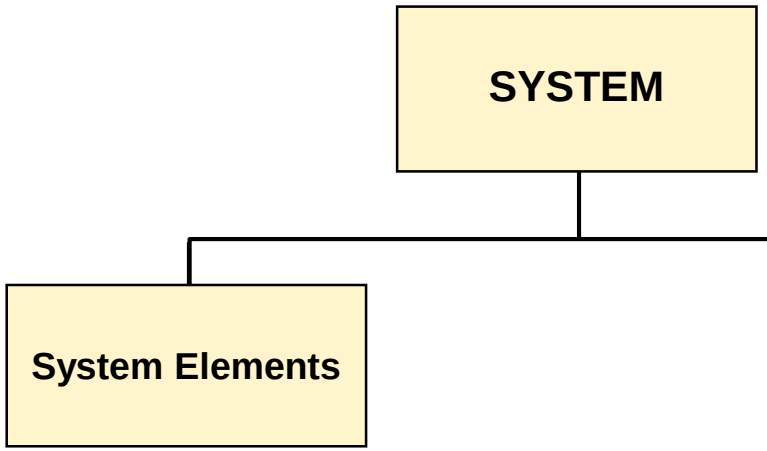
Manage efficient digital tapestry / environment that supports innovation

Assure model based approach supports the lifecycle

Develop data analytics to address system of systems and context complexity

Gaska M, Bobinis J, and Galluzzo V, Application of System Design for Operational Effectiveness for Architectural Modeling of the SoS Relationship Between Primary and Enabling Systems, Complex Adaptive Systems Conference, San Jose, CA, Publication 5, November 3, 2015

SYSTEM OF SYSTEM DEFINITIONS



System: An aggregation of system elements and enabling system elements to achieve a given purpose or to provide a capability.

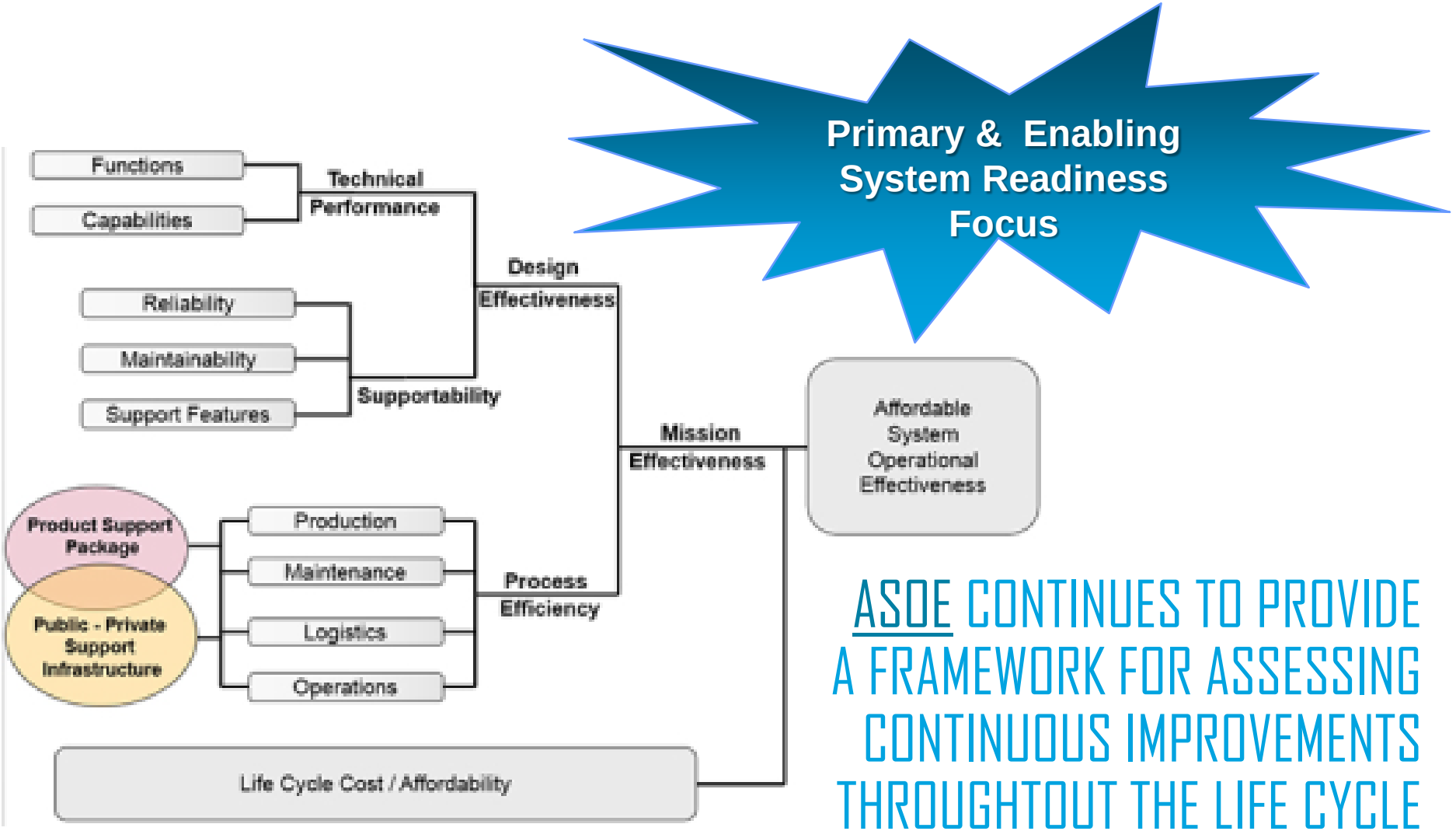
System Elements: Also referred to as configuration items, subsystems, segments, components, assemblies, or parts.

Enabling System Elements: Provide the means for putting a capability into service, keeping it in service, or ending its service, e.g., processes or products used to enable system development, test, production, training, deployment, support, and disposal.

Each system element or enabling system element may include but is not limited to hardware, software, people, data, processes, facilities, and tools.

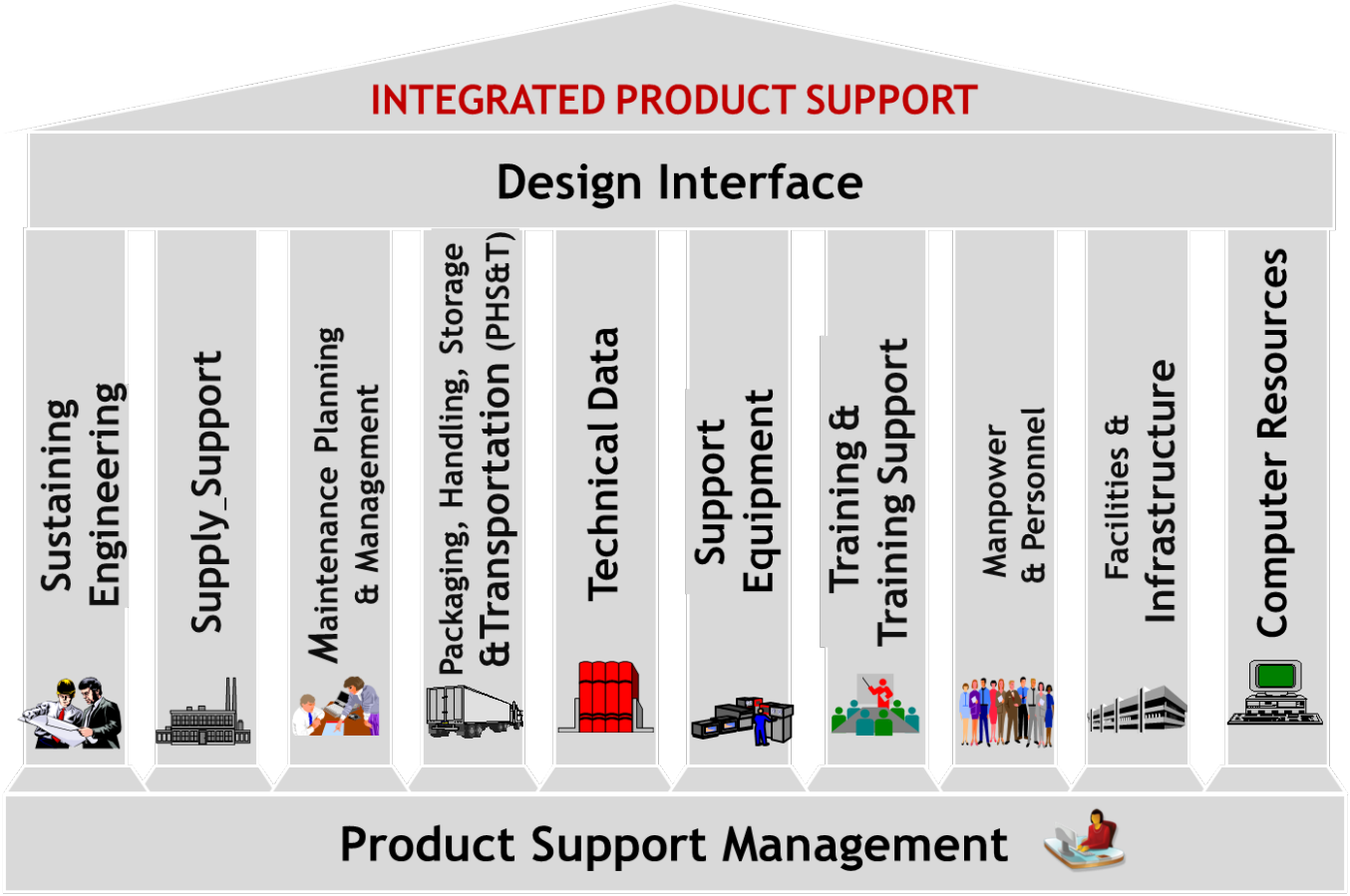
- **Defense Acquisition Guidebook. Chapter 4.2.1.2. System of Systems. Figure 4.2.1.2 as of June 1, 2015.**

AFFORDABLE SYSTEMS OPERATIONAL EFFECTIVENESS (ASOE)



ASOE CONTINUES TO PROVIDE A FRAMEWORK FOR ASSESSING CONTINUOUS IMPROVEMENTS THROUGHTOUT THE LIFE CYCLE

COMPLEXITY OF THE "X" = SUSTAINMENT



AcqLinks and References:

- **[1] Website:** ACQuipedia – Sustainment Engineering
- **[2]** Integrated Product Support Element Guidebook, Chapter 3 – Dec 2011

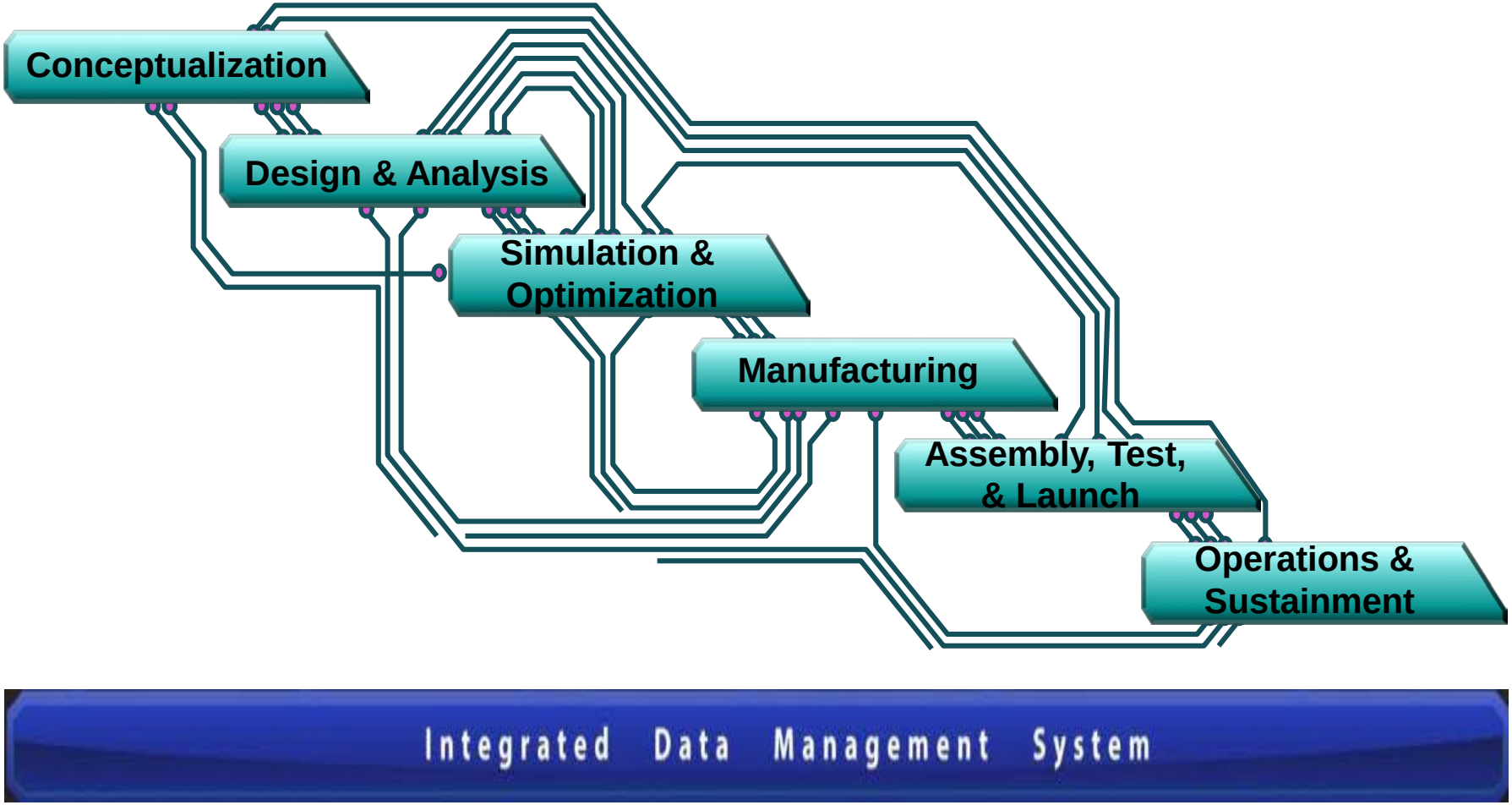
ENABLING DIGITAL ENVIRONMENT HISTORY: CONCURRENT ENGINEERING

Shared product, process and organization information as 1990s enabler focus of DARPA Initiative in Concurrent Engineering (DICE)

Douglas R. SNEAKERS: A Concurrent Engineering Demonstration System Concurrent Engineering. Thesis, Worchester Polytechnic Institute, 1994.

WETICE. *24th IEEE International Conference on Enabling Technologies: Infrastructure for Collaborative Enterprises.* Larnaca (Cyprus), Greece. June 15-17, 2015.

DIGITAL TAPESTRY AND SHARED DATA PERSPECTIVES: INTEGRATED DATA MANAGEMENT AS PART OF MBE



Oster C. Digital Tapestry. *Model Based Systems Engineering Workshop at INCOSE International Workshop.* Jacksonville, Florida. January 21, 2012.

Gaska M. Importance of CM/DM in the Current and Emerging DoD Product Support Environment. *Association for Configuration and Data Management Conference.* Savannah, Georgia. March 3-5, 2014.

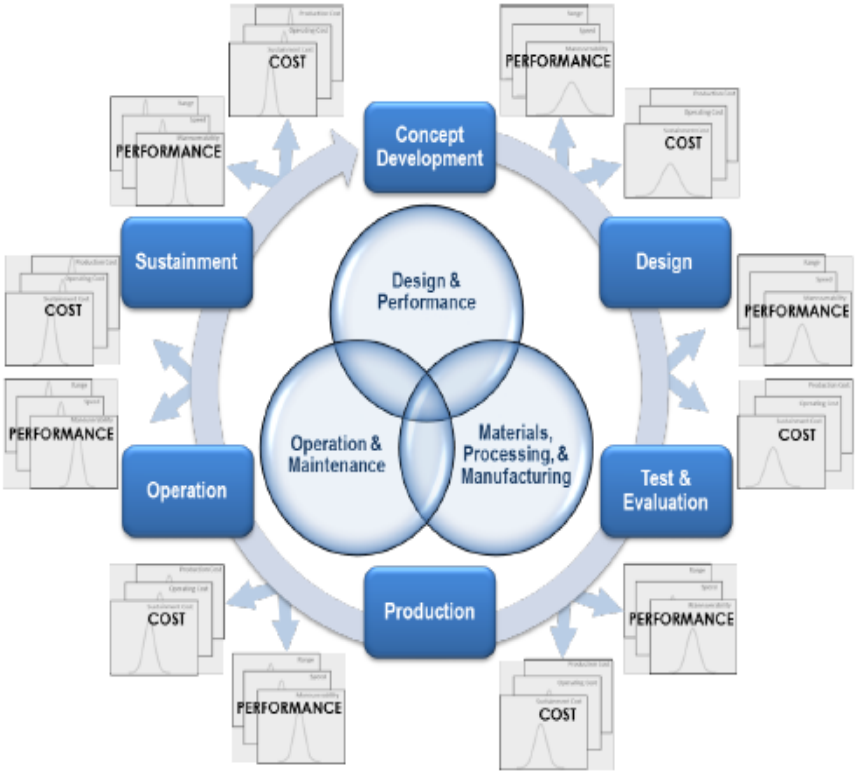
DIGITAL THREAD: OVERVIEW AND INTRODUCTION TO EXHIBIT

Aircraft Airworthiness and Sustainment Conference, Brench Boden, May 23, 2017

Digital Thread Concept

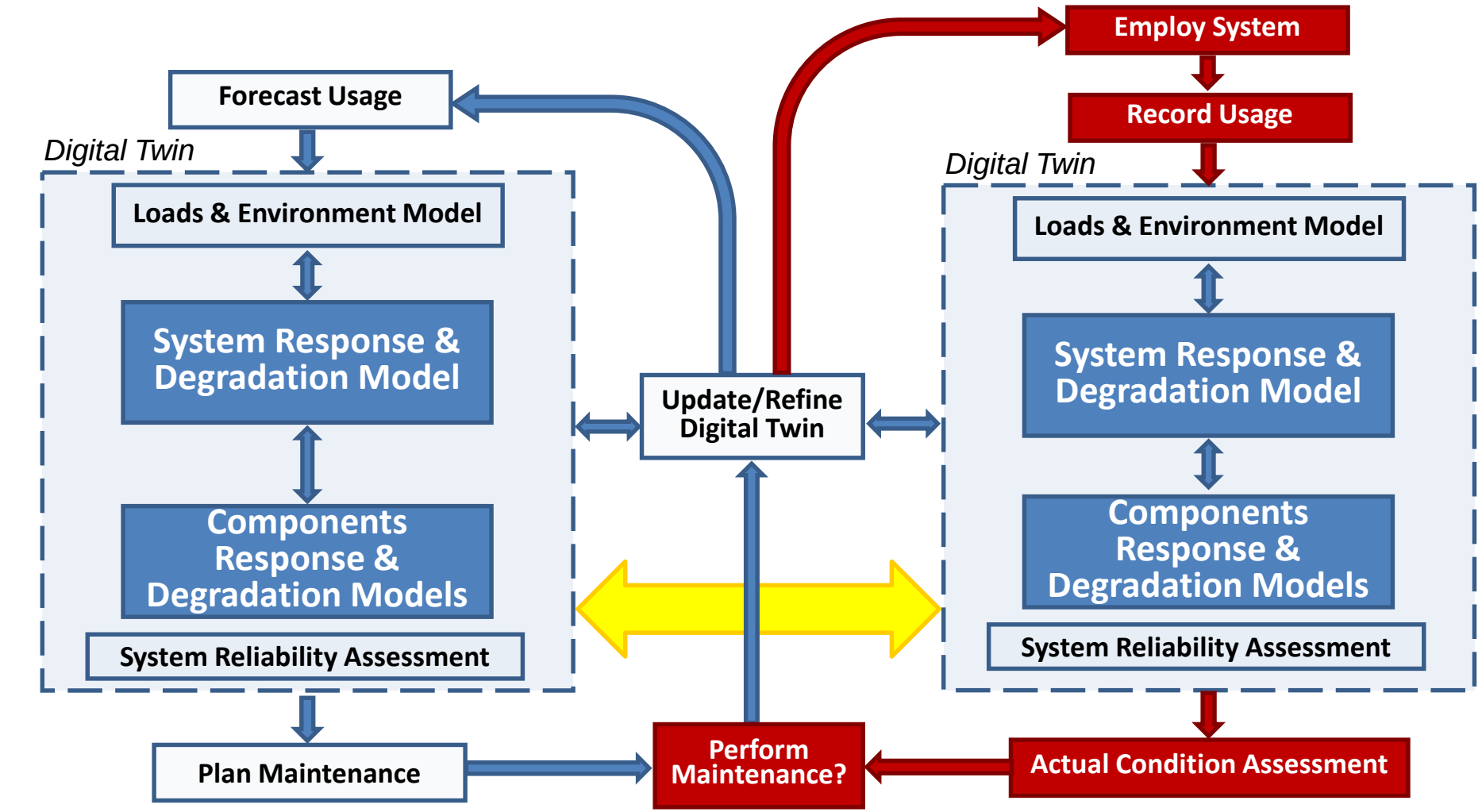
Main Technical Goals:

- Use ALL AVAILABLE INFORMATION in analyses
- Use PHYSICS to inform analyses
- Use PROBABILISTIC METHODS to quantify program risks
- CLOSE THE LOOP from the beginning to the end and back to the beginning of the acquisition lifecycle



Make ***INFORMED DECISIONS*** throughout lifecycle

Use of DTw to Inform Mx Planning



Dr. Pamela Kobryn and Eric Tuegel, "Digital Twin and Digital Thread for Sustainment", Aircraft Airworthiness and Sustainment Conference, May 23, 2017.

DIGITAL MANUFACTURING AND DESIGN INNOVATION INSTITUTE

Mission: Establish a state-of-the-art proving ground for digital manufacturing and design that links IT tools, standards, models, sensors, controls, practices and skills, and transition these tools to the U.S. design & manufacturing industrial base for full-scale application

Announced in February 2014; UI Labs team selected in 2014

Builds on digital thread focus at National Institute for Standards and Technology (NIST)

Rebranding as MxD – Manufacturing times Digital in 2019

Harris G. DMDII Institute Overview for The Lockheed Martin Mechanical Engineering and Advanced Manufacturing Workshop , 7 May, 2014. Approved for Public Release.

National Institute for Standards and Technology (NIST). Enabling the Digital Thread for Smart Manufacturing Project. Internet. June 1, 2015.

Model Based Enterprise Capability Center

PM/Government

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

Model Based Enterprise Capability Center (MBECC)

Model Based Engineering

Model Based Manufacturing

Model Based Systems Engineering

Institutes DMDII/Centers of Excellence

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

Model Based Sustainment/ Logistics

- Model Surrogate
- Creator of System History Documentation
- System User Training
- Obsolescence

+ MB Definition for System Employment, Use and Support

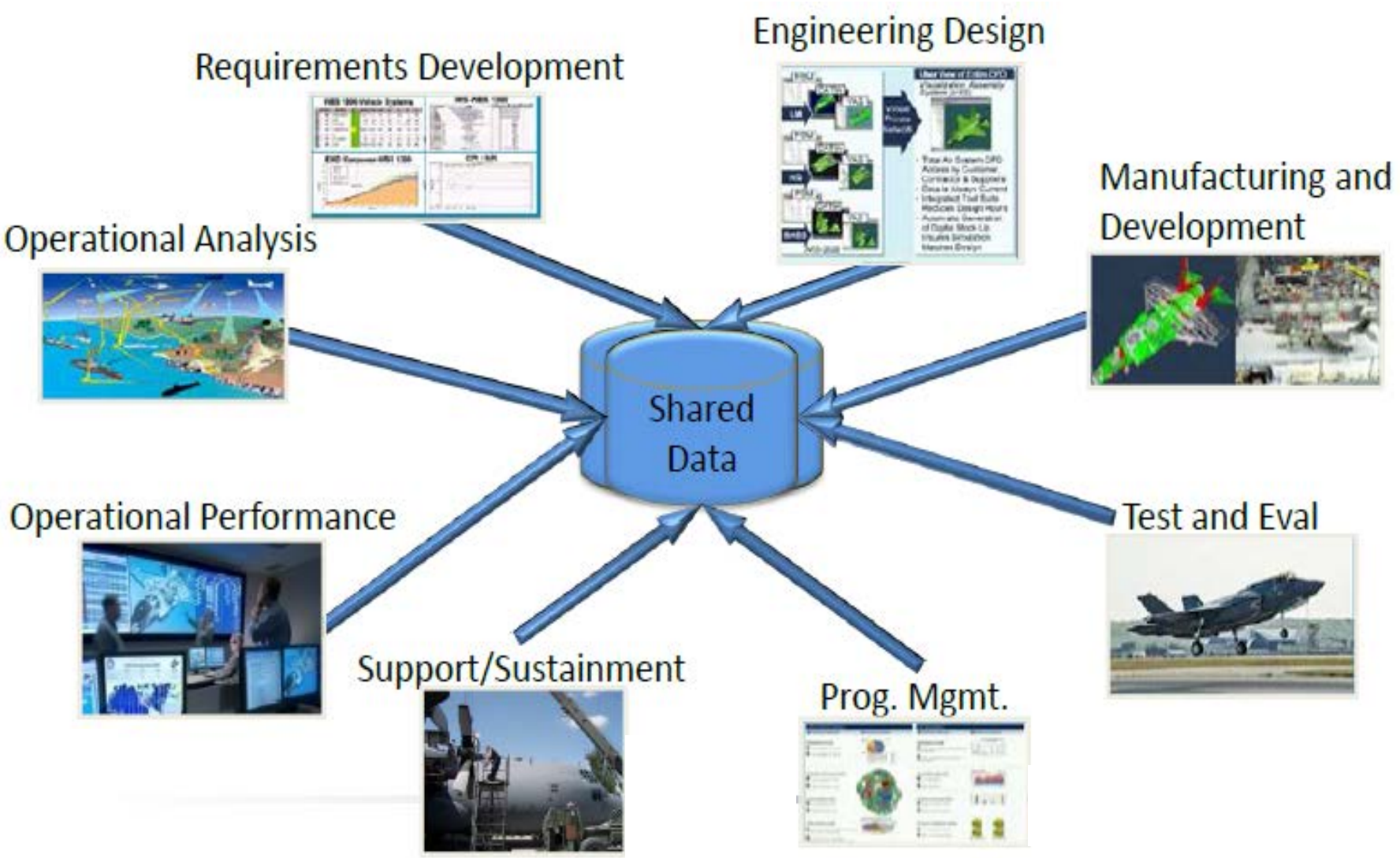
ational Standards

ses in Government PM Shops

itute Developments in the Digital Thread

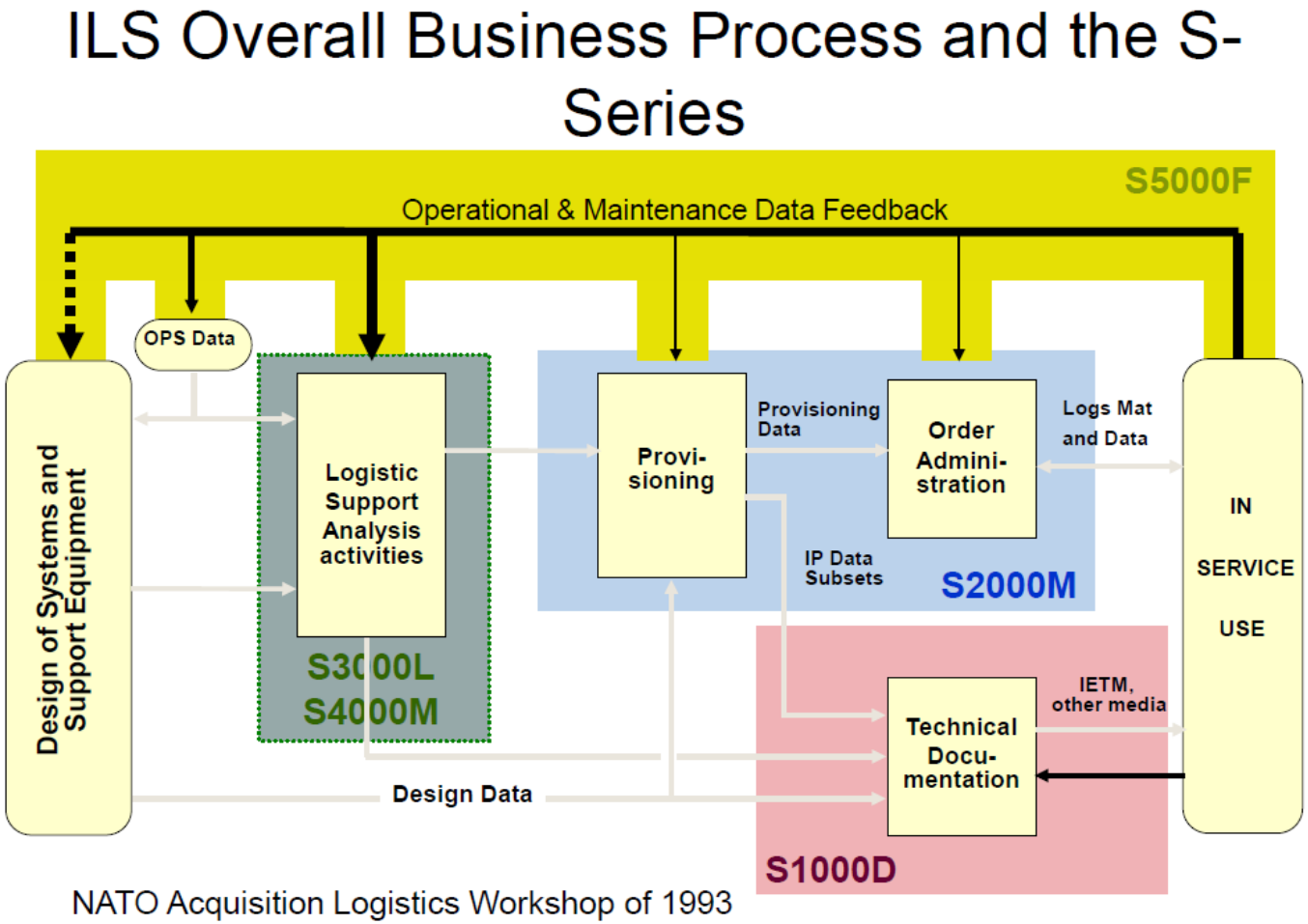
y in Government Organizations

SHARED DATA FOR LIFECYCLE SUPPORT



Landers T, Bijan Y. Practical Implementation of Model-Based Systems Development. *NDIA Annual Systems Engineering Conference.* Springfield, VA. October 28-30, 2014. and INCOSE, 2016

EXISTING LOGISTICS STANDARDS FOR MBE INTEGRATION



Aerospace Industry Association [S-Series Standards]

INDUSTRY 4.0 SUSTAINMENT INTEGRATION

Focus on extending Industry 4.0 technologies to sustainment

Digital transformation life cycle perspectives (PHM Society 2018)

Connected supply chain optimization (CTMA/DLA Partners 2018)

Internet of Things (IoT) for life cycle/service management

Augmented/virtual/mixed reality (A/V/MR) for maintenance

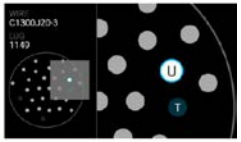
INDUSTRY 4.0 AND A/V/MR

Digital Thread and Industry 4.0 (Don Kinard, NIST MBE Conference, 2018)

Augmented Reality

Guided Work Instructions with Voice Controls (After)

Operator's view in glasses



Remote Augmented Reality

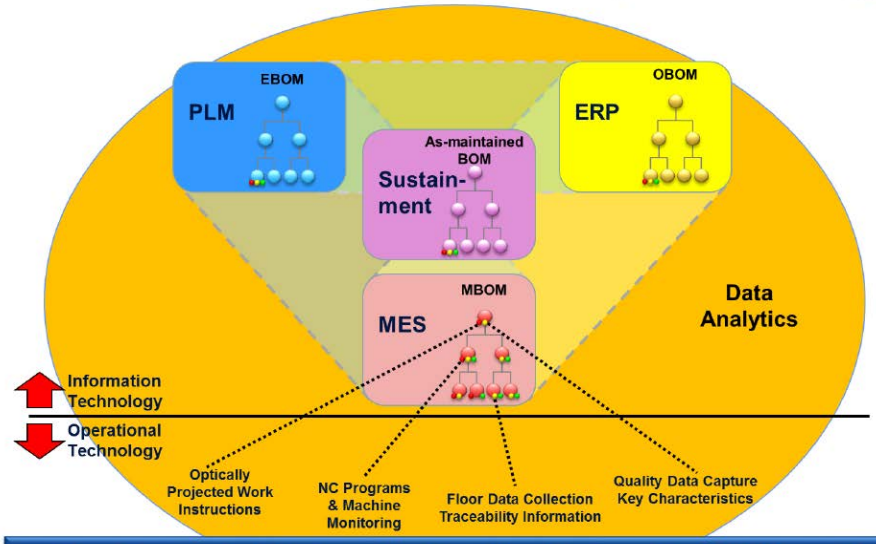
"Technician" view on Tablet

"Expert" view at Desktop Computer

"Technician" view on Tablet

"Expert" view at Desktop Computer

The Connected Enterprise – Industry 4.0



The Connected Enterprise Enables Automated Metrics, Financial Reporting, Data Analytics, Integration with Factory Equipment, and Real Time Management Visibility

SUPPLY CHAIN AND MAINTENANCE USE CASES

Virtual Subject Matter Expert (SME) – virtual SME can see what maintainer sees

Hands free maintenance - use case synergy with manufacturing (as early as Hopps, AeroDef 2013)

Heads up work instructions— Work Instructions in AR/ MR, with 3D overlays and text that links to a server

TechAssist at DoD Maintenance Conference 2017

Smart Glasses and AR in Aerospace Manufacturing: Finding the Niche (Christi Fiorentini, AWE, 2016)

Aeronautics Global field service collaboration and travel reduction

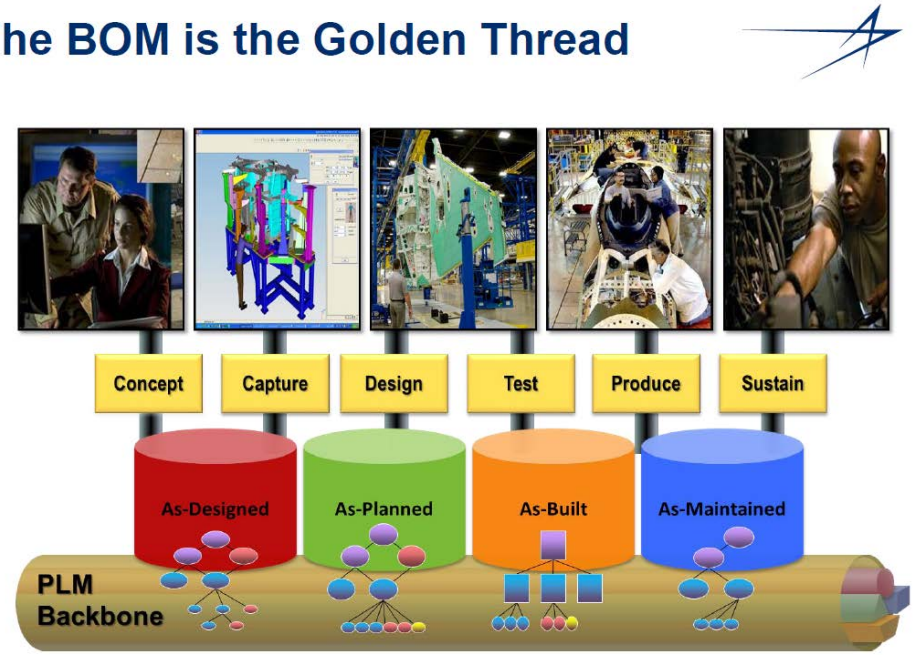
Training and Logistics Solutions

LIFECYCLE PERSPECTIVES

Early design with Collaborative Human Immersive Lab (CHIL)

Applying Virtual Reality, and Augmented Reality to the Lifecycle Phases of Complex Products (Rabbitz and Crouch, 2017)

A/V/MR leveraging the Bill of Materials (BOM) across the lifecycle (Don Kinard, NIST MBE Conference, 2018)



DIGITAL DATA: ADDITIVE MANUFACTURING FOR SUSTAINMENT

America Makes Maintenance and Sustainment Advisory Group Chair

OSD Additive Manufacturing for Maintenance Operations (AMMO)

Collaboration on AM Business Model Wargames / Workshops

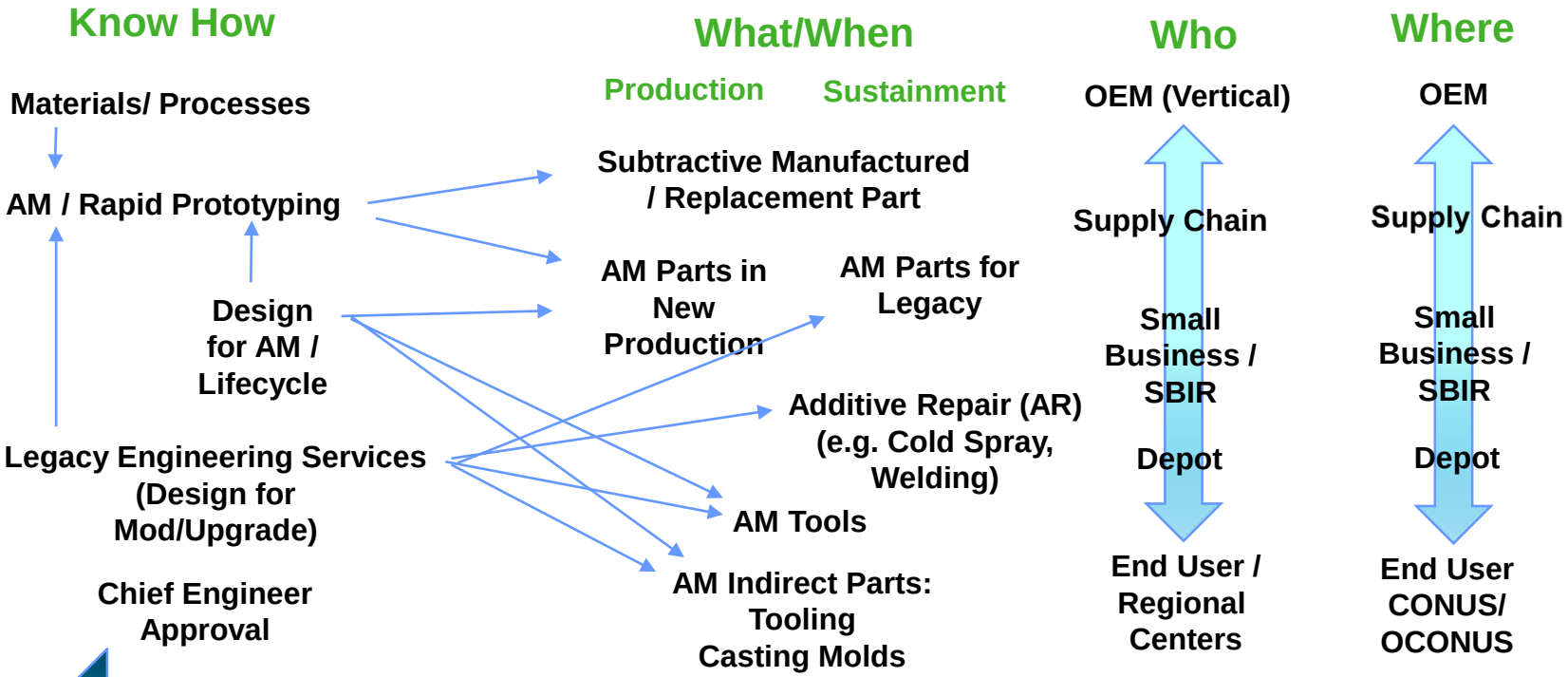
America Makes and Maturation of Advanced Manufacturing for Low-cost Sustainment (MAMLS) Phases I - III

PUBLIC PRIVATE PARTNERSHIP COLLABORATION TO APPLY SCIENCE AND TECHNOLOGY TO IMPROVE SUSTAINMENT OF LEGACY SYSTEMS

INDUSTRY USE CASES AND VALUE CHAIN

Joint Staff Enterprise Development "JED" Talk June, 2015

Why? Faster, Lower Cost, Improved Readiness, Lower Inventory/Warehousing



Model Based Engineering / Digital Thread / Intellectual Property Agreements/Contracts

How Much? Business Model/Business Case

Qualification and Certification (Machine/Design Authority/Quality/Airworthiness)

OSD JOINT ADDITIVE MANUFACTURING WORKING GROUP (JAMWG) RELATED EFFORT

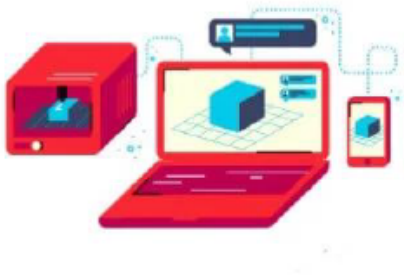
Kelly Visconti, Additive Manufacturing, OSD Perspectives, DoD Maintenance Conference, 2018

Project Managed by America Makes

JAMWG Directed Project

Joint Additive Manufacturing Model EXchange (JAMMEX)

- Develop a system to share 3D print files in a secure environment



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OSD/AMERICA MAKES ADDITIVE MANUFACTURING WORKSHOPS

Initial Additive Manufacturing Sustainment Business Model Wargames 2016 at LM Center for Innovation, Suffolk, VA

Second Wargame at LM Global Vision Center (GVC), Crystal City, VA in 2017

2018 Workshop event at GVC included Working Group on Additive Manufacturing Model Exchange and Blockchain (see summary)

OSD JAMWG co-sponsoring 4th event June 18-19, 2019 at GVC with Working Groups aligned with Stakeholder Councils including Data and Model Sharing (Register)

OSD AND AMERICA MAKES SPONSORED WARGAMES/WORKSHOPS INCLUDE FOCUS ON AM DATA AND MODEL SHARING

AGILITY AND AFFORDABILITY CHALLENGE

Acquisition approach to support lifecycle management

Tech insertion mods and upgrades for enhanced capability

Defect/reliability/maintainability root cause analysis

Obsolescence focus and Modernization Through Spares history

Acquisition reform research (UMD)

Model Based Enterprise supports agile development / DevOps

SUPPORTING ADAPTIVE ACQUISITION CONCEPTS

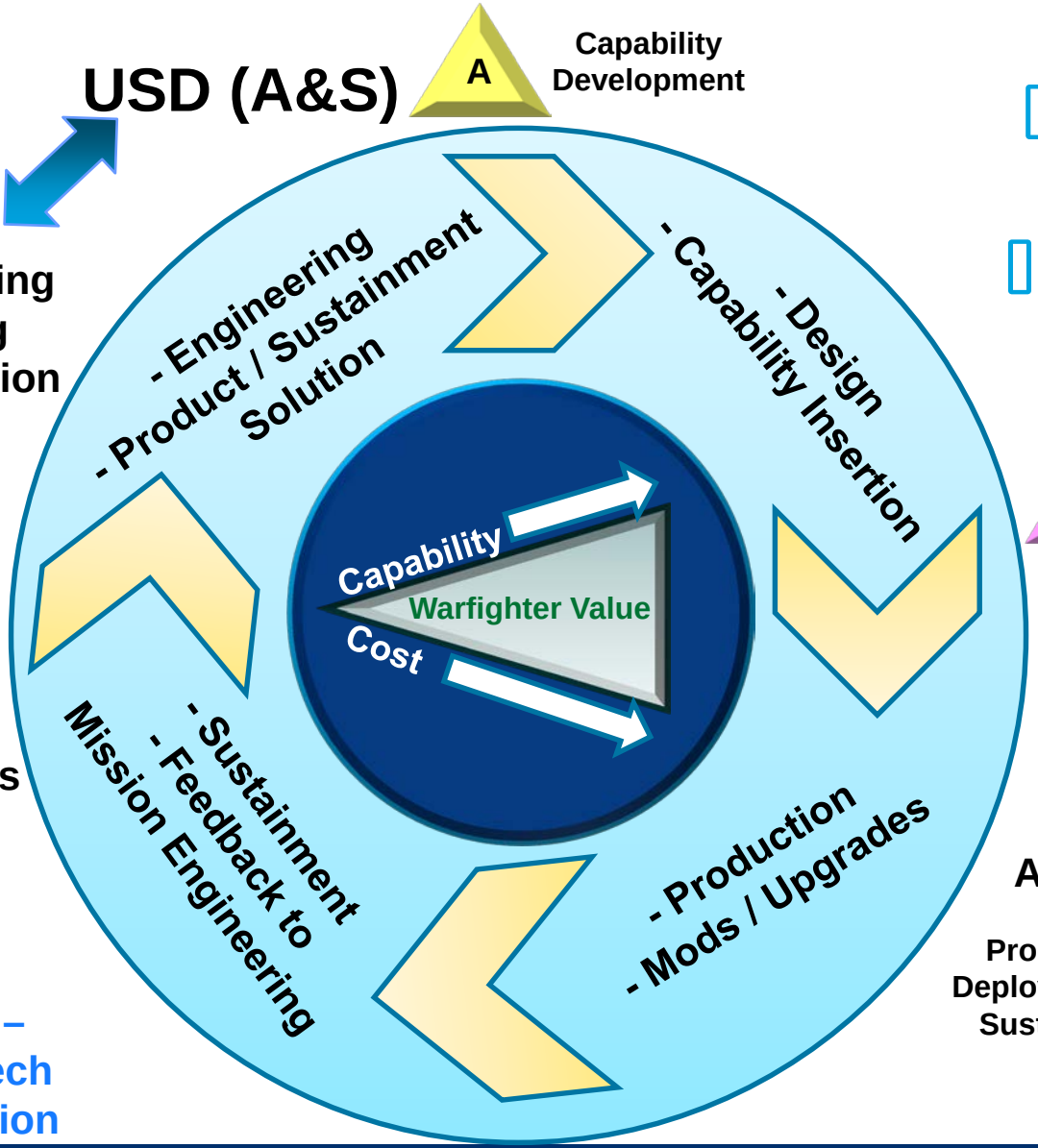
USD (A&S)

USD (R&E)

- Mission Engineering
- Rapid Prototyping
- Technical Maturation
- JROC Guidance

Operations

- Supported by sets of systems to achieve mission objectives
- R&M feedback
- Address DMSMS – opportunity for tech / capability insertion



CONTINUOUS CAPABILITY OPTIMIZATION

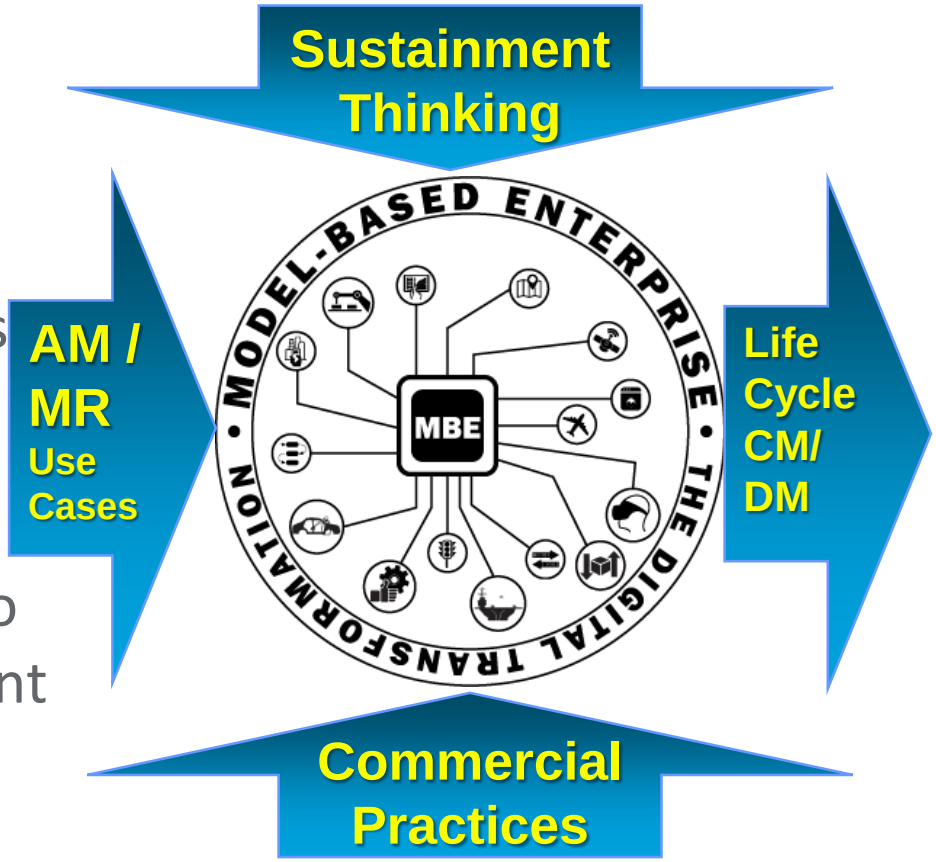
RECOMMENDATIONS

Integrate “sustainment thinking” throughout the Model Based Enterprise

Build models with the life cycle in mind with cybersecurity protections and configuration management / data management (CM/DM)

Leverage use cases in AM and MR to test MBE approaches for sustainment

Extend commercial best practices where possible for A&D domain




LOCKHEED MARTIN

ABSTRACT

This presentation will highlight the importance of a model-based enterprise (MBE) to sustainment and across the life cycle. Model-based X where "X" is sustainment needs to be considered as part of the systems of systems engineering starting early in the life cycle. Computer-aided manufacturing, inspection tools, and approaches should be planned for use in sustainment to include repairs and ease of mods and upgrades to update capabilities. The complexity of managing the digital thread or tapestry is greater when sustainment is considered, with the need to linking and management the "as maintained" bill of materials for each delivered system. Application of data analytics and artificial intelligence (AI)/machine learning (ML) supports prognostics and health management and performance feedback. System of systems modeling methods that include application of the Affordable Systems Operational Effectiveness (ASOE) framework to help organize the sustainment considerations for both the primary and enabling systems to reduce life cycle costs and improve reliability and support return on investment (ROI) case studies. There are several opportunities for leveraging digital thread for sustainment as a concentration area. The first is application of augmented/virtual/mixed reality for maintenance opportunities and supported by global subject matter expert networks. The sustainment community pull for application of advanced manufacturing approaches to include additive manufacturing also relies on distributed access to technical data packages to support manufacturing at the point of need for parts that can be printed. A third focus area is on acquisition reform focus on capability management for legacy systems to meet the challenges of the National Defense Strategy. Systems designed with standards-based architectures and interfaces can support lower cost and more agile modifications and upgrades of both hardware and software in a system.