Production System Cost Modeling within a Model-Based Systems Engineering (MBSE) Environment

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Agenda

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- Project Overview
  - Production Cycle
  - MBSE Overview
  - Optimizing Production System *AND* Product at same time
- Cost Analysis of Production Systems
  - Methods
  - Application: Wing Study
- Next Steps

Standard Production Cycle

Typical approach with Cost Analysis

Project Inputs

High level cost & requirements

Detailed Engineering

Product/Project Technical Requirements

Cost Analysis

Detailed Engineering to Production System Planning and Design

Manufacturing Development & Test

Initial production articles (SDD, LRIPS, Testing)

Cost Analysis

Produce product

LRIP to full rate production

Production of Product

Ramp to full rate production

Cost Analysis

Operations and Support

Sustain, Maintain, & Support Fielded Product

Product Support

Service throughout its life cycle

01

STEP ONE

From Initial project documents and NTP, produce detailed design data (Specs, Dwgs, BOMS, etc)

Include INITIAL COST BOUNDARIES (sale $ limits).

02

STEP TWO

Determine manufacturing approach: capital, tooling, facilities, flow, labor, qual, etc.

REFINED COST AND BUDGETS (Re-Engineer for Cost?)

03

STEP THREE

Validate production planning at rate

Redesign for cost (Lean Activities).

04

STEP FOUR

Improve performance, support fielded units, decommission, etc.

MBSE Production Cycle with Cost Analytics

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Proposed MBSE Approach with Cost Analysis

Project Inputs High level cost & requirements	**Detailed Engineering** Product/Project Technical Requirements	Concurrency Early Cost Analysis
Detailed Engineering to Production System Planning and Design	**Manufacturing Development & Test** Initial production articles (SDD, LRIPS, Testing)	Throughout Life Cycle
Produce product LRIP to full rate production	**Production of Product** Ramp to full rate production	Establishes objectives
Operations and Support Sustain, Maintain, & Support Fielded Product	**Product Support** Service throughout its life cycle	Facilitates Management at all levels

01 STEP ONE

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Model Based Product Engineering

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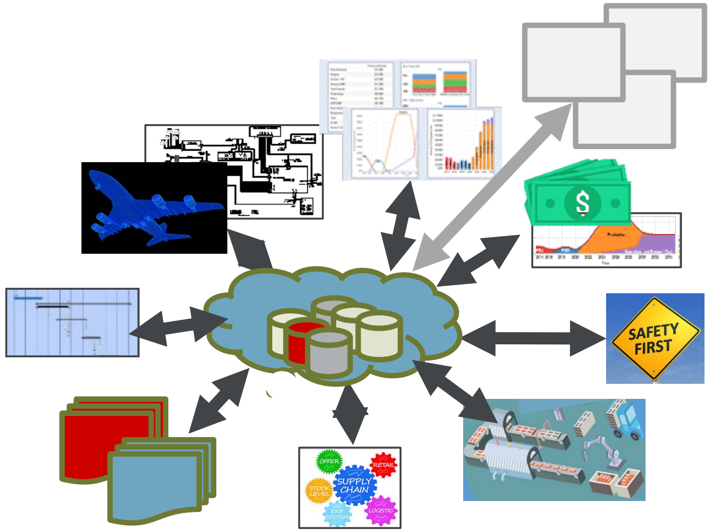
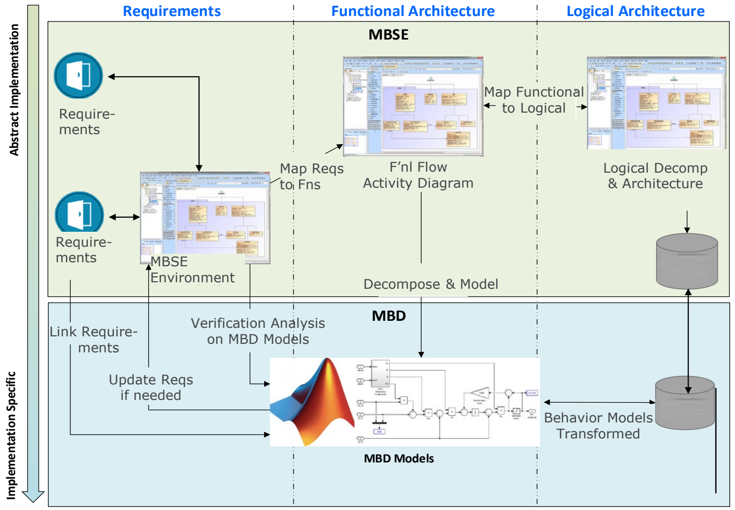
- Production Systems by definition are created to make some sort of product
- Advances in Technical Product Engineering leading to sophisticated tools
- Produce tremendous amount of disparate information
  - Solid Models, Notes, Specs, Renderings
  - Product data sheets, Bills of Materials (BOMs)
  - Floor Plans, Simulations, Analysis
  - Approved Suppliers, Routers, and more



- Data provided to multiple consumers throughout the product life cycle
  - Each with varying needs
  - To enable planning, tracking and execution of the product production
  - Product Lifecycle Management Systems (PLM)

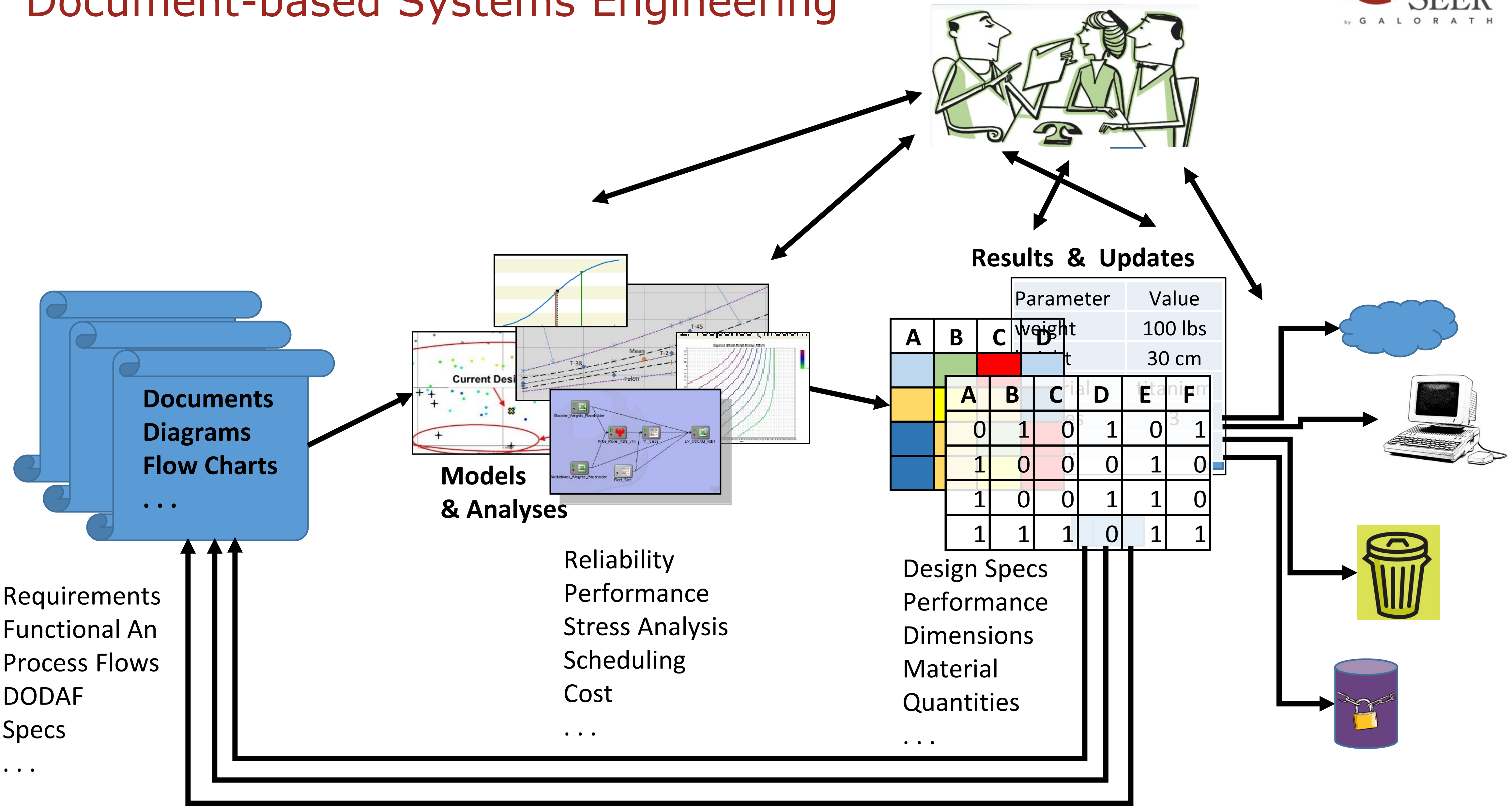
Model-based "what"

- Model-based "**Engineering**" - MBE
  - An **approach** to product development, manufacturing and life cycle support **using digital models and simulations**
- – Model-based "**Systems Engineering**" - MBSE
  - Digital principles for **system-level modeling & simulation** of physical & operational behavior throughout the system life cycle
  - Single source of truth
- – Model-based "**Definition**" - MBD
  - A Part's **definition** using a 3D model
- – Model-based "**Instruction**" - MBI
  - Graphical display of information necessary to **build / assemble**
  - Includes MBD engineering intent (process specs, geometric dimensions & tolerances, …)

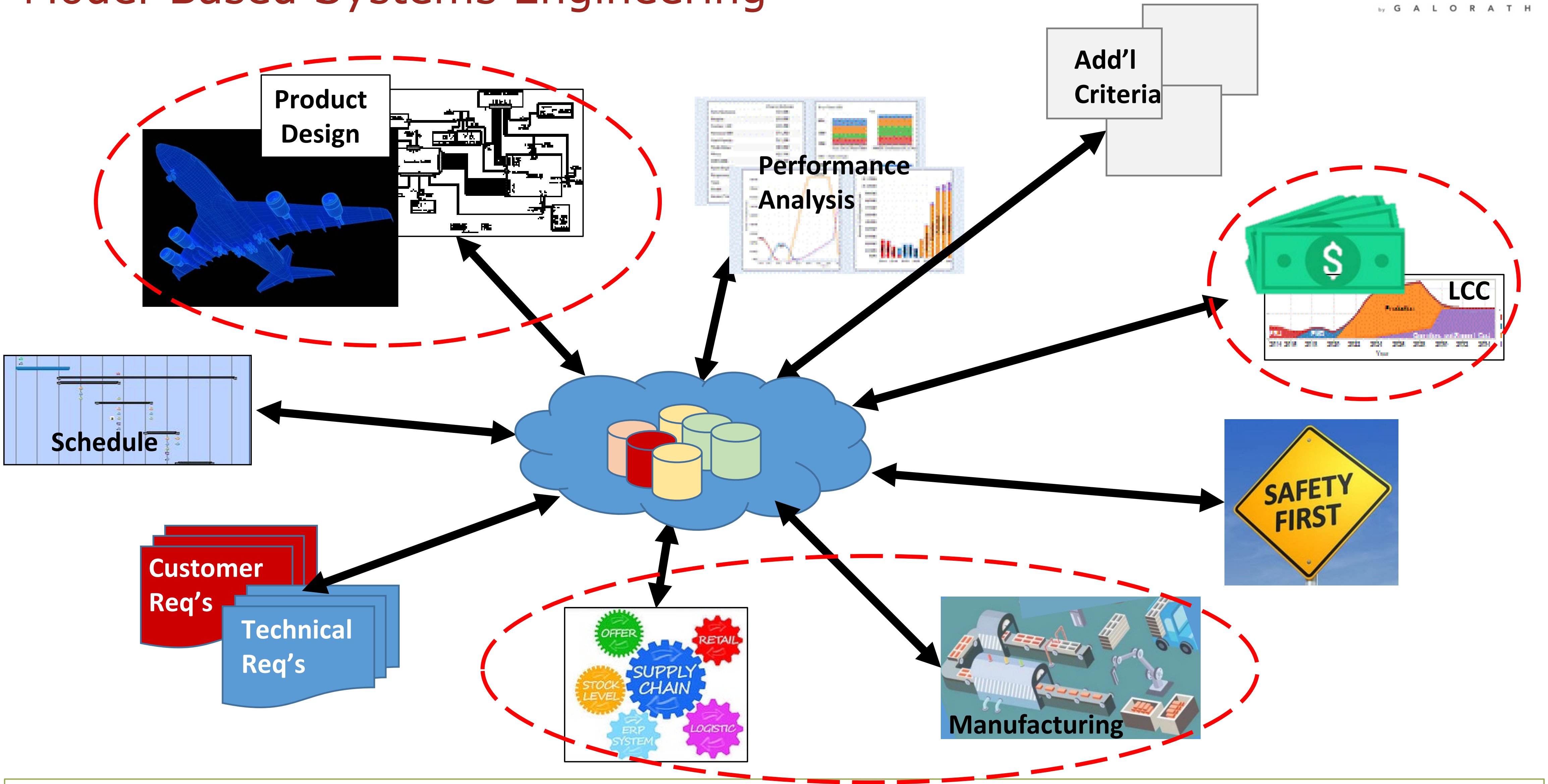


From NIST/INCOSE

Document-based Systems Engineering



Model-Based Systems Engineering

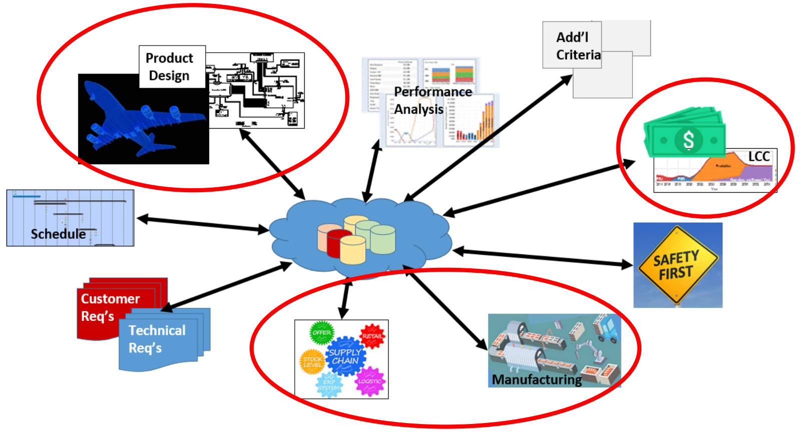


MBSE is the *formalized application of modeling* to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.*

*SEBOK - IEEE, SERC, INCOSE

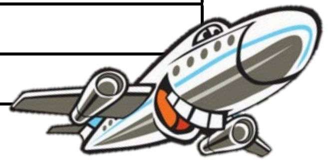
Cost Estimating Methods for Production System Design

- Objective: Optimize the design *and* cost of the production system
  - In conjunction with the product design



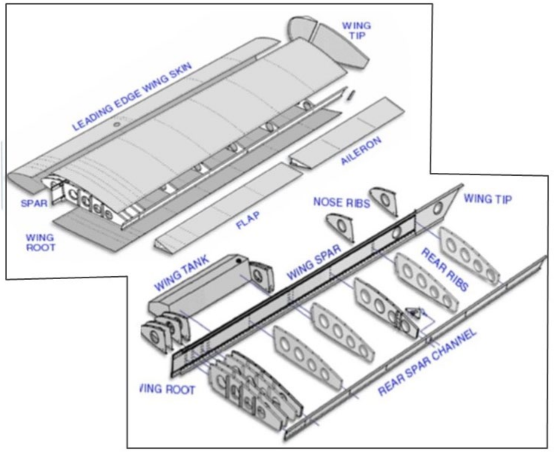
- Cost Estimating Methods
  - Top down/parametric
  - Bottoms-up
  - Analogies

Design Parameters: Product
Dimensions
Manufacturing processes
Machines
Labor rates
Tooling
. . .

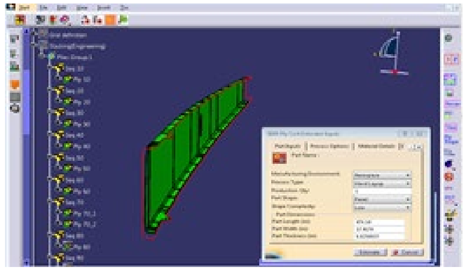


Design Parameters: Production System
Layout / Square footage
Operator stations
Tasks & Times
Machine Available Capacity
Crew size & utilization
Flow efficiency
Transportation
Equipment & Tooling
. . .

Application: Estimate cost of Production System via bottoms-up, process based methods

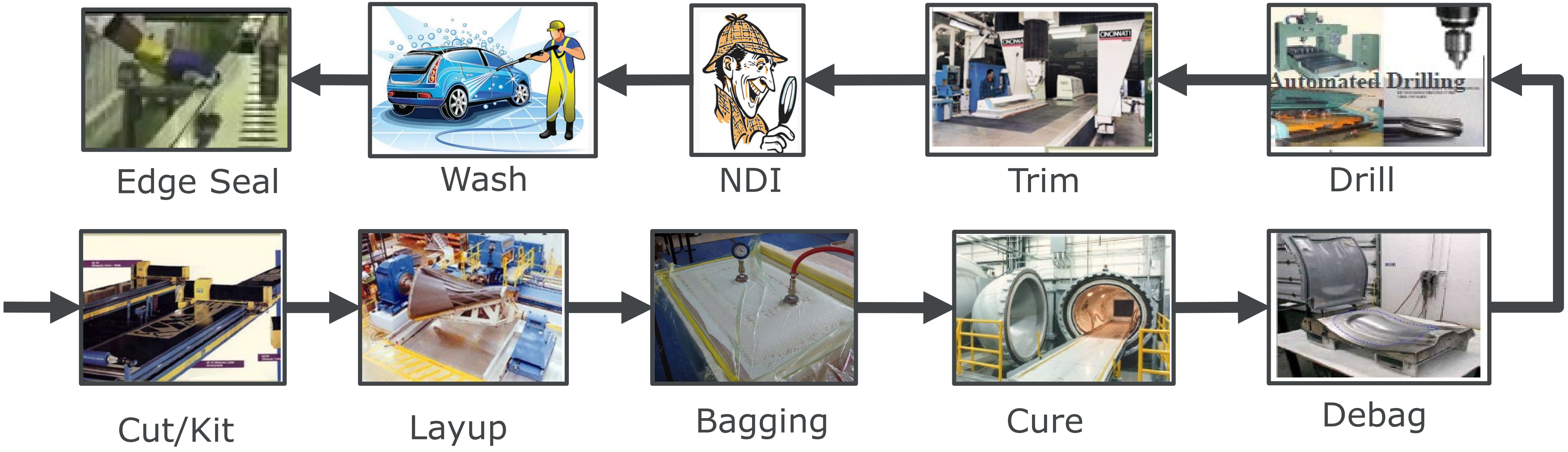


- Approach
  - Use the product design to determine manufacturing processes
    - Which determine stations, operations, crew, square footage, …
- Product
  - 20 CATIA files represent parts of the wing
    - 10 manufacturing processes identified in product design notes
  - Typically bottoms-up, process based estimating . . .
    - Is time consuming
    - Requires expert knowledge of manufacturing processes, materials, machines
    - Is prone to inconsistencies and varying assumptions
- Proposal
  - What if we could reduce the time and effort to produce an estimate based on the product design *AND* enable more consistent results?
    - Use CAD design (CATIA models) to estimate the Production System
    - Develop bottoms-up process based models



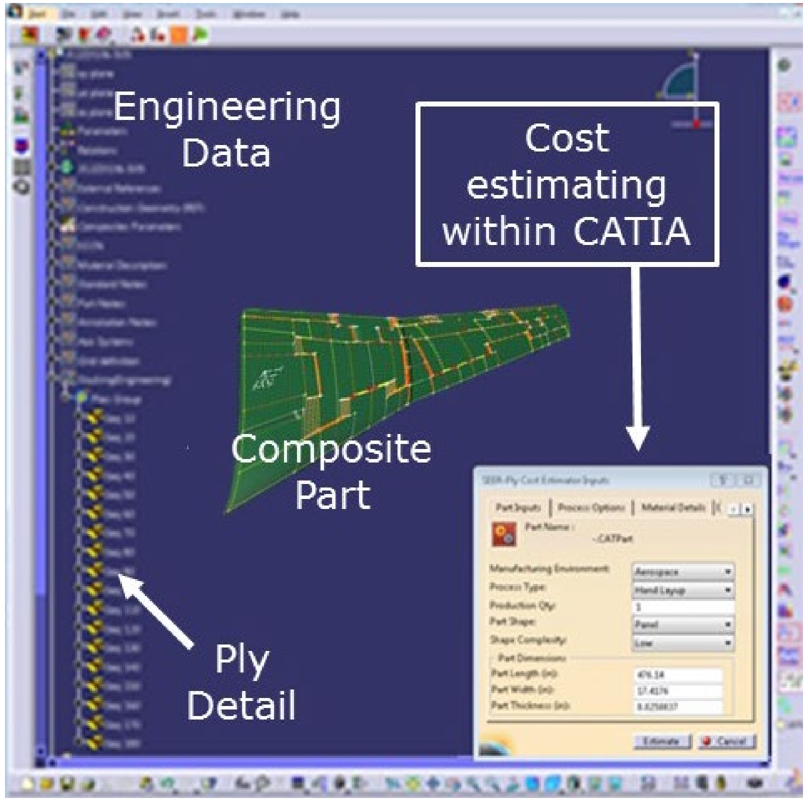
General Composite Production Operations

- Bottoms-up
- Process-based
- Manufacturing operations flow



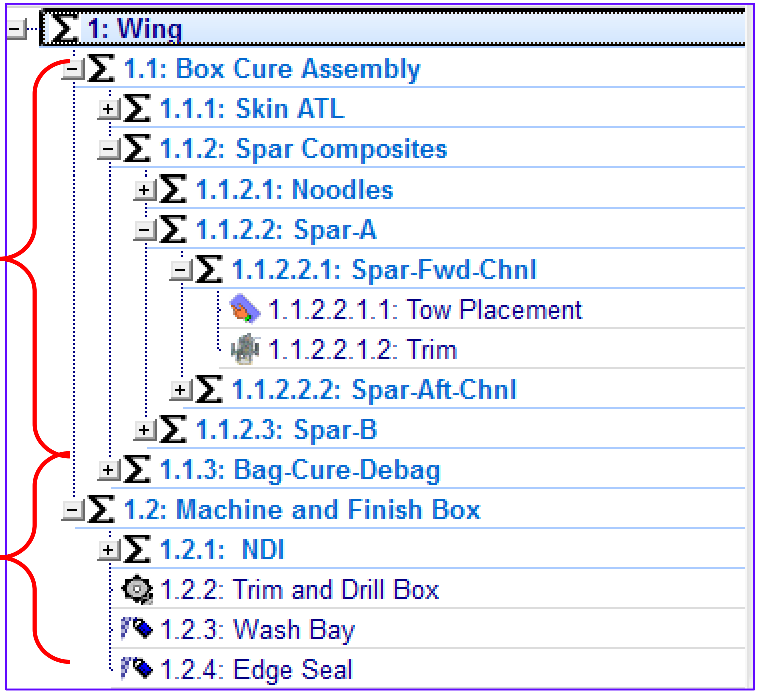
CAD to Cost Estimation

- Engineering data extracted from CAD model
  - Dimensions, material, processes, ply books (up to 100's), . . .
- Default values based on selected process
  - Industry or Calibrated
- Update or enter additional inputs as needed
  - Part related
  - Process related
  - Material related
- Estimate within CATIA
  - Get immediate results
  - Run trades (materials, dimensions, processes, …)
    - Real time feedback on cost impact of design decisions

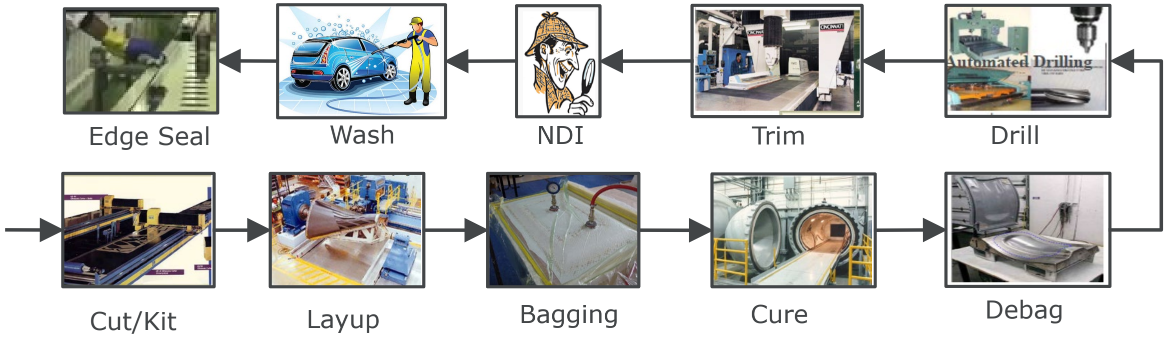


Assemblies Process-based Estimation

- Individual part CAD-to-Cost models aggregated into a WBS assembly



- Additional assembly process steps
  - Bottoms-up, process-based



- Put it all together

Calibration for Reuse, Consistency, Standardization

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- Calibrate model to reflect own environment
  - By adjusting input parameters and saving as default environments
- Calibrated models
  - Provide more consistency
    - Initial default parameter values
    - Standard processes & assumptions
  - Save time with fewer inputs and smaller calibration effort
- Approach
  - Analyzed multiple processes and parts
  - Produced templates and guidelines
  - Developed knowledge bases and standards files

Calibration points
Quantities
Complexities
Standards
Utilization
Material
Quality
Automation
Efficiency
etc

Industry defaults

Calibrated models

Results of Study

- Objective: Optimize the design *and* cost of the production system
  - In conjunction with the product design
- Can we *reduce the time and effort* to produce an estimate based on the product design *AND enable more consistent results*?

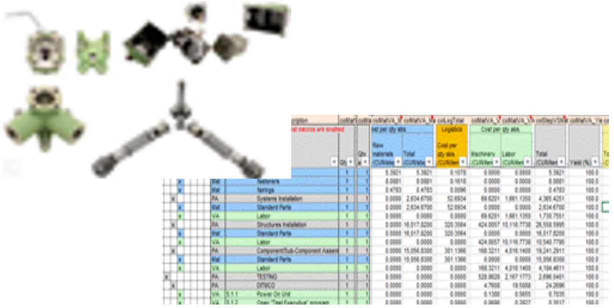
- Calibrated results compared to actuals
  - 2% for CAD-to-Cost parts
  - 5% for Entire assembly
- Time savings & Consistency achieved
  - Reduced estimating effort by 30% for future parts
  - Reduced variability by 90%

Process Steps	**Delta from Actuals**
Skin Cut, Kit, Layup	-1%
Spar Cut, Kit, Layup	-2%
Bag, Cure and Debag	5%
Trim and Drill	-2%
NDI	6%
Wash	11%
Edge Seal	15%
Total	5%

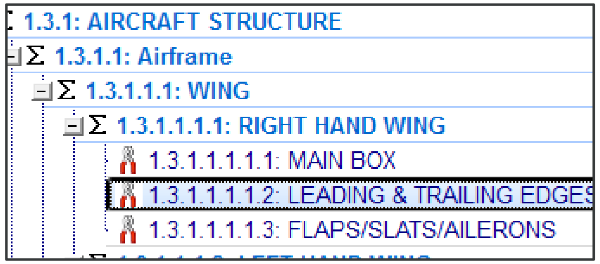
- Preliminary Conclusion
  - Concurrent Production System Optimization based on Product Design is Feasible & Desirable

Other Estimating Methods

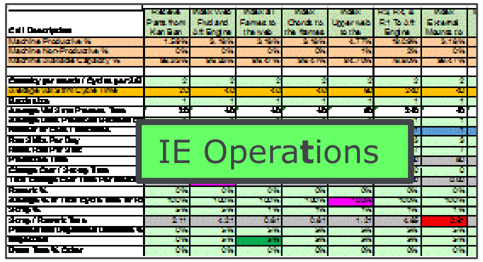
- Teardown
  - Disassembly of a part with each piece individually estimated
  - Very detailed lists of parts, material, manufacturing processes
  - Very time and labor intensive and may require lab space



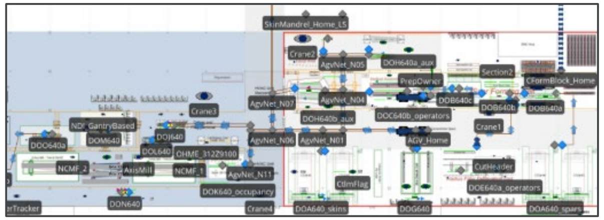
- Top-down parametric (industry and in-house models)
  - High level modeling; easy to run quick trade studies
  - May lack fidelity in lower level details & trades



- Bottoms-up, IE generated operations analysis
  - Generally very detailed
  - May not be conducive to quick trade studies



- Production Flow Simulation
  - Manual input of operations, flow, times, and cost data
  - Provides additional information (utilization, spatial analysis)



What's Next?

- Analyze additional methods & tools to estimate the production system
  - Develop process to determine best estimating method
  - Develop guidelines and calibration libraries for consistency across user base
- Integrate cost models data into MBSE environment for automatic updates
  - To ensure current and accurate data is available to other users
  - Link cost analysis output data to other Production System analyses
- Promote concept of integrated, predictive cost analytics early on
  - and throughout the life cycle

Integrating cost models into an MBSE environment

provides visibility into cost impacts of design decisions

Abstract & Authors

- Model-based Systems Engineering (MBSE) incorporates digital models to represent system-level physical attributes and operational behavior throughout the system life-cycle to support product development. To date, many MBSE efforts have focused on technical requirements with little emphasis on cost. Integrating cost models into MBSE provides visibility into cost impacts of design decisions. This presentation explores optimizing production-system design, manufacturing processes, and operations, by integrating various internal and industry production-system cost models into an MBSE environment.

- Dan Kennedy is the Director of Engineering Services at Galorath Incorporated (SEER). Dan currently facilitates the creation, adoption and use of advanced estimation tools and methodology that quantify costs and cost drivers in manufacturing design and operations. Dan received his BS in Mechanical Engineering from the University of Utah and has spent more than 30 years in Engineering and Manufacturing having held Senior roles in Operations and Program Management.

- Karen Mourikas is an Associate Technical Fellow at The Boeing Company specializing in Operations Analysis, Affordability, and Systems Optimization. Her current work includes Production Systems Cost & MBSE modeling, Product Teardown & Optimal-cost analyses, involving machine learning and natural language processing, and Affordability analyses. Karen has MS degrees in Applied Math and in Operations Research Engineering from the University of Southern California. Karen is a life-time member of ICEAA, has presented at several ICEAA & ISPA/SCEA conferences and was the recipient of the ICEAA 2018 Technical Achievement of the Year Award.