Smart Manufacturing and Space Systems

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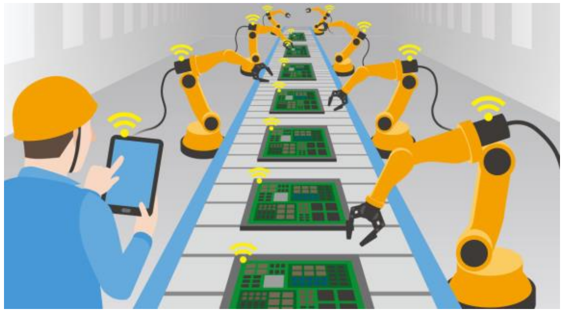
Agenda

- Smart Manufacturing Study
  - *Defining Smart Manufacturing*
  - *Key Observations*
  - *Findings*
- Opportunities/Drivers/Barriers for Space Systems
- Manufacturing Systems & Mission Assurance
- Key Findings
- Conclusions

Smart Manufacturing Study

Smart manufacturing holds the promise of transforming manufacturing industry through the automation, digitization and fusion of manufacturing and design data.



Background

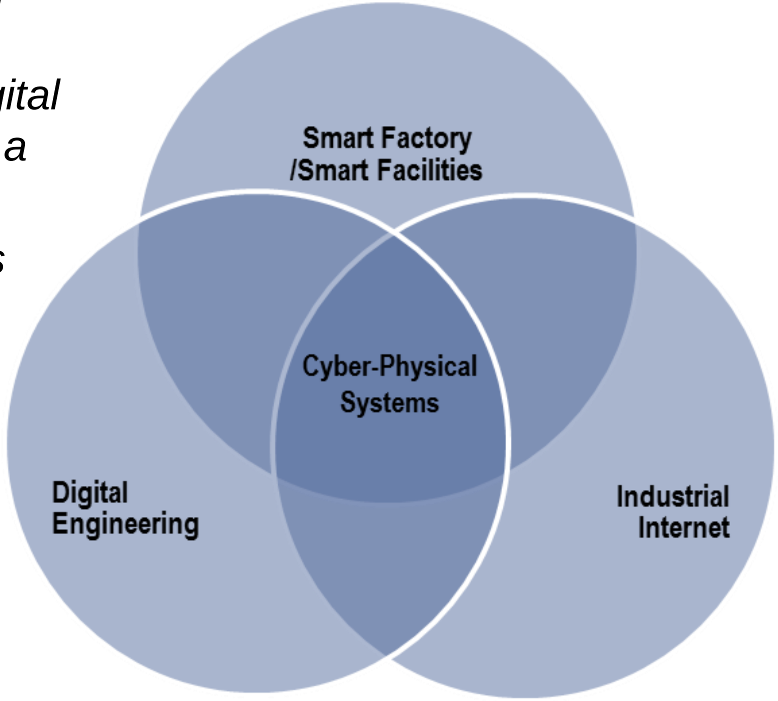
- Objective was to inform where potential capability gaps and research/development is needed for space system applications
- Conducted comprehensive literature search, benchmarked 15 companies, and attended 11 smart manufacturing conferences

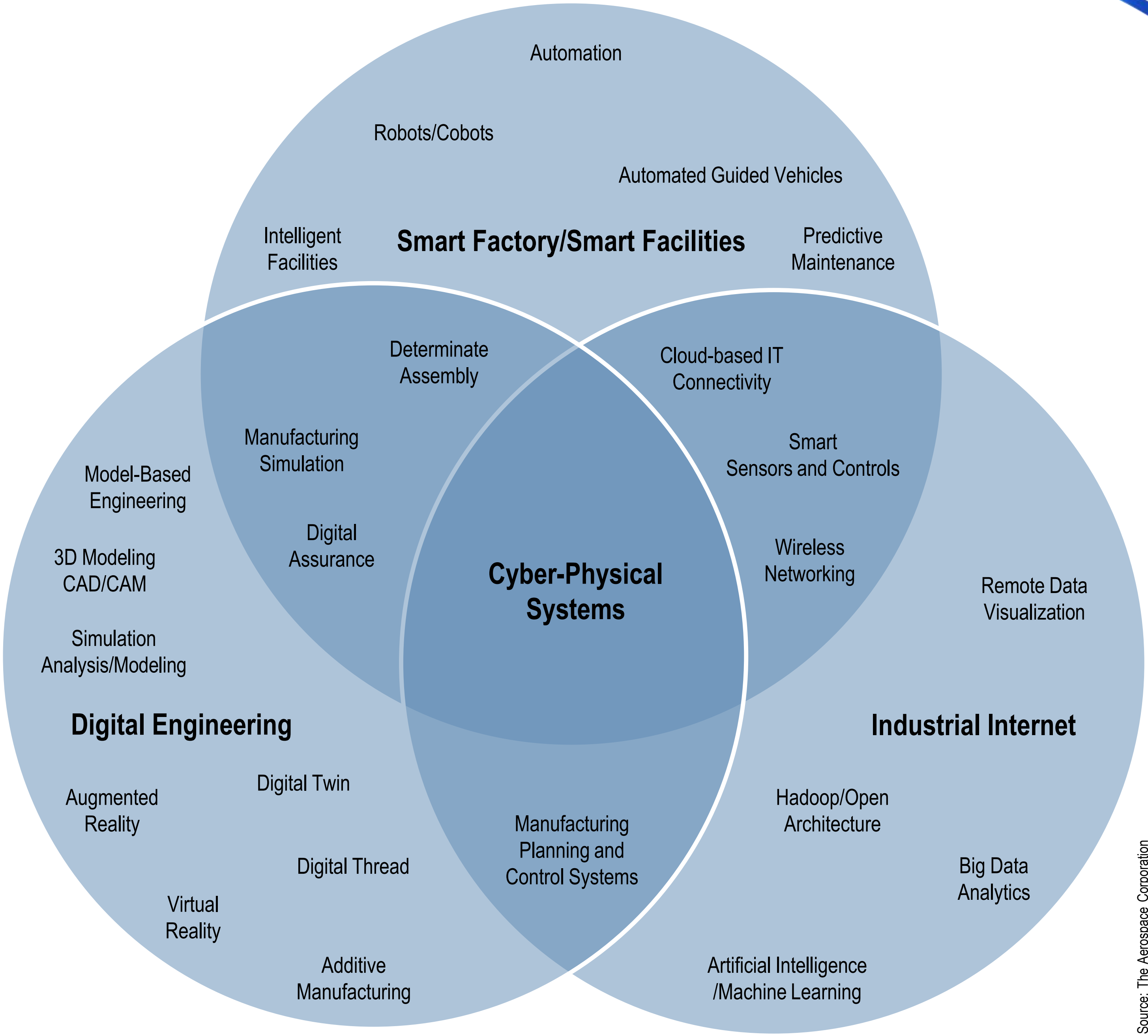
Key Findings

- Benefits best realized in high-volume, continuous production systems with a justified ROI
- Space systems production is mature, complex, and low-volume – tied to acquisition requirements that drive Project manufacturing
  - *"Smarter" manufacturing opportunities include islands of automation, robotics, smart sensors, data digitization, additive manufacturing*
- Challenges include the digital transformation and respective analysis and infrastructure
- Recommendations include consideration of different acquisition strategies with larger buys to align with emerging technologies with planned production and investments

Smart Manufacturing Life Cycle Defined

- Smart Manufacturing takes advantage of advanced information and communication technologies to enable the automation, digitization and fusion of manufacturing and design data throughout the product lifecycle
  - ***Cyber-Physical Systems*** *are at the heart of an optimized smart manufacturing production systems*
  - ***Digital Engineering*** *starts with product design digital data and through model-based engineering drives a digital workflow throughout the product lifecycle*
  - ***Industrial Internet*** *monitors production processes through Internet-connected machines/equipment and big data analytics that enables remote data visualization*
  - ***Smart Factory/Smart Facilities*** *apply automation and self-diagnostic smart sensors /controls to a connected enterprise backbone to facilitate the efficient operation of the production system*

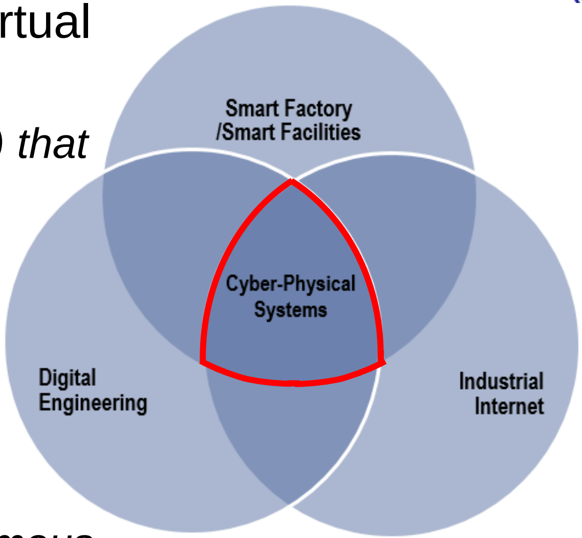


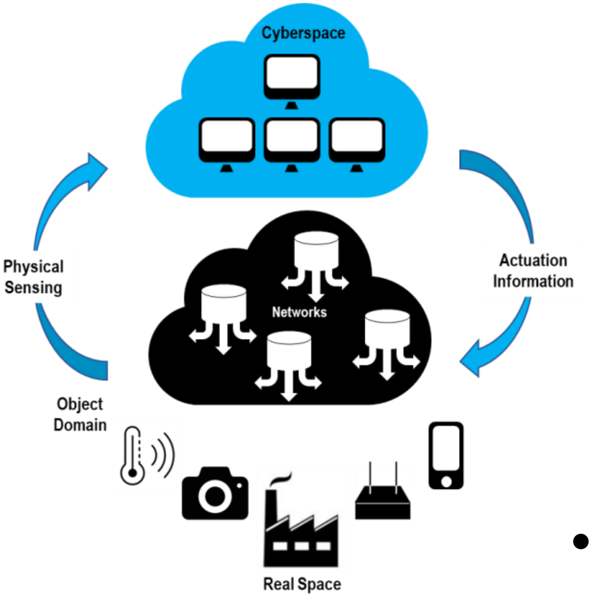


Source: The Aerospace Corporation

Key Observations: Cyber-Physical Systems (CPS)

- Enabling technologies link the physical world with the virtual world of information processing
  - *Constituent systems and devices (e.g. sensors or actuators) that interact with one another through computational algorithms and predictive analytics and rely on the prevalence of high-speed wireless networks connected to the internet*

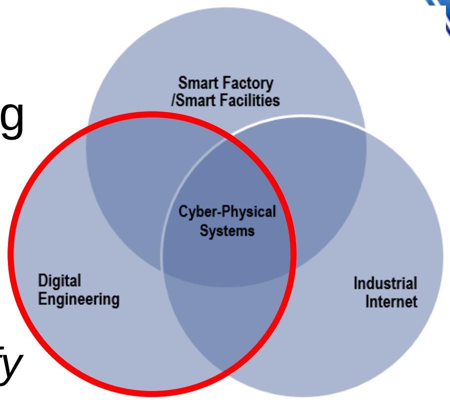




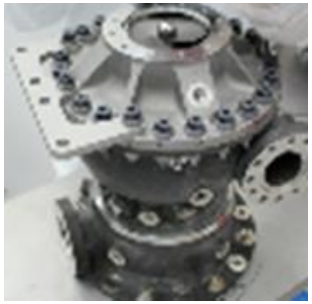
- CPS in production systems quickly advanced smart factory implementation
  - *Smart electrical grids, autonomous automobile systems, automatic pilot avionics, medical monitoring, robotic systems, process control systems, and autonomous "lights-out" factories*
  - *Manufacturing Planning and Control Systems manage enterprise processes to include: purchasing, inventory tracking & control, and production scheduling*
- Challenges include security, interoperability, network integration, reliability, and affordability

https://www.youtube.com/watch?v=Pw1JFAo4qew

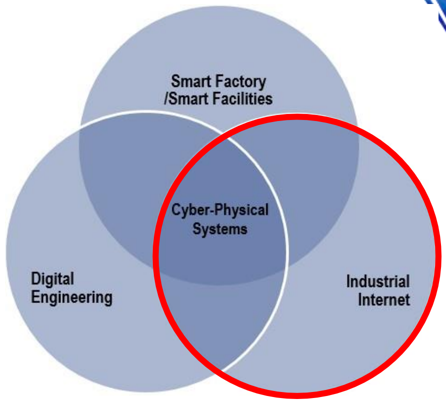
Key Observations: Digital Engineering



- Ecosystem comprised of digital twin/digital thread elements that starts with the 3D model and bill-of-material – representing the digital foundation across engineering disciplines through model-based engineering applications
- Virtual Reality – 3D Environments
  - *Visual immersion to enhance concepts/product designs, and identify manufacturing challenges, critical clearances and part interferences*
- Digital Assurance
  - *Automatic optical inspection equipment compares assembled hardware against a database of correct assemblies to verify proper orientation and critical clearances*
- Additive Manufacturing (Microcosm of SM)
  - *3D printing layer-by-layer of the near-net final part from digital file … "Art to Part"*
  - *Space community laying foundation for primary structures*
- Challenges include the digital transformation in collection and processing of the large amounts of data, tools/models that can accommodate imagined complexity contours, interoperability

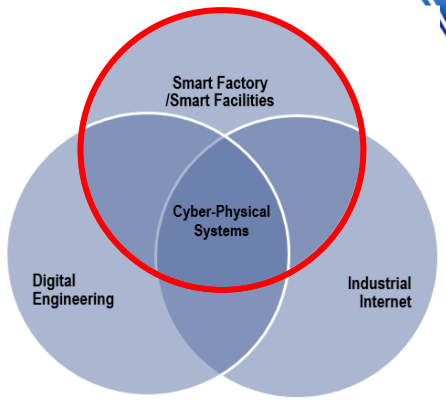


Key Observations: Industrial Internet



- Ecosystem of networked machines and equipment that use embedded sensors, actuators and other devices to collect data aggregated in a Cloud-based platform with other data (Big Data analytics) to drive smarter, faster decisions
- Smart Sensors/Controls
  - *Provide assembly guidance, wirelessly feed data into databases for statistical trending, and identify out-of-control situations*
- Augmented Reality
  - *Lasers project outline/information onto the part to ensure correct ply is used in right orientation for composite manufacturing*
- Open Architecture
  - *Splits files into large blocks and distributes them across nodes in a cluster and processes large datasets – "big data in the cloud"*
  - *Enables upgrading of components easily – continuous custody of unstructured data (video, audio, environmental, etc.)*
- Challenges include need to upgrade infrastructure, interconnectivity to accommodate collection and computing processing demands

Key Observations Smart Factory/Smart Facilities



- Ecosystem that uses automation and intelligent building management systems to respond in real-time conditions to optimize production processes and facility management
- Smart Facility Environmental Controls
  - *Automate facility maintenance tasks (e.g., centralized control center with remote alarm capabilities)*
- Islands of Automation
  - *Enhanced quality/repeatability/productivity through automation of processes that are hazardous, mundane and time consuming (e.g. vision systems in pick-n-place machines)*
- Automated Guided Vehicles (AGVs)/Robotics
  - *AGVs utilized for material handing applications to eliminate hardware damage (e.g. completely eliminating "critical lifts" for missile production)*
  - *Robotics applied where high degree of precision and repeatability*
  - *is needed (e.g. High-quality automated Solar Cell welding)*
- Challenges include the capital equipment expenditures and qualification of production lines with introduced changes in processes

Opportunities/Drivers/Barriers in the Space Industry

Opportunities:
- Virtual Reality
- Digital Assurance
- Additive Manufacturing
- Mfg. Planning and Control Systems (ERP/MES)
- Smart Sensors and Controls
- Augmented Reality
- Hadoop/Open Architecture
- Islands of Automation
- Automated Guided Vehicles (AGV)
- Robots/Cobots
- Smart Facility environmental controls

Barriers:
- High Cost
- No customer buy-in/lack of resource sharing (no incentives)
- Lack of equipment/machine connectivity and protocols standards
- Paper/manual systems
- Out-of-date information technology (IT) infrastructure
- Lack of additive manufacturing qualification standards
- Lack of adoption of latest additive manufacturing file formats
- Facility monuments – "TVAC chambers generally aren't moved"

Drivers:
- Enhanced productivity
- Improved quality/repeatability/accuracy
- Improved throughput/cycle time
- Greater agility and customer responsiveness
- Response to competitors

$$ ROI $$

Implementation

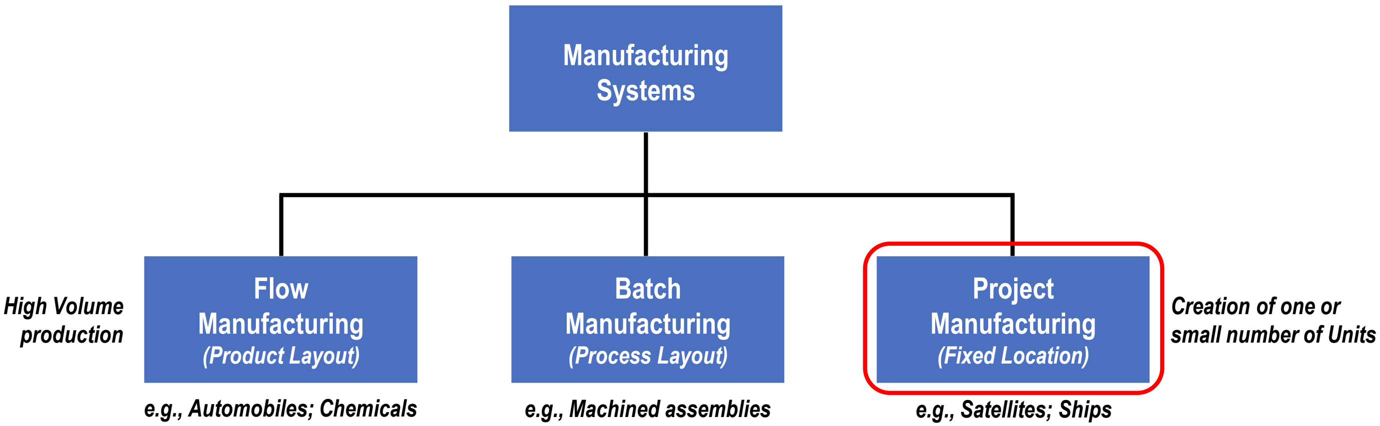
Smart Manufacturing roadmap key to planning future CAPEX

- Opportunity management requires:
  - *Working with stakeholders (i.e., senior leadership, customers) in a proactive approach to maximize the opportunity associated with a project (production) decision*
  - *Defining a business case for the technical solution*

Innovation requires Incentives to implement

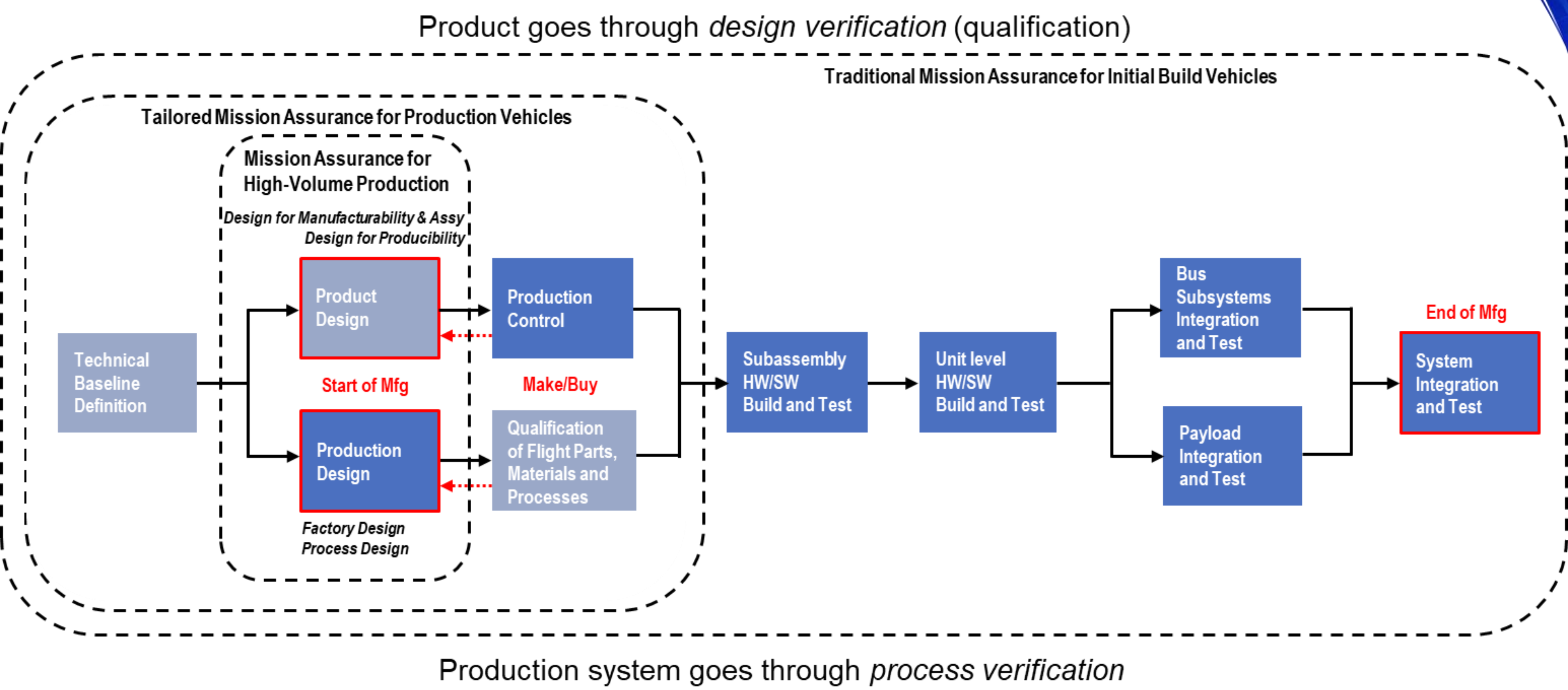
Manufacturing Systems

- Manufacturing is defined as the processing raw materials, components, and parts while building a final or finished product-based on a customer's specification and expectations
- Main features of each manufacturing system has a direct correlation to the type of acquisition strategy executed to produce these products
- Space system government acquisition requirements have significant implications on the size, complexity and risk
  - *Space systems are typically engineer-to-order products with long timelines that drive the manufacturing system to be project manufacturing*



Space Vehicle production has traditionally been Project manufacturing

Manufacturing System defines Mission Assurance



Key Findings

- Smart manufacturing technologies increases productivity
- Cyber-Physical Systems
  - *Biggest barrier to implementation is high cost to implement (i.e., ROI to justify CAPEX)*
  - *Manufacturing Planning and Control Systems drive the enterprise and need to be connected*
- Digital Engineering
  - *Smart manufacturing begins with digital product design*
  - *About half of space prime contractors still using paper-based shop floor control systems*
- Industrial Internet
  - *Drives smarter, faster business decisions with Big Data Analytics*
  - *Currently many systems and departments data is either "not accessible" or is "not shared" between organizations*
- Smart Factory/Smart Factories
  - *Start-point is to identify activities/tasks smart machines can perform better/cheaper/safer than humans; Energy savings that affect bottom-line can lead to significant cost savings through building automation*
  - *Islands of Automation are being implemented as companies modernize their facilities*

Conclusions

- Space system manufacturing could benefit with greater adoption of emerging technologies/processes with more effective and efficient results
  - *“Smarter" manufacturing technologies are being adopted as equipment is being replaced/updated (islands of automation), singular innovative applications, or as new product lines being introduced with proven positive results*
  - *Low volume associated with present acquisition programs makes the investment for wholesale implementation of smart manufacturing production lines unattractive*
- Lack of specifications/standards/requirements for emerging technologies (i.e., AM, MBSE) is a barrier for earlier adoption
  - *Costing/Planning/Scheduling built largely of data from the “last system”; Preponderance of pre-acquisition work ignorant of potential “smart” benefits*
  - *Concepts that include “benefits” from smart manufacturing may not be given credibility*
- Mission assurance models to validate process qualification are not mature
  - *Mission assurance to the front-end as the product goes through design verification (qualification) and the production system/Factory goes through process verification*
- Challenge areas with the greatest potential for adoption include digital engineering
  - *Lack of tools and analytics is inhibiting digital transformation in collection and processing of the large amounts of data, tools/models that can accommodate imagined complexity contours, and interoperability issues*

Thank You!
Questions?

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References

1. Chapman, Stephen N., J.R. Tony Arnold, Ann K. Gatewood, Lloyd M. Clive, Introduction to Materials Management 8th Edition, Pearson Education Inc., 2017.
2. Swartwout, Michael, CubeSat Database, Saint Louis University, 2017.
3. Caleb, Henry, OneWeb breaks ground on a Florida factory that will build thousands of Satellites, Space News, 16 March 2017.
4. Davis, Lorrie A. and Lucien Filip, How Long Does It Take to Develop and Launch Government Satellite Systems, Aerospace Report No. ATR-2015- 00535, The Aerospace Corporation, El Segundo, CA, 12 March 2015.
5. Johnson-Roth, G. and W. F. Tosney, Mission Risk Planning and Acquisition Tailoring Guidelines for National Security Space Vehicles, Aerospace Report No. TOR-2011(8591)-5, The Aerospace Corporation, El Segundo, CA, 13 September 2010.
6. California Manufacturing Technology Consulting (CMTC) and Smart Manufacturing Leadership Coalition (SMLC), Smart Manufacturing: The Next Revolution in Manufacturing, CMTC, 2015.
7. President's Council of Advisors on Science and Technology (PCAST), Report to the President – Accelerating U.S. Advanced Manufacturing, U.S. Executive Office of the President, October 2014.
8. Wang, L., Törngren, M., Onori, M., Status and Advancement of Cyber-Physical Systems in Manufacturing, Journal of Manufacturing Systems 37 (Elsevier), Society of Manufacturing Engineers, 4 April 2015.
9. Digitizing Manufacturing: Ready, Set, Go, Capgemini Consulting, 2014.
10. Marr, Bernard, What is Digital Twin Technology – And Why Is It So Important, Forbes, 6 March 2017.
11. GE Power Digital Solutions, GE Digital Twin: Analytic Engine for the Digital Power Plant, General Electric Company, 2016.
12. Leiva, Conrad, Demystifying the Digital Thread and Digital Twin Concepts, Industry Week, 1 August 2016.
13. Yares, Evan, Why you need to Understand Model-Based Engineering, 3D CAD World, 24 August 2012.
14. Getting It Right: The Quarterly Newsletter of Mission Assurance, vol. 7, Issue 3, The Aerospace Corporation, El Segundo, CA, 27 February 2017.
15. Let Simulation Guide You: Making the Case for Digital Exploration, Digital Engineering, ANSYS Inc., 1 October 2017.
16. How Digital Assurance is Different from Traditional QA, Cigniti Technologies, 2017.
17. Norris, Guy, 777X: A New Way to Build an Airplane – Material Progress, Aviation Week & Space Technology, 7-20 November 2016.
18. GE Digital, Digitizing Complex Discrete Manufacturing Processes, General Electric Company, 2016.

References (Con't.)

19. Evans, Peter C. and Marco Annunziata, Industrial Internet: Pushing the Boundaries of Minds and Machines, General Electric, 26 November 2012.
20. Science Direct, Recent Advances and Trends in Predictive Manufacturing Systems in a Big Data Environment, Elsevier B.V., 2017.
21. "Machine Learning: What it is and Why it Matters," SAS Institute Inc., 4 January 2018. https://www.sas.com/en_us/insights/analytics/machine-learning.html. Accessed 5 January 2018.
22. Data Visualization Techniques: From Basics to Big Data with SAS Visual Analytics – White Paper, SAS Institute Inc., 17 September 2017.
23. Van Schalkwyk, Pieter, Where is the Edge of the Edge of Industrial IOT, Industrial Internet Consortium, September 2017.
24. Weiss, Joy, and Yu, Ross, Wireless Sensor Networking for the Industrial Internet of Things – White Paper, Linear Technology Corporation, 2015.
25. Ezell, Stephen and Swanson, Brett, How Cloud Computing Enables Modern Manufacturing, American Enterprise Institute, Information Technology and Innovation Foundation, June 2017.
26. The Smart Factory: Responsive, Adaptive, Connected Manufacturing, Deloitte University Press, Deloitte Development LLC, 2017.
27. Cubberly, William H. and Bakerjian, Ramon Ed., Tool and Manufacturing Engineers Handbook – Desk Edition, Society of Manufacturing Engineers, 1989.
28. IT/OT Convergence: Moving Digital Manufacturing Forward, Cisco Systems Inc., 2017.
29. Peitzker, Stephanie, How Industry 4.0 and lean production are becoming best friends, Bosch Connected World Blog, 21 April 2017.
30. Tulkoff, Joseph, "MANTECH Program Aims to Make Factory of Future a Reality in Defense," Industrial Engineering, Vol. 16, No. 2, February 1984.
31. Johnson-Roth, Gail A; Wheaton, Marilee; McKelvin, Mark; and Hoheb, Albert, Systems Engineering Forum -Model Based Systems Engineering, ATR-2017-00357, The Aerospace Corporation, 2017.
32. O'Brien, Michael; Kabe, Alvar, "Parts Evaluation for Additive Manufacturing," TOR-2017-02432, The Aerospace Corporation, 2017.

Back-up

CESMII and Smart Manufacturing

Aerospace Active Member

- The primary purpose of the Clean Energy Smart Manufacturing Innovation Institute (CESMII) is to establish a smart manufacturing (SM) capability focused on the development of effective energy management-technology tools
  - *SM is the business, technology, infrastructure, and workforce practice of optimizing manufacturing through the use of engineered systems that integrate operational technologies and information technologies – or "cyber-physical systems"*
  - *SM Platform is a shared, open architecture and software infrastructure that integrates components required to assemble customized SM Systems on a standards-based deployment infrastructure*
- In partnership with the U.S. Department of Energy, CESMII brings over $140 million in public-private investment
  - *Awarded in 2016, CESMII is the 9th Institute of the Manufacturing USA Program, established by the White House to spur U.S. innovation, sustainability and competitiveness*
- CESMII relies on radical acceleration of development and commercialization of advanced sensors, controls, modeling, simulation, and platform development technologies through integrated, industry-led SM technical and business methodologies

Access to CESMII Partners and Resources

- $10K Annual Membership Fee for Resource Membership in CESMII
- Requires additional $5K in cost-share and/or contributions-in-kind (to be provided jointly between ETG and CSG through engagement and business development)
- Non-Disclosure Agreement
- Access to an open and secure SM platform, testbeds, R&D, implementation services, workforce training, and partnerships. Specifically:
  - *Access to knowledge base system and attendance at national and regional events and forums*
  - *Nomination of candidates for Institute Standing Committees*
  - *Participation in Regional Working Groups*
  - *Ability to host Regional Application and/or Roadmap Projects*
  - *Participate and leverage cost-shared projects nationwide*
  - *Access to Institute-generated Intellectual Property after 12 months*
  - *Opportunity to provide products/services to gain exposure and for new channels of engagement (via participation in funded portfolio projects and licensing)*
  - *Access to SM Platform technology and marketplace for evaluation and demonstration of capabilities*

CESMII Project Portfolio

- The CESMII Portfolio will address R&D challenges and knowledge gaps related to the integration of manufacturing operational technologies and information technologies, or cyber-physical systems, including:
  - *Hardware, software, and security requirements*
  - *Sensor technologies, multi-sensor data fusion, and sensor-actuator-human interfaces*
  - *Process models (e.g., physics-based, empirical, data-driven, cognitive, and quantitative) verification, validation, and uncertainty quantification*
  - *Data structures, contextualization, configuration, and management*
  - *Reference architectures and platforms for process technology digitization*
- The CESMII Portfolio will include an evolving selection of collaborative:
  - *Roadmap Projects that develop new capabilities*
  - *Application Projects that use and apply capabilities*
  - *Cross-industry or cross-application Benchmark studies and assessments*