Achieving Complex Systems Understanding Through the use of MBSE-centric Analytics

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About the Presenter

- Systems Architect at Lockheed Martin Space Systems

- A nationally recognized expert in systems engineering, software intensive systems and model-based development

- Career started with a strong software focus; has evolved to center on complex cyber-physical systems

- Has a passion for applying modeling, simulation, analytics and computational capabilities to hard science and engineering problems and to make engineers more productive

- Holds M.S. and B.S. in Computer Science and Engineering from Penn State

- Currently pursuing PhD in Systems Engineering at Stevens Institute, with research focused on composable design and product family management for low volume complex cyber-physical systems

Agenda

- System, Workforce & Environmental Trends – The Context

- Model-based Systems Engineering – What, Why and How

- Beyond specifications – Integrated Models

- Systems Understanding and Analytics through Model-based Architectures

- Supporting Decision Makers and Architects Alike

- Industry Adoption and State of Practice
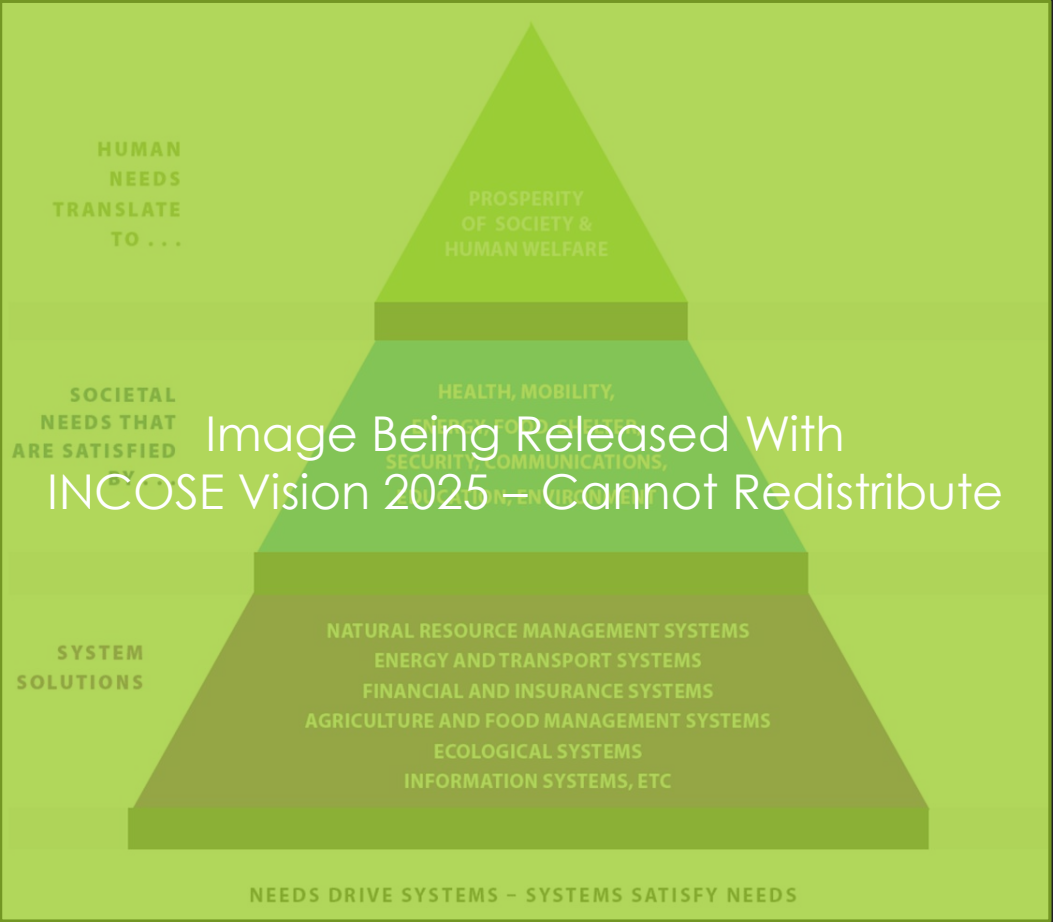
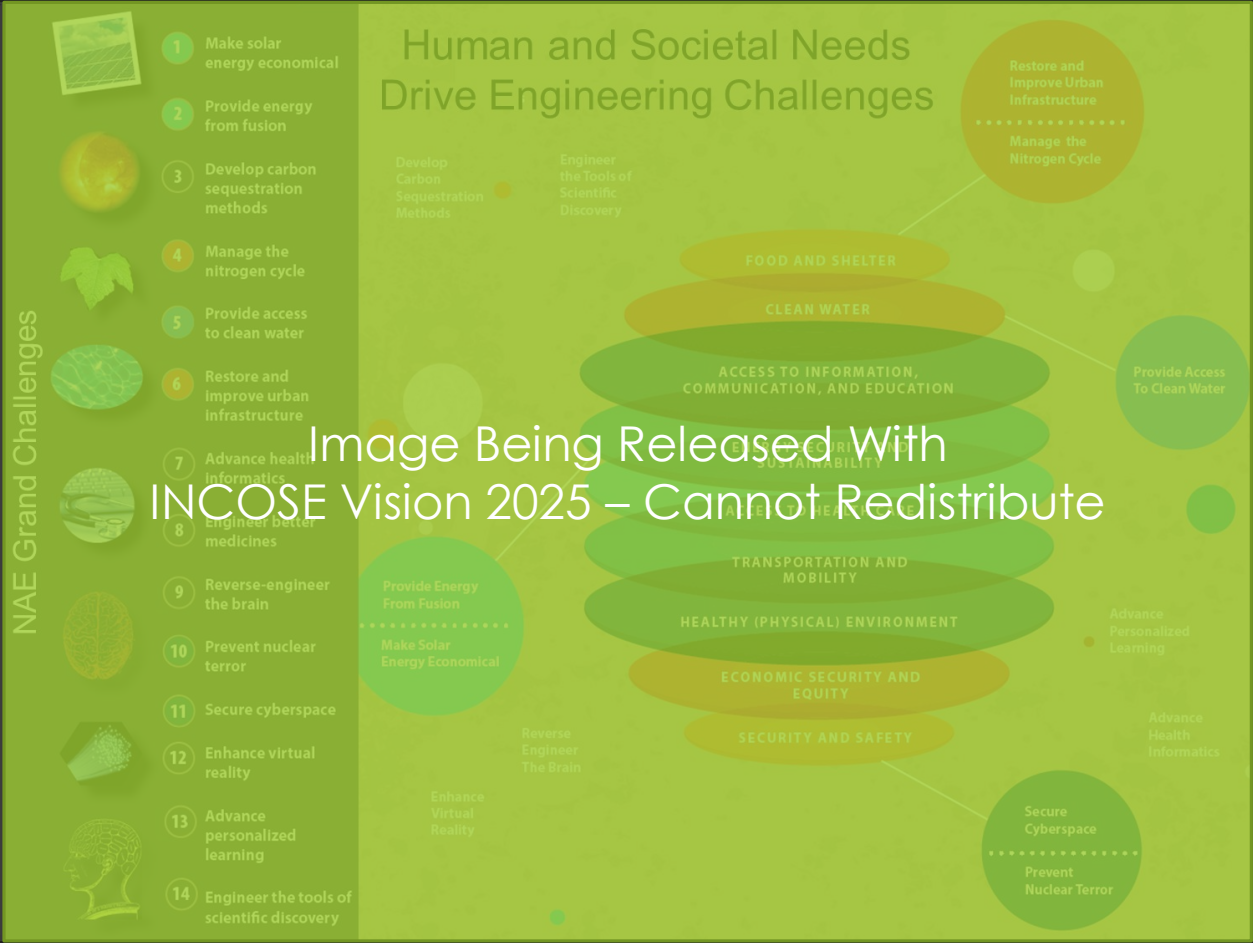- Pressing Research Needs

Global Trends

Global Trends & Technology Innovation Shape the Systems Environment

GLOBALIZATION – COUNTRIES, PEOPLE, INDUSTRY, TRADE

INCREASING SOCIO-ECONOMIC CHALLENGES

POPULATION GROWTH & URBANIZATION

INTERDEPENDENT ECONOMIES

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INCREASING PHYSICAL ENVIRONMENT CHALLENGES

GLOBAL ENVIRONMENTAL CHANGE

SUSTAINABILITY OF NATURAL RESOURCES

HUMAN-COMPUTER INTERACTION

MINIATURIZATION

COMPUTATIONAL POWER

SENSOR TECHNOLOGIES

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COMMUNICATION TECHNOLOGIES

SOFTWARE SYSTEMS

System & Workforce Trends

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System and Procurement Trends in Aerospace & Defense

- Increasing complexity in systems procurement driven by an increasing dependence on software, larger supply chains and a more complex policy environment

- Increasing complexity and a need for more rapid capability deployment is driving a need for new design methods and tools

- Systems engineering, specifically centered on the use of architecture models have reached center stage as an enabler to achieve affordability and resilience goals

The New Reality – Affordability and Resilience
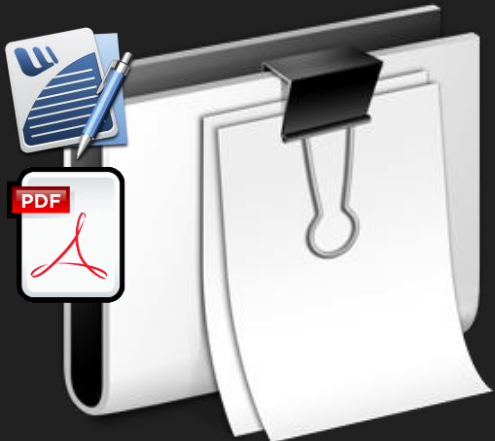
Systems 2020 Vision
- Adversary can use commercial technologies and new tactics to rapidly alter the threat to US forces
- DoD engineering, and business processes not structured for adaptability
- New research, tools, pilot efforts needed to determine best methods for building adaptable defense systems
- **Need faster delivery of adaptable systems that are trusted, assured, reliable and interoperable**
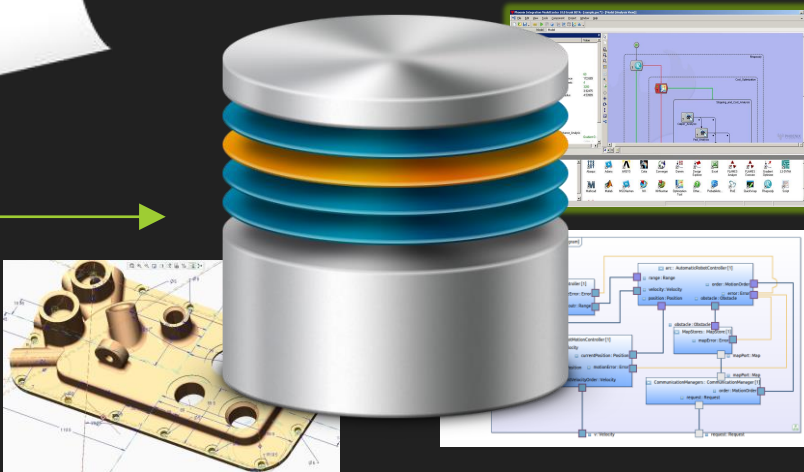
Existing Gaps and Critical Needs
- Gap: Lack of a Conceptual Design Environment
- Gap: Lack of tools to integrate system modeling capabilities across domains
- Gap: Lack of open, virtual and realistic environment for validation and producibility analysis
- Need an integrated (i.e. cross discipline) framework for concept, design and analysis of systems based on standards, open architecture and existing COTS tool sets

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ENGINEERING

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Model-based Engineering:
<u>What</u>, Why and How?

Document-Centric

Model-Centric

- Digital models have been common in engineering since the late 1960s but today's focus on Model-based Engineering goes beyond the use of disparate models

- Model-based Engineering moves the record of authority from documents to digital models including M-CAD, E-CAD, SysML and UML managed in a data rich environment

- Shifting to model-based enables engineering teams to more readily understand design change impacts, communicate design intent and analyze a system design before it is built
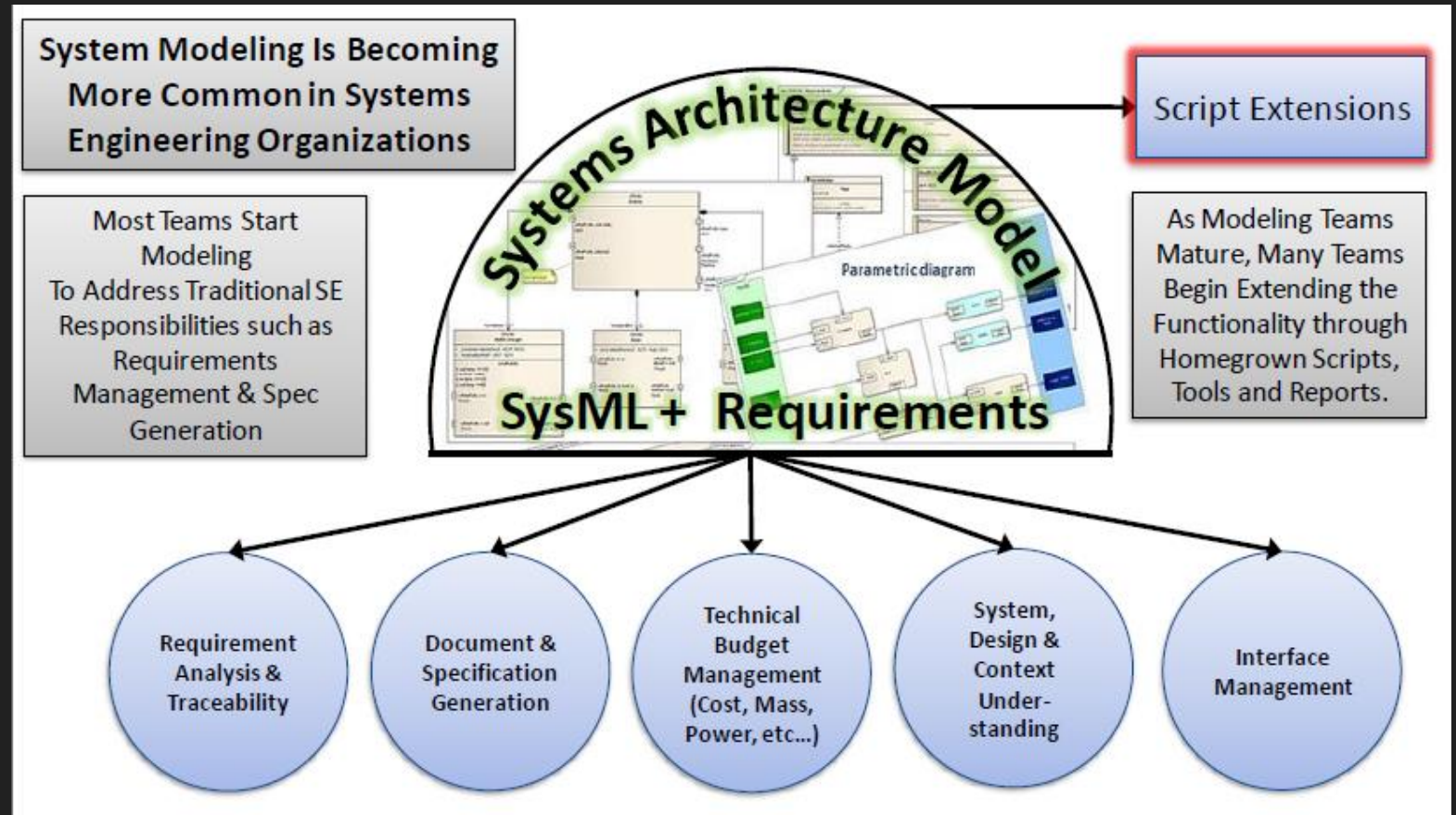
Model-based Engineering:
<u>What</u>, Why and How?

Architecture

Cost

Performance

CAD

Manufacturing

Electronics

Software

Verification

Manufacturing Engineering

Product Test & Verification

Sourcing

Product Engineering

Manufacturing & Production

Deployment

Model-Based Enterprise

Concept Engineering

Sustainment

Requirements Planning

Decommission & Recycling

- The primary focus of most current industry efforts to move toward a Model-based Engineering approach focus on integrating data through models

- Engineering Is Responsible To Understand All Items That Could Impact A Design And Determine A Resolution For Those Items – an integrated end-to-end modeling environment supports this role

- By brining together varied but related models into a data rich, architecture centric environment, new levels of systems understanding can be achieved

Image Credit Lockheed Martin

Model-based Engineering: What, Why and How?

- Model-based Systems Engineering forms a solid (and critical) core of a Model-based Engineering Enterprise

- Traditional Systems Engineering responsibilities are addressed through the application of models

- The resulting models help expand the reach of Systems Engineering into downstream disciplines through integrated requirements, specifications, interfaces and technical budgets


Image Credit Lockheed Martin

Model-based Engineering: What, <u>Why</u> and How?

- Model-based Systems Engineering provides a mechanisms for driving more systems engineering depth without increasing costs

- Data-centric specifications enable automation and optimization, allowing SEs to focus on value added tasks and ensure a balanced approach is taken

- Unprecedented levels of systems understanding can be achieved through integrated analytics, tied to a model-centric technical baseline.
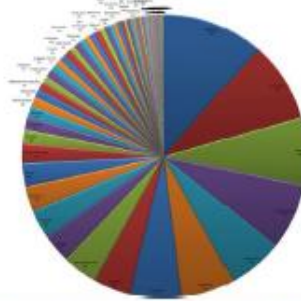

- **Drive a consistent specification**

- **Analyze & Interrogate the System Design**

- **Automate, Automate, Automate!**

Image Credit Lockheed Martin

Model-based Engineering: What, Why and __How__?

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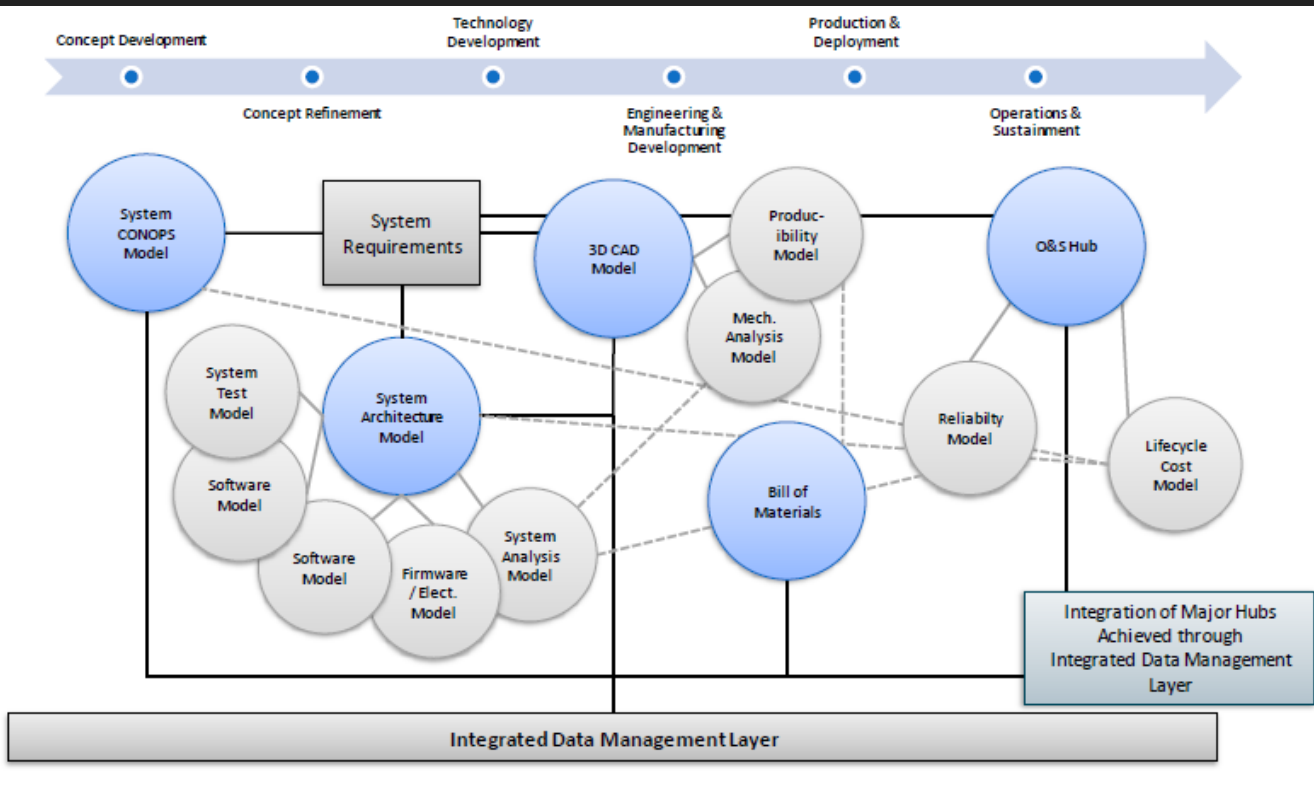
- The key to a successful model-based approach is scoping the problem!
  - What do you want to get out of your models?
  - What fidelity do you need to accomplish those goals?
  - What are the success criteria for the effort?

- Scoping and managing a modeling effort is both an art and a science
  - Driving change in an organization takes time and continuous investment

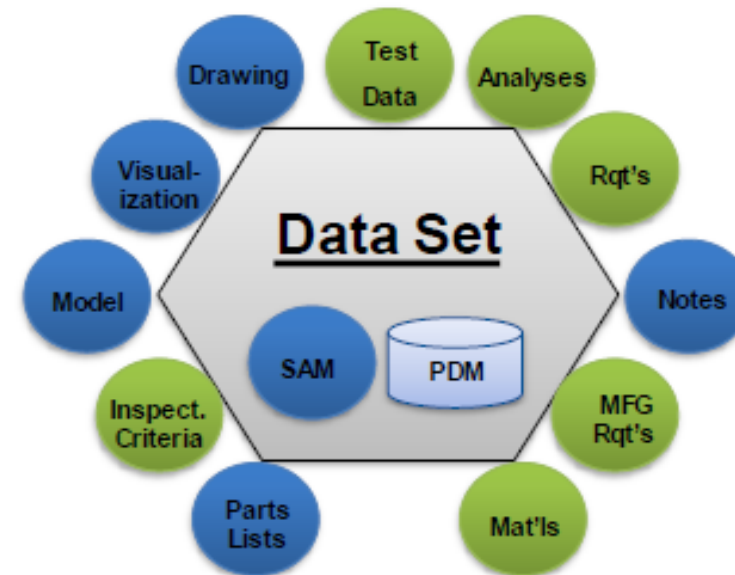# Beyond Specifications: Integrated Systems Models
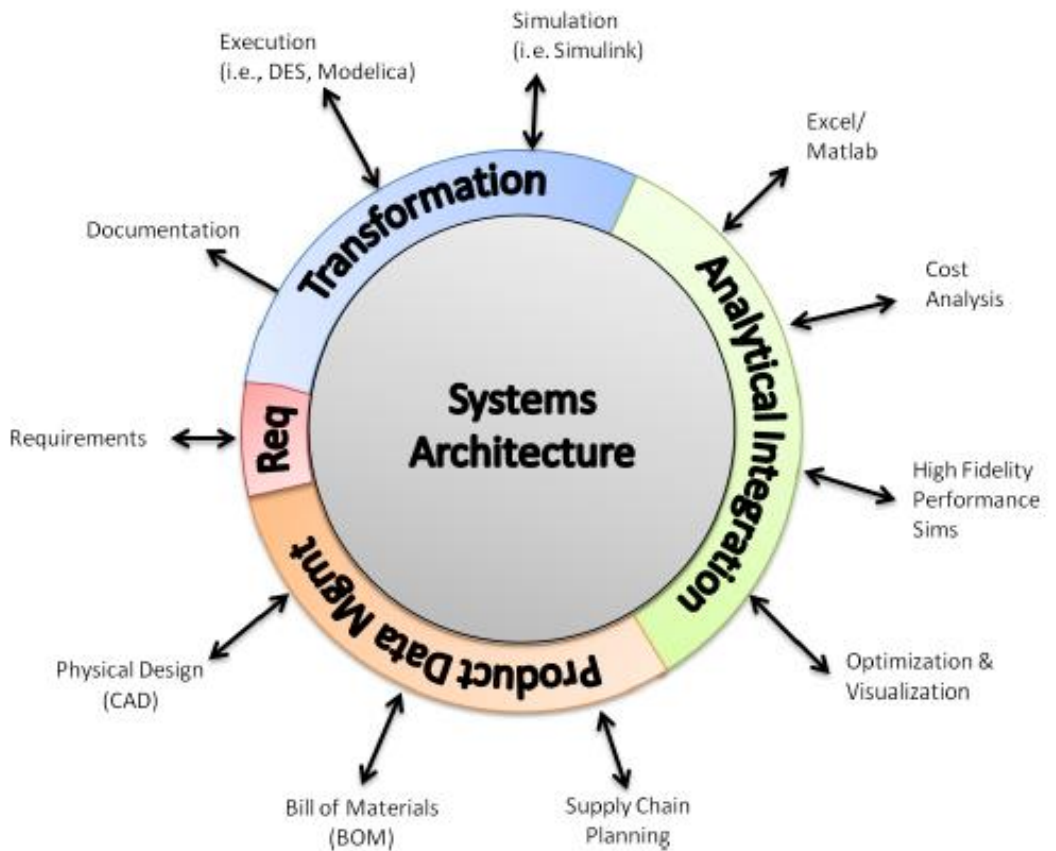
- Model-based Systems Engineering doesn't end with the creation of specifications and ICDs

- A Systems Architecture Model provides a "hub" for data integration and transformation across the product lifecycle

- Specifically of note is the ability to link analysis through the systems model to provide insight into architectural and system level decisions

Model-based Engineering Baseline: An Integrated Data Set

A Product Data Set Contains Artifacts That Define A Product...

- Systems Architecture Model
- 3D Model
- Specifications
- Notes
- Metadata or Attributes
- Bill Of Material
- Design Requirements
- Other Product Descriptive Info

Data Set

Drawing, Test Data, Analyses, Rqt's, Notes, MFG Rqt's, Mat'ls, Parts Lists, Inspect. Criteria, Model, Visualization, SAM, PDM
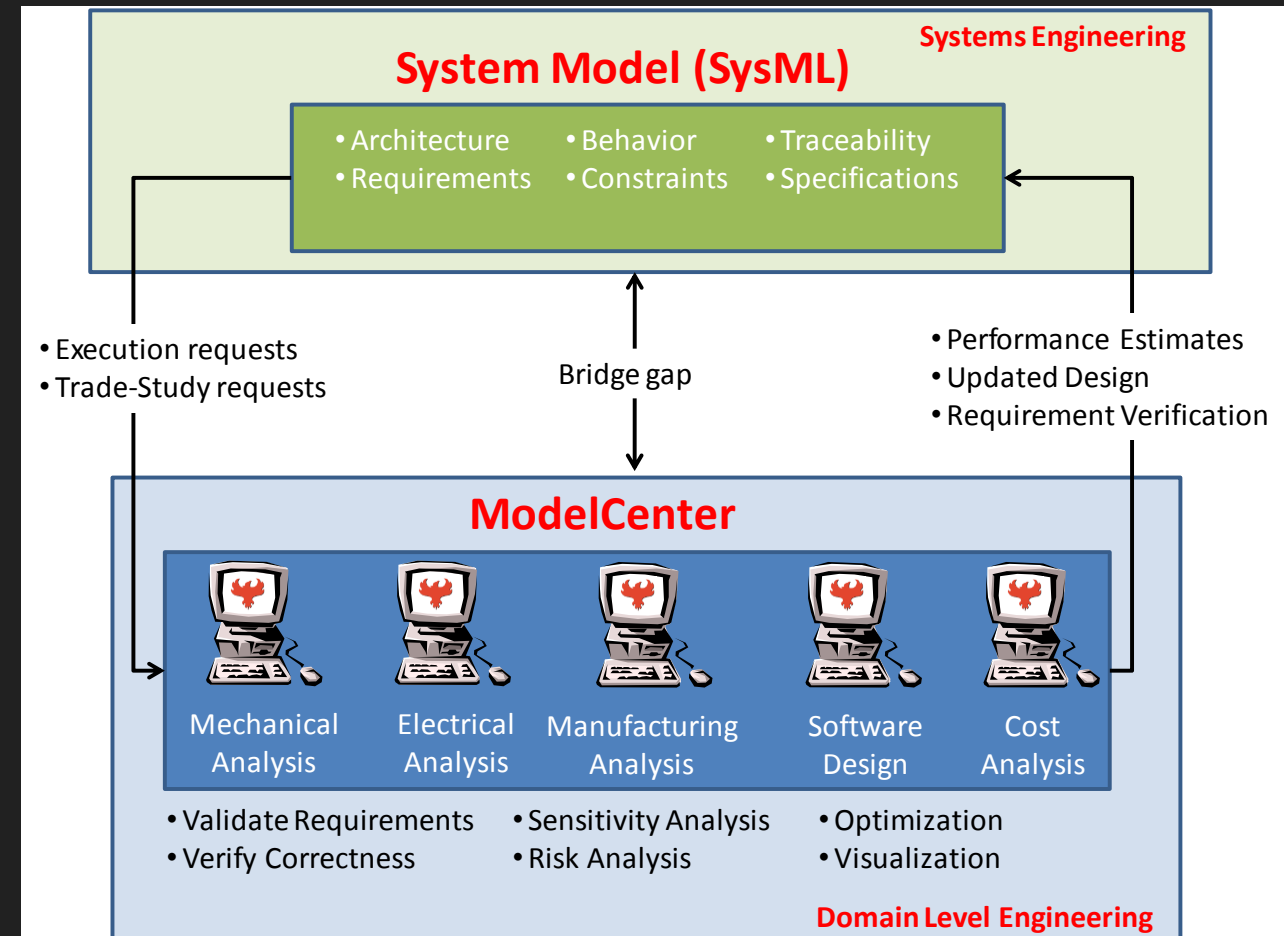
The Entire Data Set Must Be Managed

Systems Understanding and Analytics through Model-based Architectures

- A critical task in Systems Engineering is the upfront trade and analysis process to ensure the best value system is developed to satisfy the mission need

- As missions become more complex, understanding all items that can impact the system performance becomes harder.

- Integrating high fidelity analytics through a consistently defined systems architecture can help provide insight into key system characteristics not evident through traditional analysis alone.

- Integrated tools allow engineers to analyze many more system configurations against mission scenarios, helping to identify key driving requirements and lowest cost alternatives for systems design.
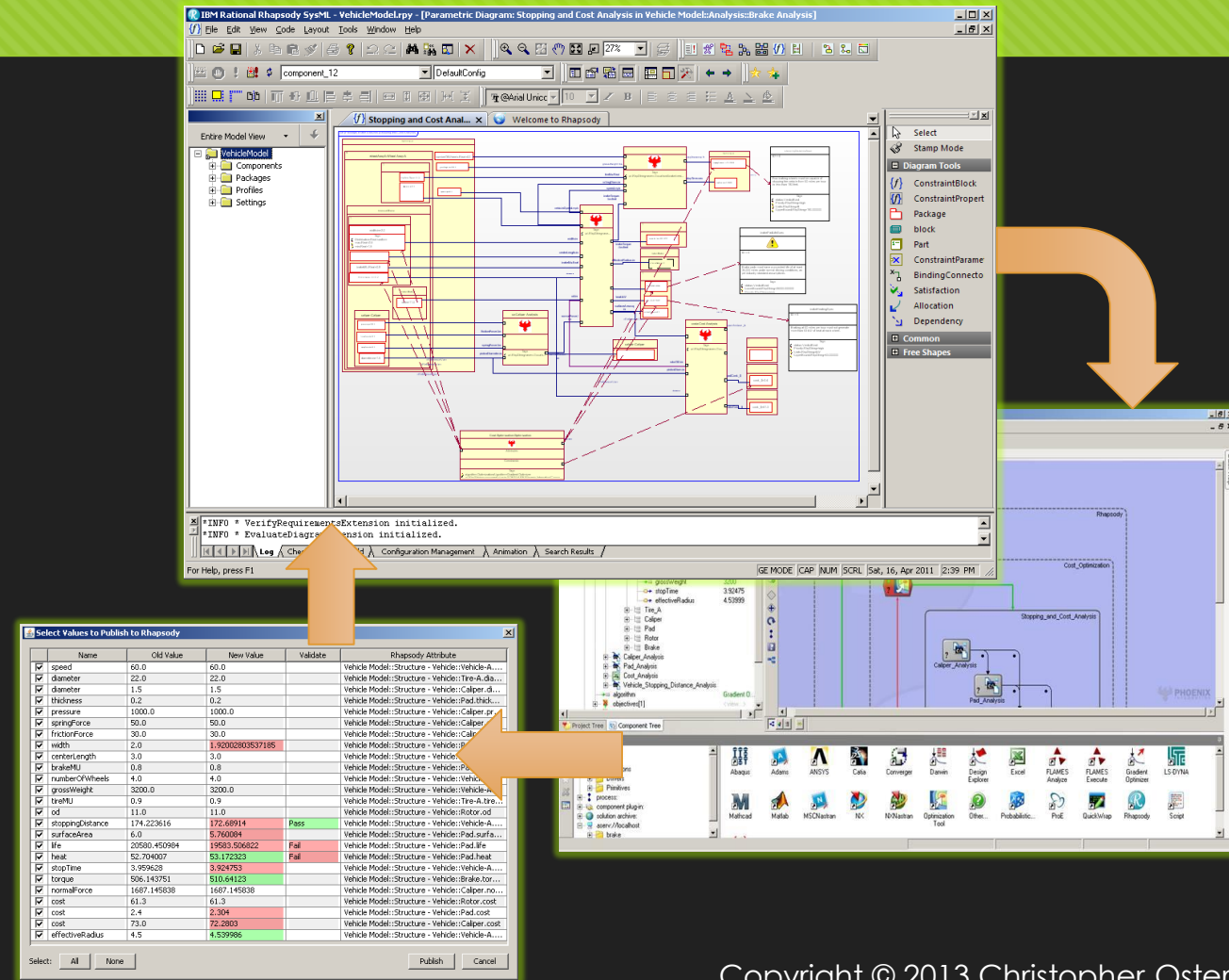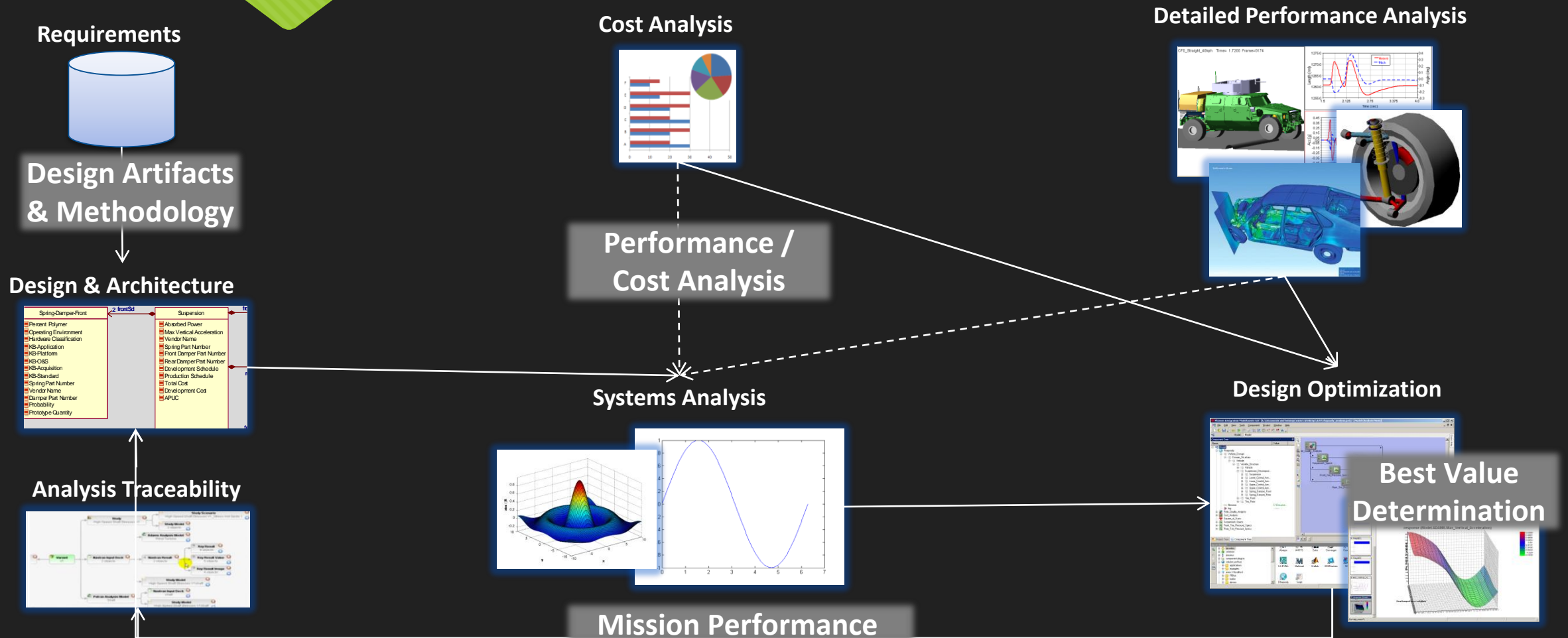
Expanding base of MBSE Tool Capabilities

- The MBSE tools marketplace has been expanding beyond just graphical modeling and requirement tools with a focus on data and model integration

- Phoenix Integration ModelCenter ® has been expanded to help bridge SysML to multidisciplinary analysis through the release of the ModelCenter MBSE Pak

- With MBSEPak, SysML parametric models within Rhapsody® or MagicDraw® can be executed, linking requirements to design to analysis and back


Systems Engineering

System Model (SysML)

- Architecture
- Requirements
- Behavior
- Constraints
- Traceability
- Specifications

- Execution requests
- Trade-Study requests

Bridge gap

- Performance Estimates
- Updated Design
- Requirement Verification

ModelCenter

Mechanical Analysis | Electrical Analysis | Manufacturing Analysis | Software Design | Cost Analysis

- Validate Requirements
- Verify Correctness
- Sensitivity Analysis
- Risk Analysis
- Optimization
- Visualization

Domain Level Engineering

Image Credit Phoenix Integration

Model-based Integrated, Multidisciplinary Analysis

Requirements

Design Artifacts & Methodology

Cost Analysis

Detailed Performance Analysis

Performance / Cost Analysis

Design & Architecture

Systems Analysis

Design Optimization

Analysis Traceability

Best Value Determination

Mission Performance

Architecture Centric Analytics

- A SysML Architecture can serve as a hub for integrated analytics, capturing analysis, analysis context, requirements and key architectural parameters

- Analysis context specifies the boundaries of the analysis, parametric views define the analysis to be performed and requirements diagrams can capture design goals, thresholds and driving requirements to bound the tradespace

- This model-centric approach provides a consistent, managed framework for analysis which often tends to be ad-hoc

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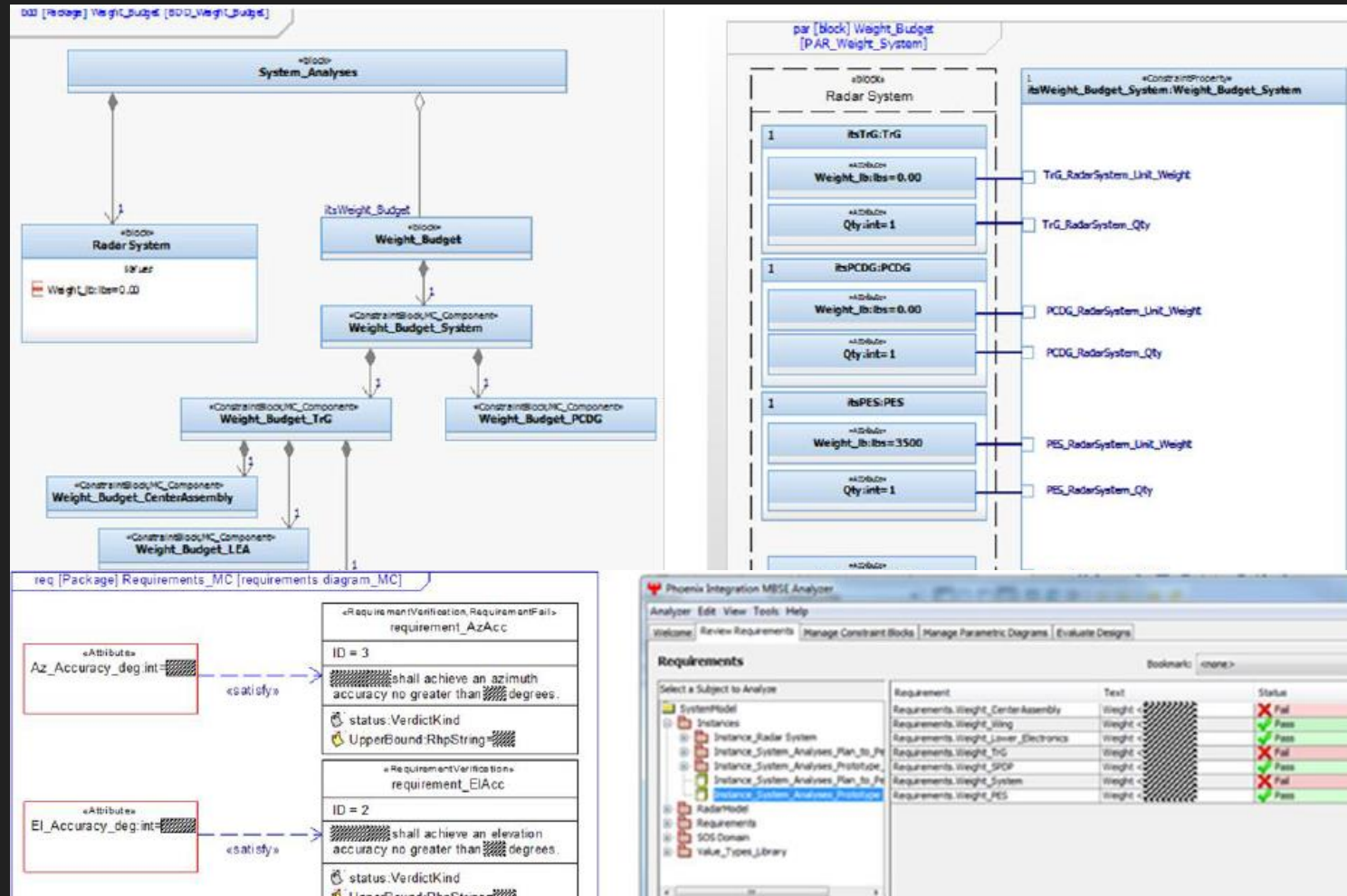
Support for New Business

- Rapid analysis and architecture centric tools can support new business teams as well as traditional architects and engineers by providing faster insight into optimal solutions

- Linking models, analyses and visualizations enable teams to engage customers in the decision making process while finding optimal solutions for a problem.
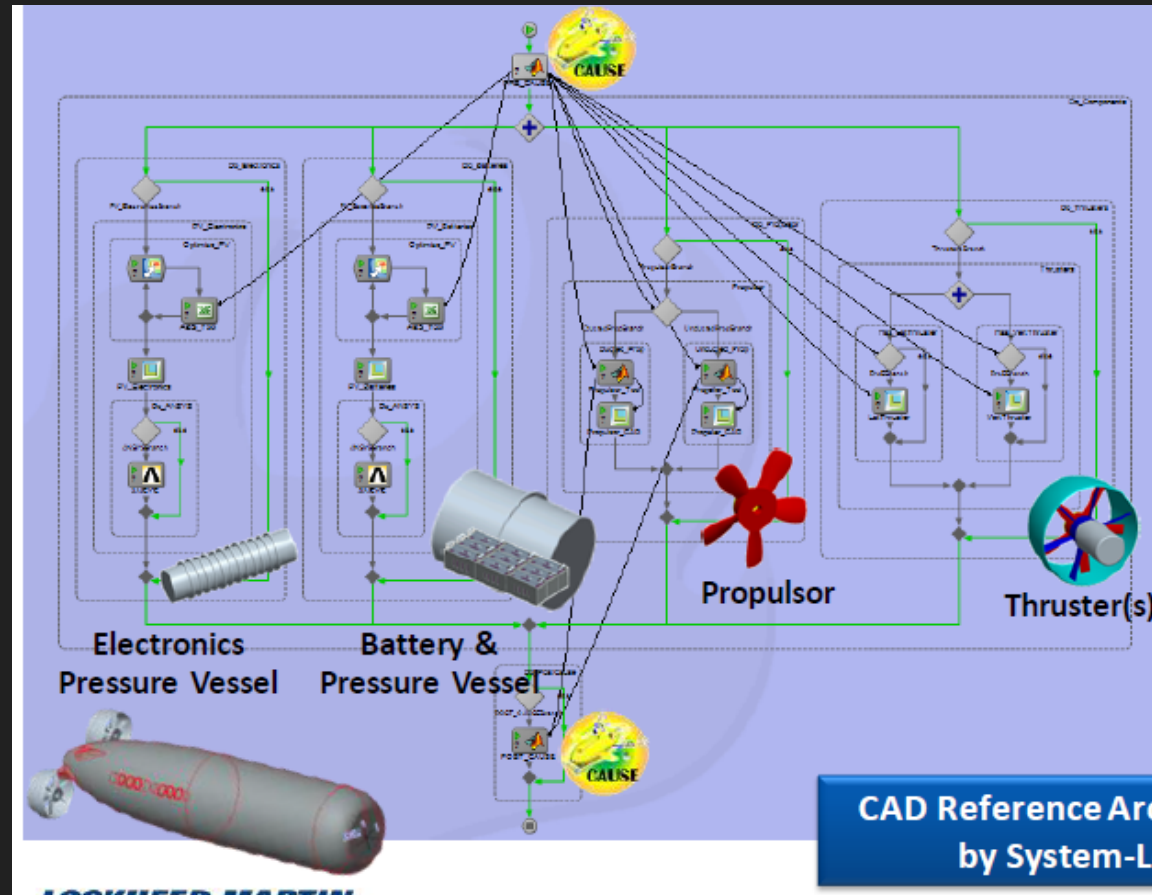
Component Requirements Are Based on System-Level Allocation

Component Analysis Models Provide Higher-Fidelity Sizing & Design

Second CAUSE Run Captures Higher Fidelity Estimates & Identifies System-Level Impacts

CAD Reference Architecture is Driven by System-Level Analysis

Image Credit Lockheed Martin

Support for Systems Architects

- Putting analytics at the fingertips of Systems Architects provide insight to requirements and architectural features that drive performance and cost.

- Multi-dimensional analysis can provide perspectives to architects which help to identify the "knee in the curve" between cost and performance in an n-dimensional trade space.

Image Credit Kim et. All CSER 2013 and Phoenix Integration
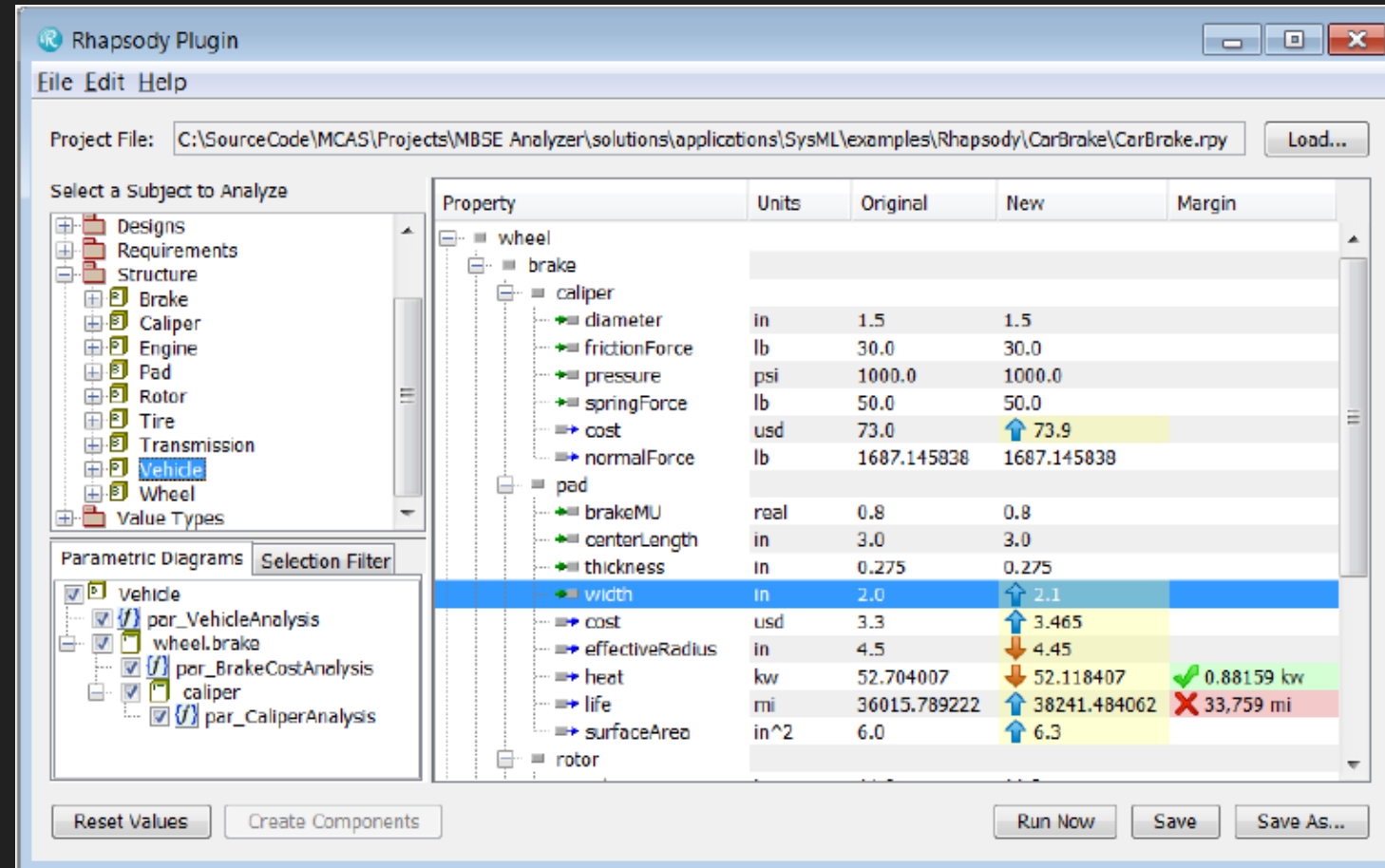
Integrated Modeling and Analysis Support for Decision Makers

- Decision makers will have more information and options from which to draw conclusions

- Integrated analytics models will both increase the amount of information available to decision makes as well as help decision makers make sense of the information

- Tools to explore, visualize and understand a complex tradespace, rooted in MBSE can provide early insight into the impact of decisions ranging from technical solutions to complex public policies

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Support for Decision Makers
Shifts in SE to Socio-Political Problems

- Systems Approaches are becoming more common in the analysis and implementation assessments of complex policies within government, industry and academia

- Key to the impact of Systems Engineering in policy analysis is understanding the likely impacts and outcomes of one or more policy decisions

- Model-based architectures provide a mechanism for capturing and characterizing the key parameters of a policy and the context and ecosystem of that policy

- Integrated model-centric analysis provides a basis for rapidly assessing outcomes, providing better insight into likely impacts prior to implementing the policy

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Industry Adoption: MBSE and Integrated Analytics

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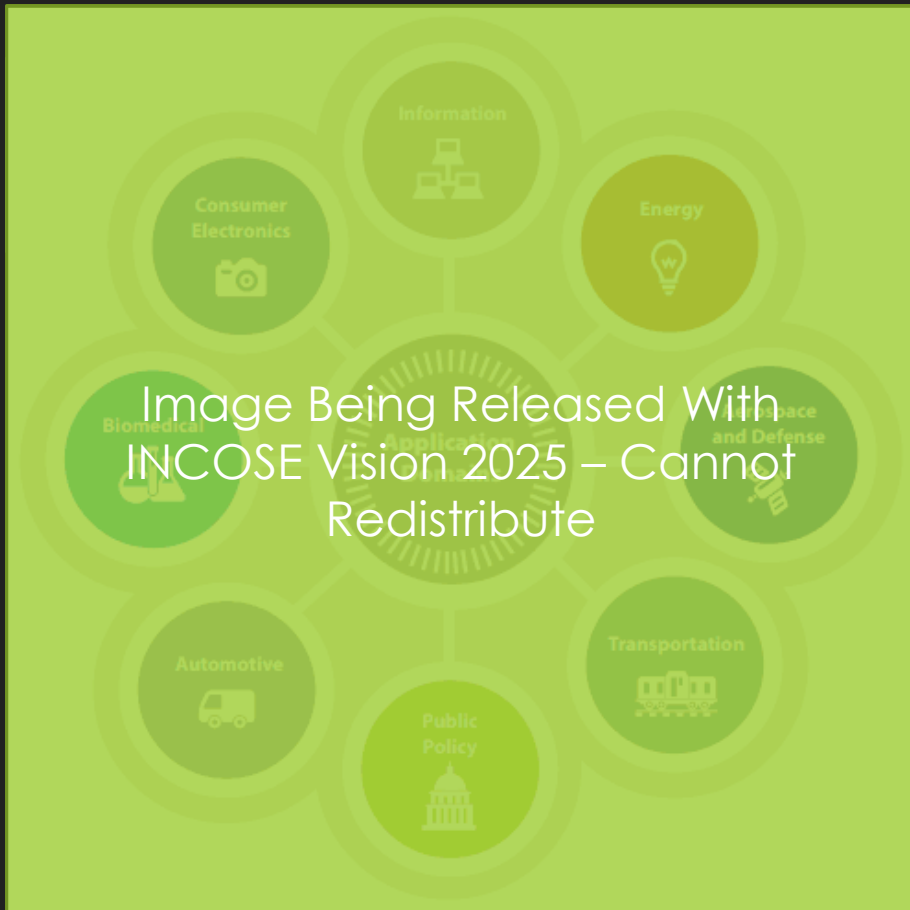
- There is an evident increase in adoption of model-based systems engineering approaches generally across Aerospace & Defense, Automotive and the Consumer Products Markets

- Expansion to analytics and trades is driving a rapid increase in adoption rates within many organizations

- The increasing user base is helping drive improvements in available tools and underlying standards

- "Coopetition" type partnerships are helping to drive rapid improvements to Model-based technology

- There are many new research problems being created as technologies move forward

Research Needs and Academic Partnerships

- Model-based Product Family Design Methods and Tools

- Better Visual/model-based Constraint Languages

- Better MBSE Visualization and Data Translation Techniques

- More User-friendly Mechanisms to Link Models & Model Parameters

- Better Tools and Methods for Maintaining Semantic Consistency Amongst Models

- Better "Executable Model" Technologies for a Broader Set of Problems