Hidden Costs of Producibility and the Potential ROI of Developing Advanced Manufacturing M&S Capabilities

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NDIA White Paper on Manufacturing M&S

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- Key findings from 18 month study on current DFM practices*
  - Producibility is a neglected "ility" due to the lack of analytical tools
  - Many costly producibility issues inadvertently designed-in
  - Current commercially available DFM analysis tools inadequate
  - Focused M&S research and investments needed to close gaps
- Roadmap development underway for key M&S focus areas
  - Systems engineering trade study and design methodologies
  - System integration, assembly, and test modeling
  - Enterprise level supply chain design and analysis methods
  - Electrical, mechanical, and assembly yield modeling
  - Quantitative DFX analyses including complexity characterization
  - Life cycle cost modeling including uncertainty and risk analysis

*NDIA Manufacturing Division White Paper, "21st Century Manufacturing Modeling & Simulation Research and Investment Needs," Released May 2011.

NDIA Committee Goal is to Influence S&T Investments

Why Focus on Productibility?

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- Cost of Goods Manufactured
  - Direct material and labor costs
  - Manufacturing overhead costs
- "Producer" life cycle cost drivers
  - Low yield & process inefficiencies
  - Manufacturing process complexity
  - Excessive quality specs/controls
- Product cost reduction strategies
  - Post-NPI value engineering
  - Factory lean transformation
  - New material/process technologies
  - Strategic sourcing & material mgmt
  - Commodity "should cost" analysis

Because Producibility Drives Significant "Hidden Costs"

But is there a Business Case?

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- Most legacy fielded systems have known producibility issues
  - VE changes to improve design almost always cost prohibitive
  - Significant sustaining engineering costs incurred year-after-year
- Aerospace-wide producibility improvement initiative launched
  - Cost-benefit criteria developed based on factory financial impact
  - Focus is reducing “producer” LCC drivers impacting the factory

2009 -2011 Financial Savings Dashboard

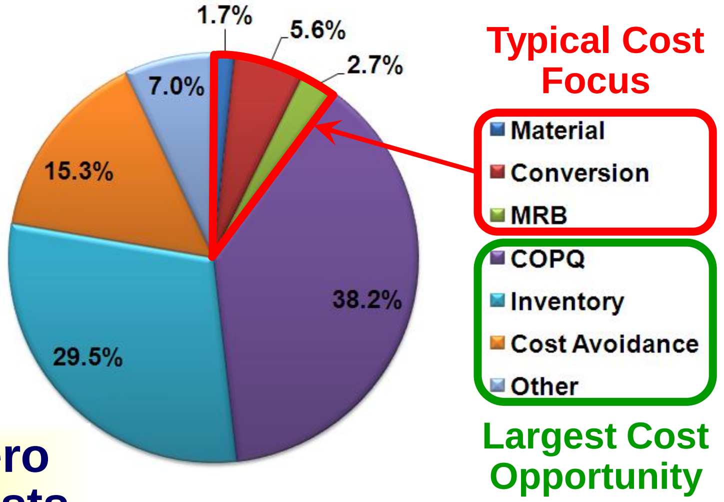
Projects Address ~5% of Active P/N’s

2009-2011 Producibility Improvement Savings One Year Forward Looking Financials				
	NUMBER OF PROJECTS	AVE YIELD IMPROVEMENT	NORMALIZED TOTAL SAVINGS	AVERAGE ROI
2009	50	21.0%	1.29%	9.9
2010	74	21.0%	0.69%	8.6
2011	82	26.0%	0.92%	5.8
Cummulative	206	23.0%	0.96%	7.8

Estimate 4-5X Greater Opportunity for Save due to 80-20 Rule

1% of Total Aero Conversion Costs

Savings Breakdown



Producibility Directly Impacts Cost of Goods Manufactured

Why is Manufacturing M&S the Solution?

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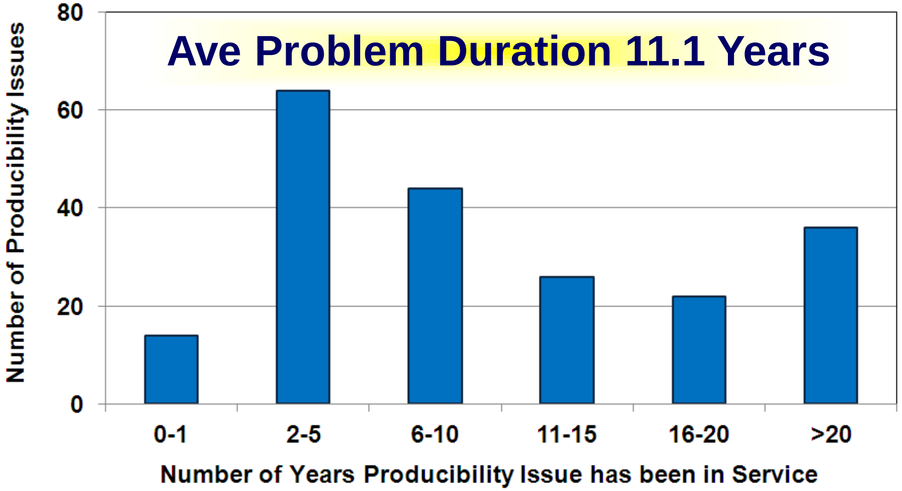
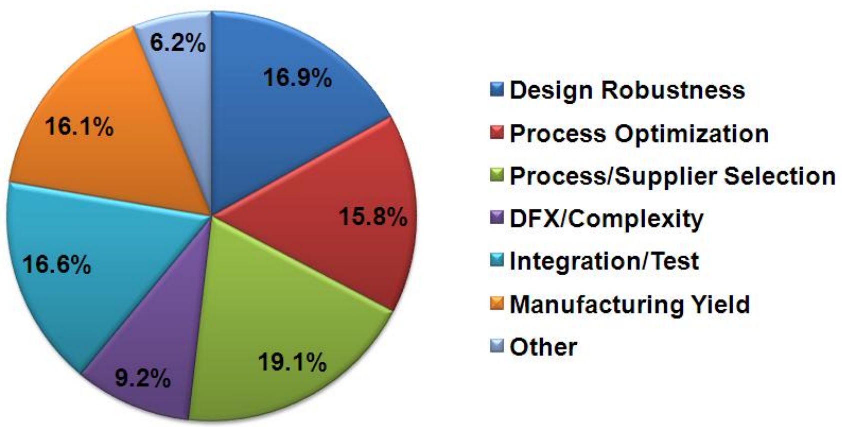
- Once design is "locked-down" producibility is "locked-in"
  - Lack of relevant M&S tools prevents factory impact prediction
  - Inadvertently "designed-in" inefficiencies can persist for years
- Producibility issues primarily impact factory overhead costs
  - Root cause affinity mapping used to understand origins of issues
  - Analysis substantiates proposed M&S research focus areas

Problem Duration Histogram



Producibility Driver Breakdown



Significant ROI Associated with Development of M&S Tools

Mechanical vs. Electronic System M&S Needs

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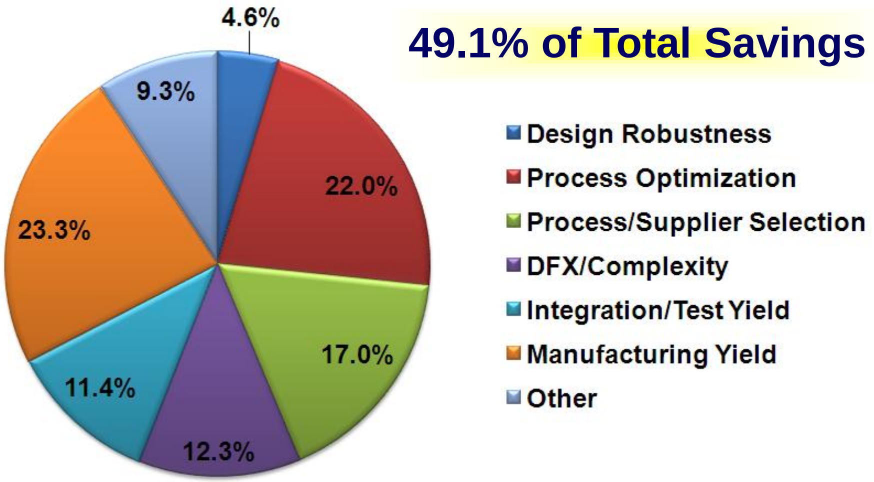
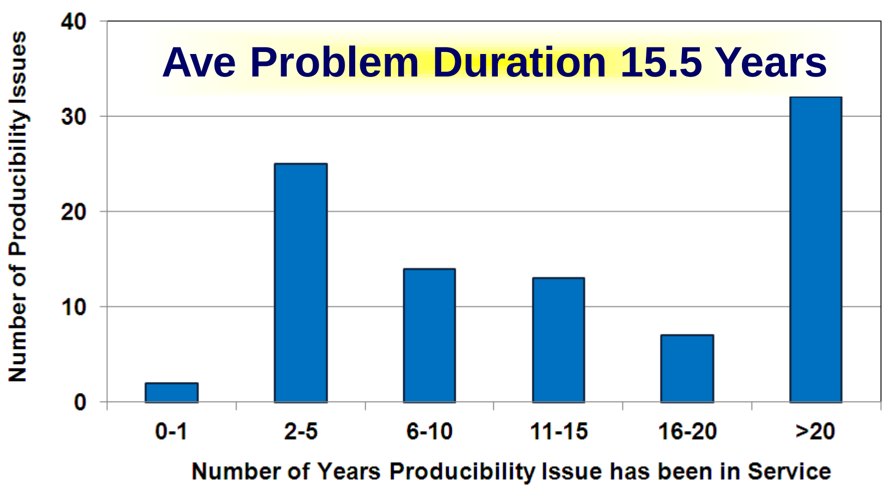
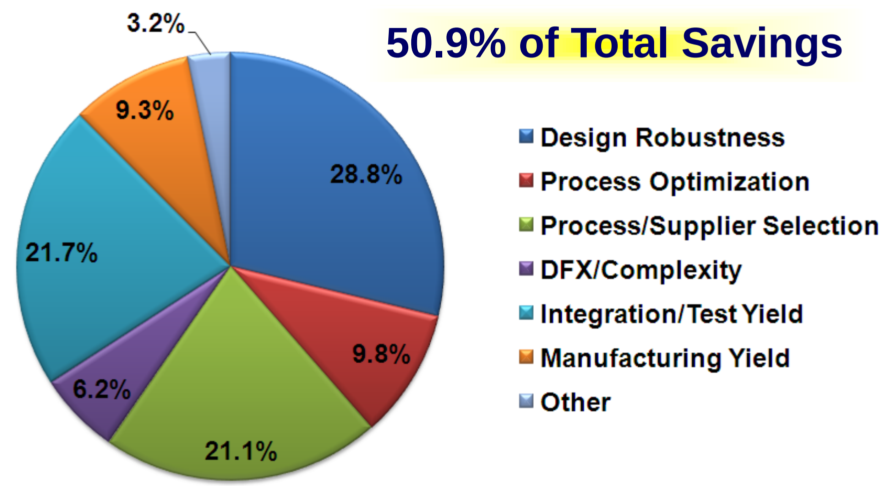
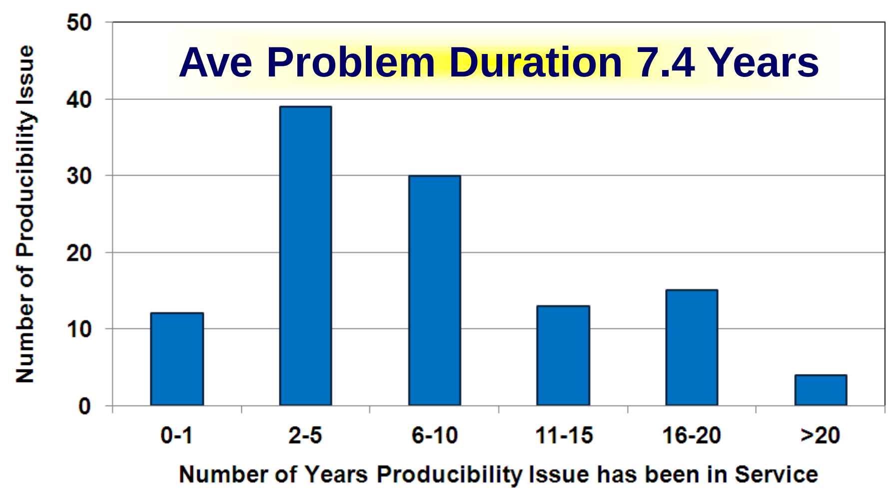
Mechanical Productibility Breakdown





Electronic Productibility Breakdown

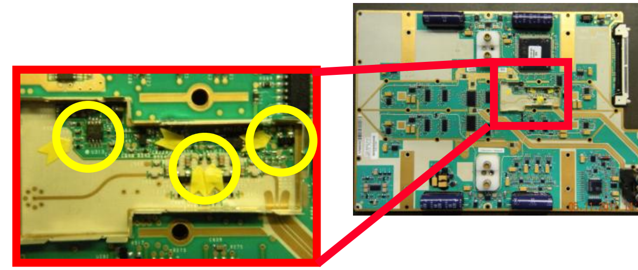


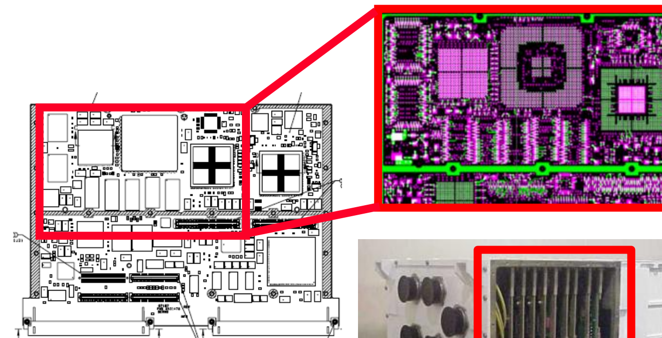


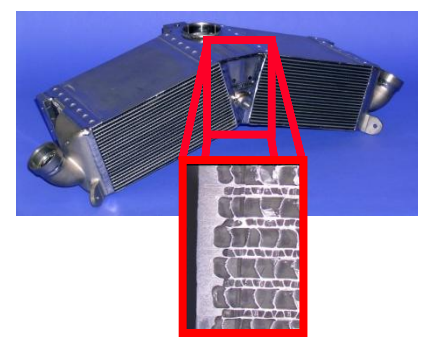
Common Themes but Different Priority Focus Areas for Mechanical vs. Electronic System M&S Tool Development

“Real World” Producibility Examples

- **Avionics RF transponder**
  - **Circuit architecture drove trial & error frequency tuning of individual cards**
- **Display graphics PBA card**
  - **Functionality upgrade for a dense design drove yield into single digits**
- **Engine controller chassis**
  - **Size constraint drove compact design requiring blind PBA installation**
- **Advanced alloy impeller**
  - **Material developed that current cutters cannot efficiently machine**
- **Advanced heat exchanger**
  - **Weight drove non-optimal joint design susceptible to braze erosion**







Many Producibility Issues Inadvertently “Designed-In”

Current Model-Based Approach Limitations

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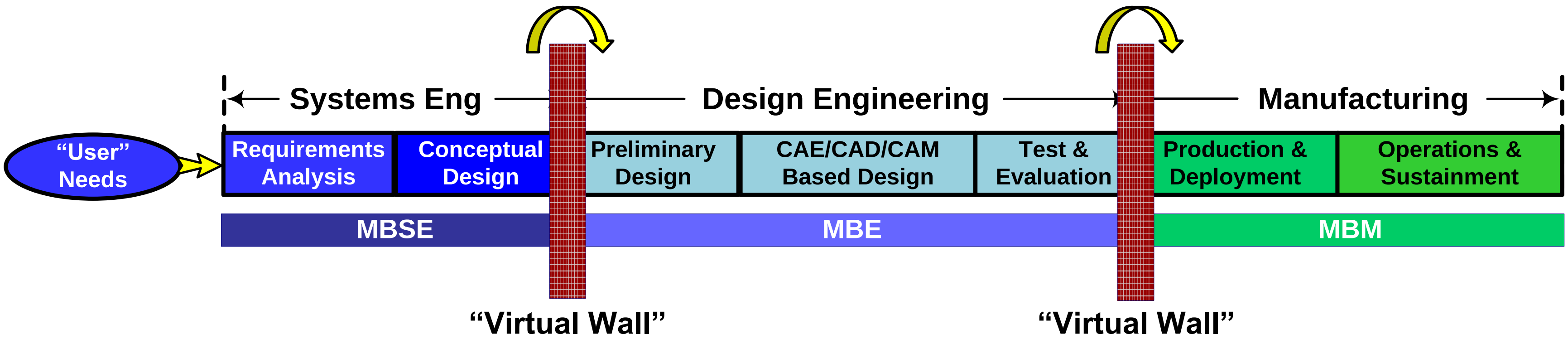
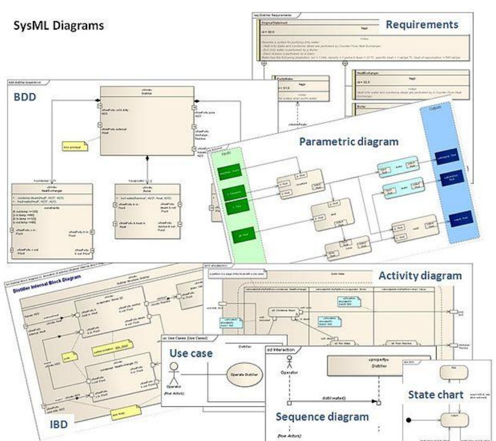
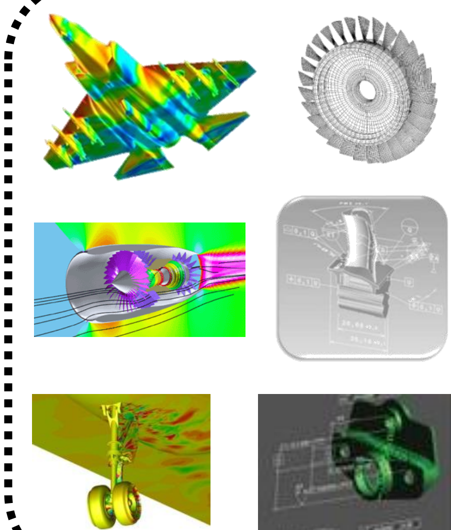


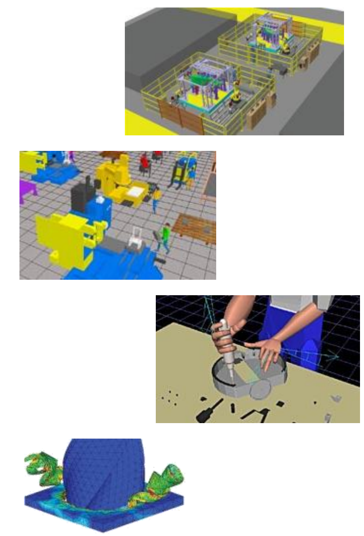
"Function Centric"



"Geometry Centric"



"Operation Centric"



Same Producibility Problems now just Happen "Virtually"

Design-Manufacturing Interdependence

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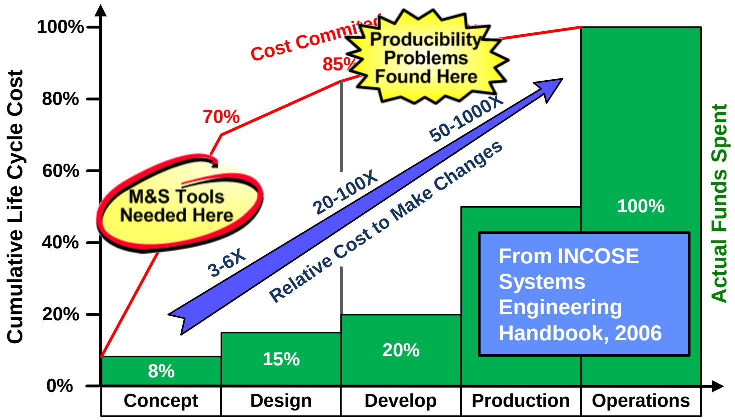
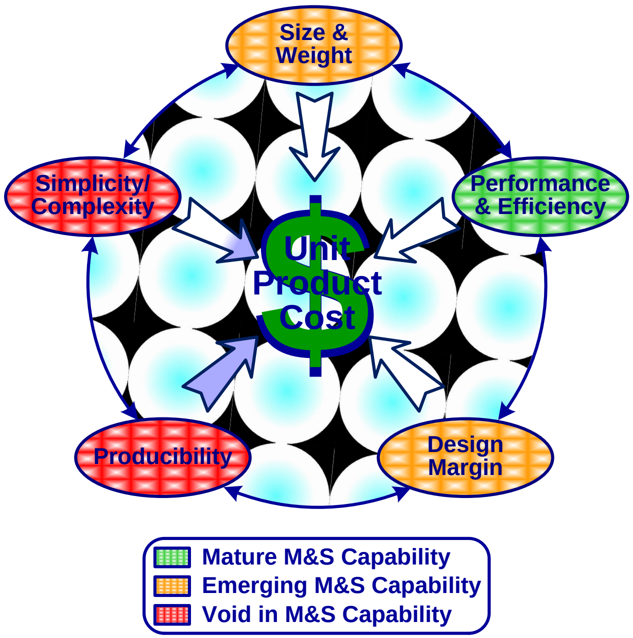
- **Early design decisions lock-in cost**
  - Trade studies focus on performance
  - Use of exotic materials to save weight
  - Design thrown across the "globe"
- **Moving manufacturing to the "left"**
  - Concurrent engineering teams
  - Early supplier involvement
  - Design for Manufacturing (DFM)
- **Quantitative analysis tools lacking**
  - Manufacturing knowledge mostly tacit
  - High level DFM guidelines/checklists
  - Rule-based CAD/CAM occurs too late





M&S a Critical Enabler to Move Manufacturing to the Left

Sate-of-the-Art DFMA Analysis

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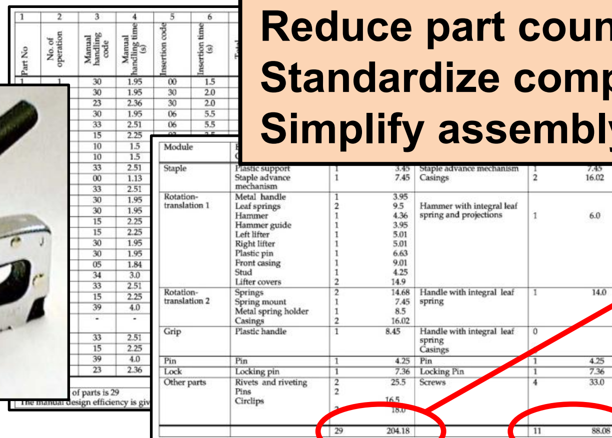
Stapler

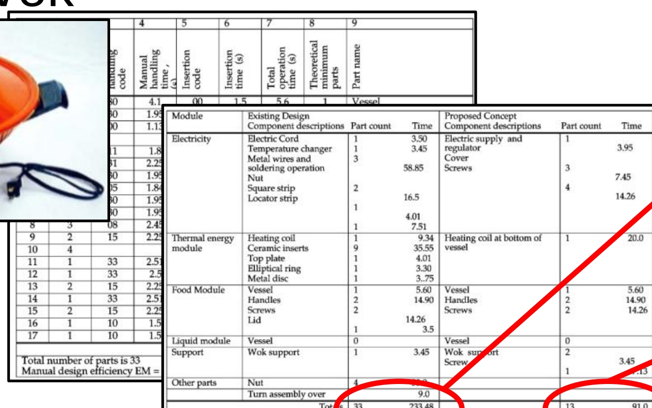


Reduce part counts…
Standardize components…
Simplify assembly operations…

“As Is” Design
- 29 Total Parts
- Assy Time 204 sec

“To Be” Design
- 11 Total Parts
- Assy Time 88 sec

Electric Wok



“As Is” Design
- 33 Total Parts
- Assy Time 233 sec

“To Be” Design
- 13 Total Parts
- Assy Time 91 sec

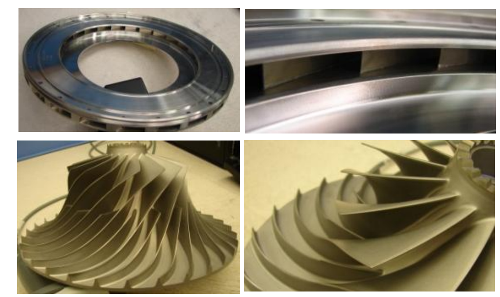
Source: R.B. Stone et. al, “A Product Architecture-Based Conceptual DFA Technique,” Design Studies, Vol. 25, No. 3, pp. 301-325, May 2004.

Simple DFMA Approaches work for Simple Products

Aerospace & Defense DFM Analysis Needs

- **A&D producibility challenges**
  - Maximum functionality in smallest package
  - Highly 3-D shapes with intricate features
  - Exotic hard to machine/fabricate materials
  - Tightly controlled dimensions & tolerances

- **Producibility a *design characteristic***
  - Ease and economy of making item(s) at rate
  - Manufacturing-Assembly-Inspection-Test
  - F(fit, form, function, complexity, capability,..)



- **Need quantitative analytical design tools**
  - Make "hidden factory" costs & risks visible
  - Predict design-driven manuf inefficiencies
  - Shape design vs. verify rule adherence

Complex Product Designs Require Advanced DFM Tools

Honeywell Producibility Analysis Toolkit

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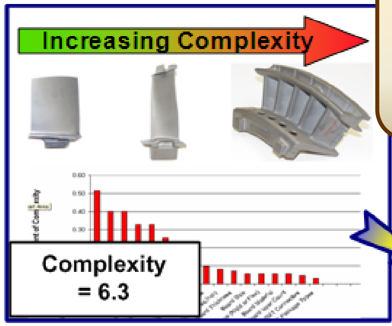
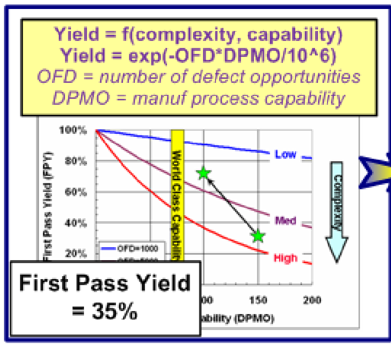
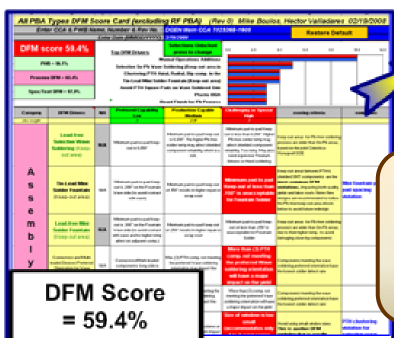
Producibility Analysis







What design attributes are driving the design to be complex?

Is there significant hidden factory rework due to low first pass yield?

Do suppliers have experience making designs of similar complexity?

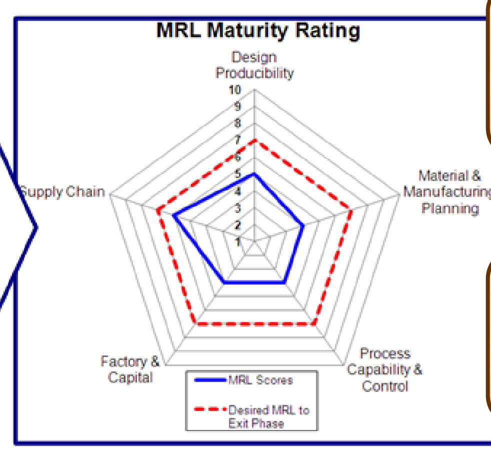
Manufacturing Complexity Model

Yield Prediction Model

DFM Scorecard Analysis

MRL Maturity Assessment Model

Manufacturing Readiness Level



What are the top manufacturing risk areas requiring mitigation plans?

Are producibility trades being conducted in early NPI activities?

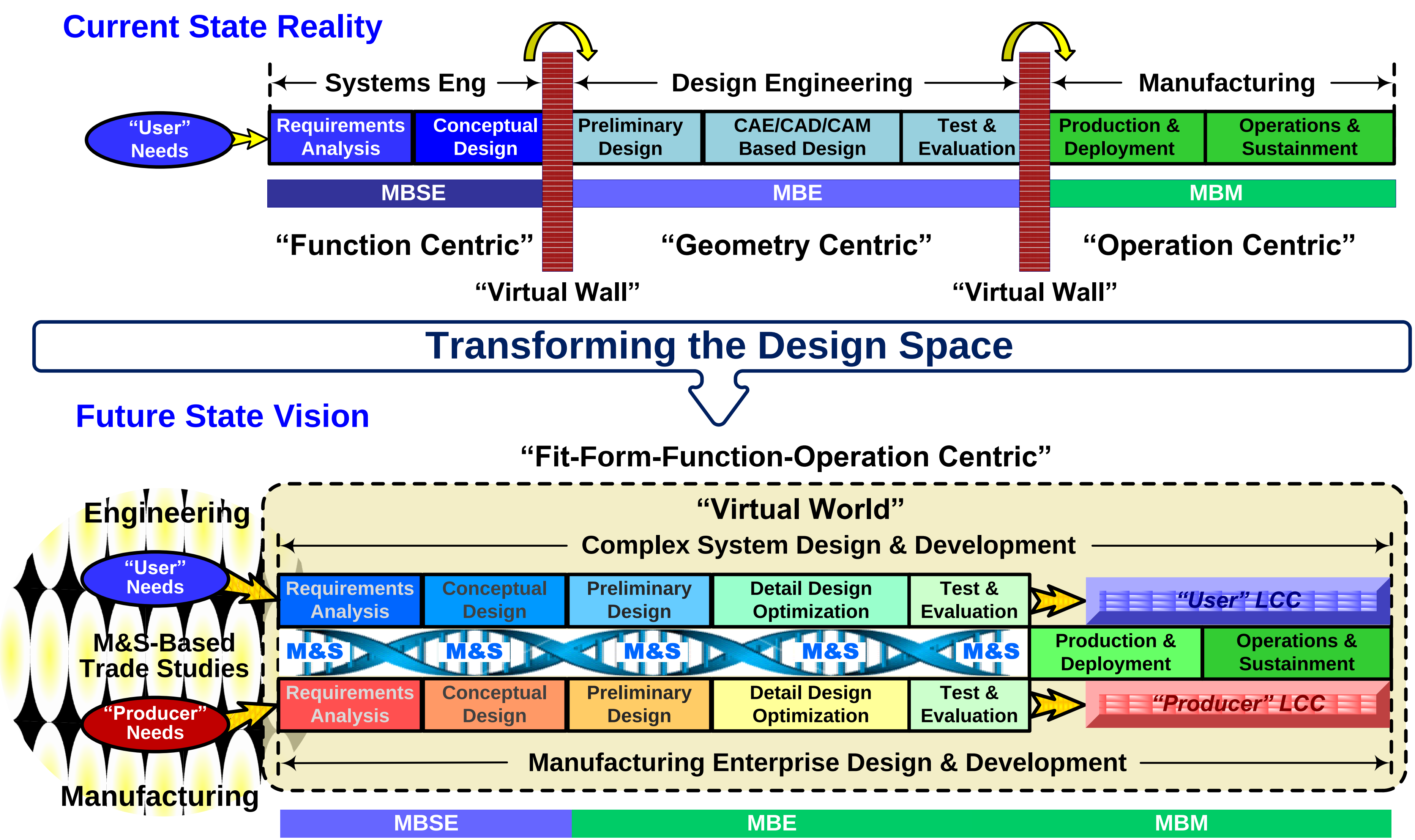
Does the "similar to" baseline have DFM violations and how severe?

What alternative design options increase yield and minimize re-work?

What is the design strategy to minimize DFM violation impact?

Analysis Based Approach to Identify Manufacturing Risks

“Virtual Manufacturing” Frontier



Need to “Re-Engineer” Product Development Processes

Summary and Key Takeaways

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- Producibility issues drive up the Cost of Goods Manufactured
  - Neglected "ility" due to lack of analytical predictive tools
  - Inadvertently "designed-in" inefficiencies can persist for years
  - M&S tools needed to help guide product-process improvements
- Advanced manufacturing M&S is a potential "game changer"
  - Quantitative tools to predict system producibility characteristics
  - Supply chain analysis tools to predict industrial base behavior
  - Design methods integrate manufacturing into SE trade space
- National research agenda needed for "virtual manufacturing"
  - Improving A&D system affordability is an industry-wide problem
  - No single company has resources to solve this problem alone
  - Focused research & investments needed to develop capabilities

M&S is a Transformative Technology of the Future for the Advanced Manufacturing Discipline

Questions?

Contact Information

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Reliability Engineering Discipline

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Reliability Theory

Reliability: Probability that a device will perform its intended function during a specified period of time under stated conditions.

Analytical Basis

$$MTBF = \frac{1}{\lambda} = \frac{total\ operating\ hours}{number\ of\ failures}$$

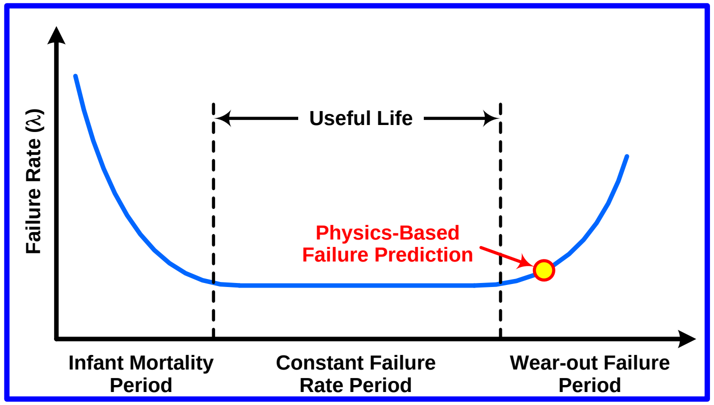
$$R(t) = \int_t^{\infty} f(t)dt = e^{-\lambda t}$$

$$f(t) = \frac{1}{\theta} e^{-t/\theta} \qquad \lambda = \frac{1}{\theta}$$

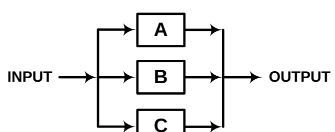
RAMS

Reliability
Availability
Maintainability
Safety

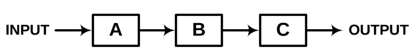
Physics of Failure Analysis



Modeling Relationships

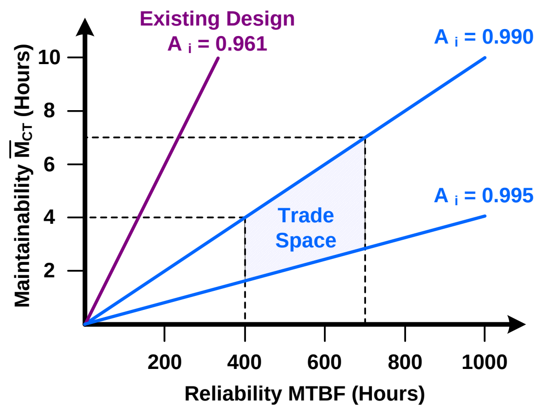


$$R = 1 - (1 - R_A)(1 - R_B)(1 - R_C)$$



$$R = (R_A)(R_B)(R_C)$$

Trade Off Evaluations



Configuration	A_i	MTBF	$\overline{M}_{CT}$
Existing Design	0.961	125	5.0
Alternative 1	0.991	450	4.0
Alternative 2	0.990	375	3.5
Alternative 3	0.991	320	2.8

Focus is Early Detection of Failure Modes and System Safety

What About Producibility?

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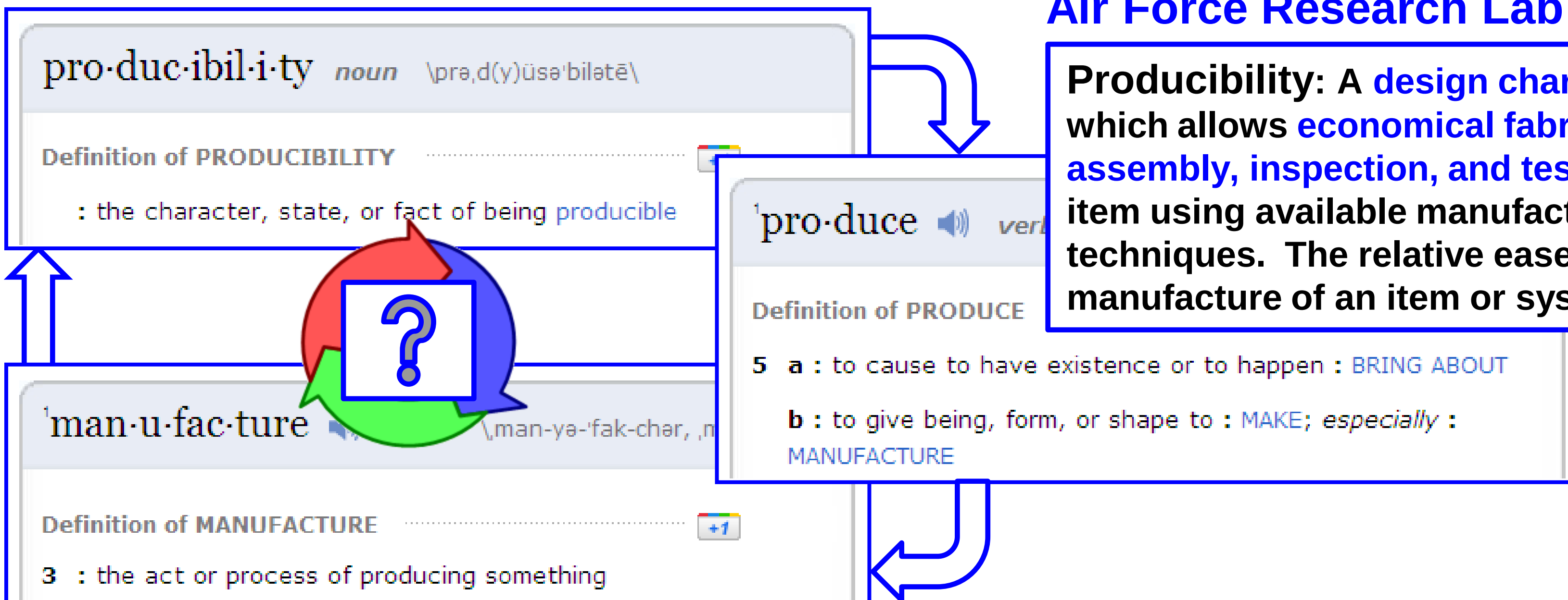
Merriam-Webster.com



Air Force Research Lab

Producibility: A design characteristic which allows economical fabrication, assembly, inspection, and testing of an item using available manufacturing techniques. The relative ease of manufacture of an item or system.

BusinessDictionary.com

Producibility: Ease of manufacturing an item (or a group of items) in large enough quantities. It depends on the characteristics and design features of the item that enable its economical fabrication, assembly, and inspection or testing by using existing or available technology.

Defense Acquisition University

Producibility: The measure of relative ease of manufacturing a product. The product should be easily and economically fabricated, assembled, inspected, and tested with high quality on the first attempt that meets performance thresholds.

Analytical First Principles Basis Needed for Producibility

Yield Improvement Impact Prediction

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$$ADD_{rework} = (Yield_{actual} - Yield_{target}) \times Demand / Manuf_{days}$$

$$COPQ_{savings} = ADD_{rework} \times Rework_{time} \times Manuf_{days} \times Burden_{rate}$$

$$WIP_{savings} = ADD_{rework} \times \Delta\ Cycle\ Time \times Std\ Cost$$

- ADD_{rework}: average daily demand for the rework operations driven by low yield
- $COPQ_{savings}$: projected annual cost of poor quality savings due to yield improvement
- $WIP_{savings}$: projected inventory savings due to yield improvement
- $Yield_{actual}$: actual yield of the process step where the defect(s) are generated
- $Yield_{target}$: target yield of the process step where the defect(s) are generated
- $Rework_{time}$: conversion processing time associated with the rework loops
- Δ Cycle Time : additional manufacturing cycle time associated with rework loops
- Demand: projected forward 12 month demand for savings calculations
- Std Cost: standard cost of the part/item being reworked
- $Manuf_{days}$: number of actual manufacturing days in a calendar year
- $Burden_{rate}$: labor burden rate associated with the rework operations

Y=f(x) Formula Links Product Yield to Factory Financials