Harmonizing Modeling and Simulation and MBSE to Cope with Rampant Complexity

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Topics

- **What is Modeling?**
- **What is Simulation?**
- **What are the Applications of Modeling and Simulation?**
- **What is Model-Based System Engineering (MBSE)?**
- **The M&S and MBSE Correlation**
- **Problem Complexity**
- **System Complexity**
- **Engineering Tool Complexity**
- **Principles of M&S that can be Applied in MBSE**
- **Case Studies**
- **Conclusion**

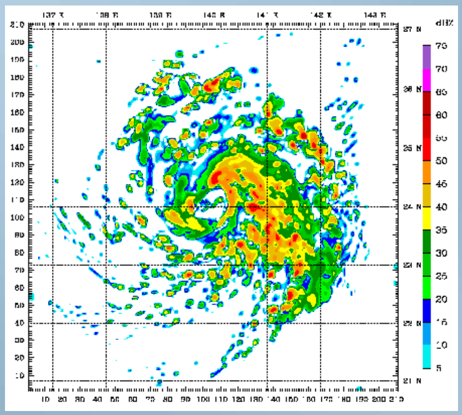
What is "Modeling?"

- **A *Model* is a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process. (Department of Defense Modeling and Simulation (M&S) Glossary, October 1, 2011; available at http://www.msco.mil/MSGlossary.html)**
  - The model is used, in a simulation, to predict how the real system might perform or exist under various conditions, constraints or environments
  - Modeling is the process of creating a model of a real or anticipated System of Interest by understanding and defining
    - Inputs (events, state data, initialization data, model control)
    - Outputs (events, state data)
    - Behaviors and rules of input to output transformations
    - Environment
    - The intended use of the model (drives fidelity and resolution)
    - The level of abstraction

Orrery, a model of the Solar System
(Lego Orrery by V&A Steamworks)

What is "Simulation?"

- ***Simulation*** **is a method for implementing a model over time (Department of Defense Modeling and Simulation (M&S) Glossary, October 1, 2011; (http://www.msco.mil/MSGlossary.html)**
  - Usually means a computation system (simulator) that is capable of executing the model(s) instructions over time in order to accurately generate behavior
  - Used to predict how the real system might perform under various conditions, constraints and environments
  - Imitates the inputs, outputs and behaviors of the modeled System of Interest
  - Often used when *closed-form, analytical solutions* are impossible
  - If the Model represents uncertainties, applies specialized calculations to imitate how uncertain behaviors and parameters create variability in outputs

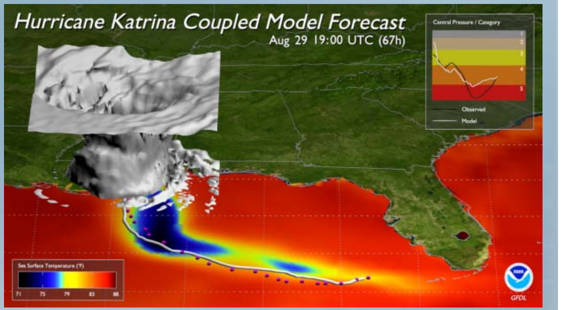


Typhoon Mawar 2005 computer simulation Attribution: Dr. Paul Mullins, Slippery Rock University

The Tellurium clock of Marc Maradan (http://www.computus.org/journal/?p=2571)

What are the Applications of Modeling and Simulation?

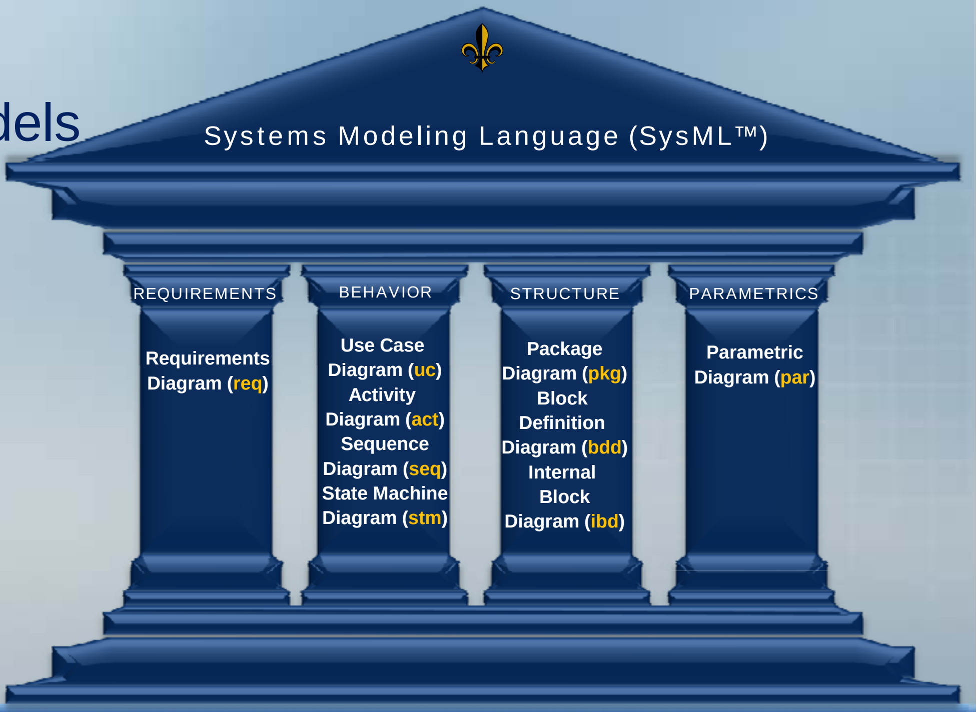
- **Two primary applications of M&S**
  - Used to enhance cognition about the real world without actually manipulating it
    - Simulating complex activities (e.g. landing a man on the moon)
    - Simulating complex systems (e.g. hurricanes)
    - Simulating impractical events (e.g. launching a nuclear warhead to test missile defense)
  - Used to aid in the building of a new systems or adding capabilities
    - Cost Analysis
    - Trade Study Analysis
    - System Architecture Analysis
    - Performance Analysis
    - An Enabling System Surrogate for Testing
    - System Training Simulations



Tsar Bomba mushroom cloud.

What is Model-Based System Engineering?

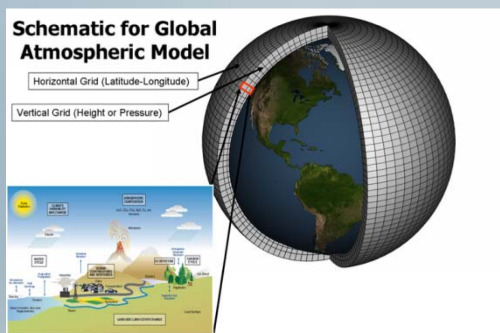
- **Essentially, Model Based Systems Engineering (MBSE) is all about creating and evolving real world solutions using a model of the system – the "system model"**
  - System design artifacts transitioned from document-based to model-based
    - Single source for the design "truth"
  - Formalizes the practice of systems engineering through the use of models (requirements, structure, behavior, parametrics) using SysML
  - Results in quality/productivity improvements & lower risk
    - Increased rigor and precision
    - Improved communications among system/project stakeholders
    - Better management of complexity

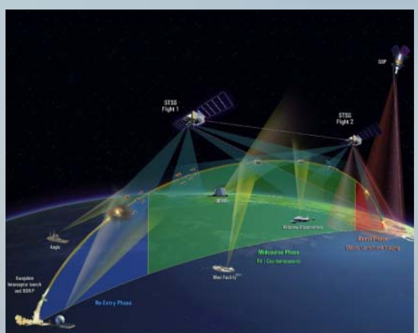


The M&S and MBSE Correlation

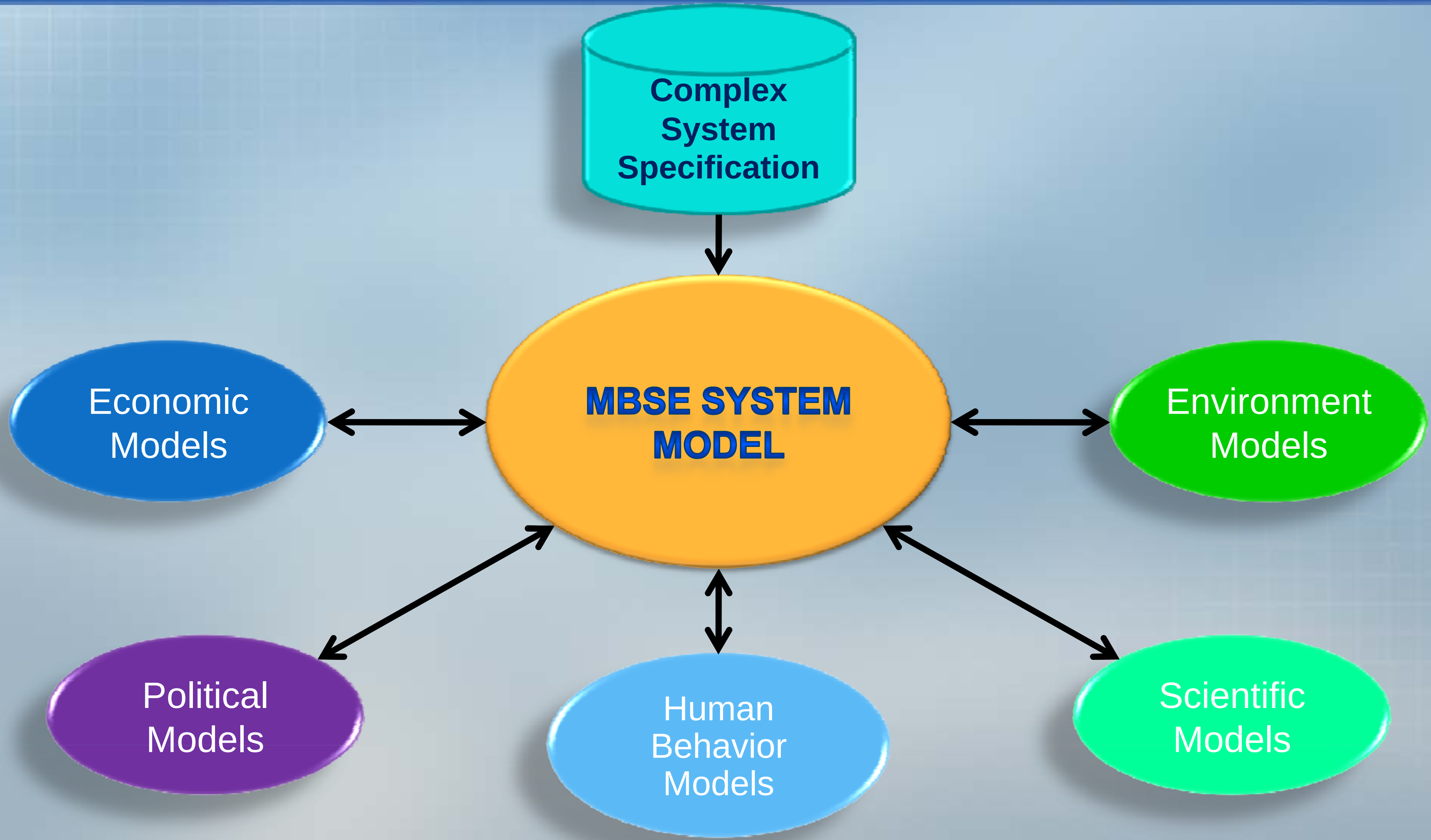
- **The attraction between the worlds of M&S and MBSE is growing stronger as the two move closer together**
- **As stated in the INCOSE State of the Practice – 2020**
  - "MBSE extends to domains beyond engineering to support complex predictive and affects-based modeling that includes integration of engineering models with scientific and phenomenology models, social, economic, political models, and human behavioral models."
  - Modeling standards based on a firm mathematical foundation that support high fidelity simulation and real world representations

Taken from INCOSE 2007 Symposium briefing (http://www.incose.org/enchantment/docs/07docs/07jul_4mbseroadmap.pdf)





The M&S and MBSE Correlation in Complex Systems



The M&S and MBSE Correlation in System Development

Problem Complexity

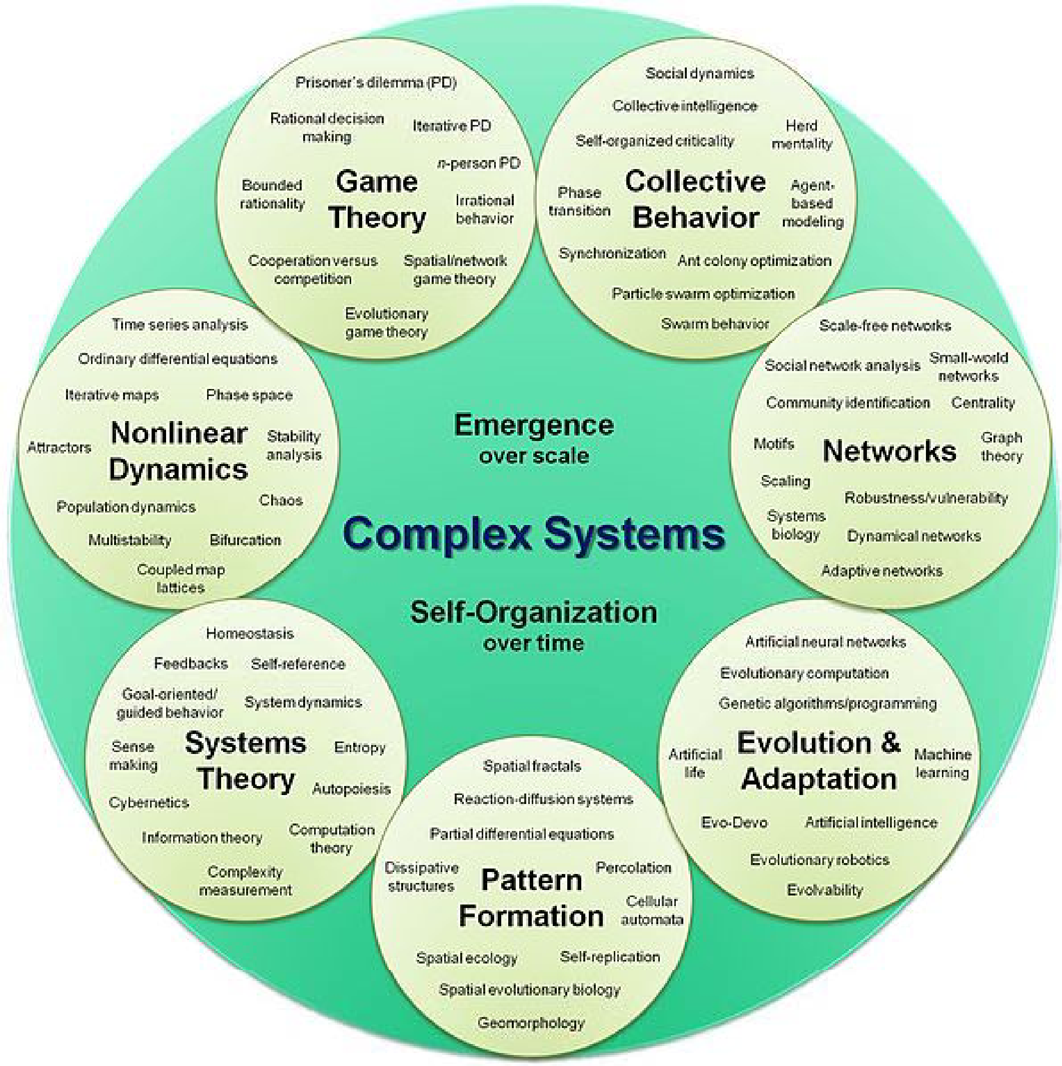
- **"It is generally agreed that increasing complexity is at the heart of the most difficult problems facing today's systems of architecting and engineering." (Rechtin and Maier in "The Art of System Architecting", page 7, 8)** http://web.mit.edu/esd.83/www/notebook/20ViewsComplexity.PDF
- **Some of the forces that are driving complex problems are**
  - Wicked Problems [1]
    - You don't understand the problem until you have developed a solution
    - Wicked problems have no stopping rule
    - Solutions to wicked problems are not right or wrong, simply "better," "worse," "good enough," or "not good enough"
    - Every wicked problem is essentially unique and novel
    - Every solution to a wicked problem is a "one-shot operation"
    - Wicked problems have no given alternative solutions
  - Social Complexity
    - The number of stakeholders involved
    - The diversity of the stakeholders

[1] Rittel, Horst W. J.; Melvin M. Webber (1973). "Dilemmas in a General Theory of Planning"

Types of Problem Complexity

- **Technical**
  - Dynamic Operating Environment (e.g. underwater vehicle)
  - Interface Complexity (e.g. amount of information flow and physical characteristics)
  - Behavioral Complexity
  - Non-deterministic (emergent) Behaviors (e.g. unknown feedback loops)
  - Random / Unpredictable Data
  - Threats (e.g. security, environmental)
- **Programmatic**
  - Dynamic Stakeholder Environment (rapidly changing needs)
  - Threats (e.g. political, funding, regulatory)
  - Technology Changes (e.g. disruptive, end-of-life)
- **Mission**
  - Dynamic Mission Environment (e.g. red/blue force layouts)
  - Threats (e.g. adaptive adversarial capabilities)

System Complexity



Created by Hiroki Sayama, D.Sc., Collective Dynamics of Complex Systems (CoCo) Research Group at Binghamton University, State University of New York

System Complexity

- **Dynamic Complexity**
  - "A system presents dynamic complexity when cause and effect are subtle, over time. (Peter Senge, "The Fifth Discipline")
    - Different behavior in the short term vs. the long term
    - Obvious stimuli produce non-obvious results
  - A system is complex when it is composed of a group of related units (subsystems), for which the degree and nature of the relationships is imperfectly known. (Joseph Sussman, "The New Transportation Faculty")
    - The emergent behavior of the system is difficult to predict, even when subsystem behavior is predictable
      - Small changes in inputs or parameters may produce large changes in behavior

    http://web.mit.edu/esd.83/www/notebook/20ViewsComplexity.PDF
- **Detailed Complexity (Complicated)**
  - A system that is composed of a great number of different parts
    - The system has predictive behavior
    - The relationships between the parts are known

Image credit: Kennedy Space Center

Engineering Tool Complexity

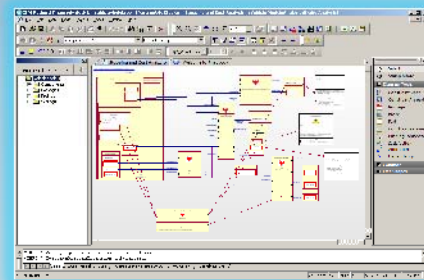
- **New rapid modeling and simulation tools are arriving in the market**
  - Allows realistic models to be quickly built and experimented with
    - Enables the rapid evaluation of alternatives
  - Flexibly interfaces to a wide range of enterprise data typically contained in stovepipes (spreadsheets, data bases, or ERP systems)
  - Goes beyond the traditional use for comparing alternative designs and directly support the use of models within an operational setting
    - Evolving M&S to enhance our everyday business, production, and operational level decisions
  - In some tools, complexity is increasing to better serve our complex solutions
    - Long learning curves
    - Increased need for “glue” code in the models
    - Advances in simulation visualization
- **Tool Integration**
  - Tool interoperability is increasing
  - Common languages are evolving (e.g. xml, XMI, SysML)

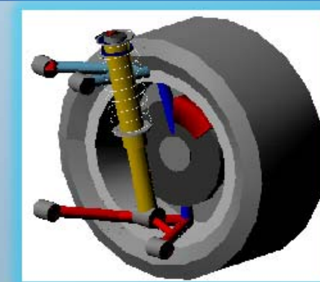
Principles of M&S that can be Applied in MBSE

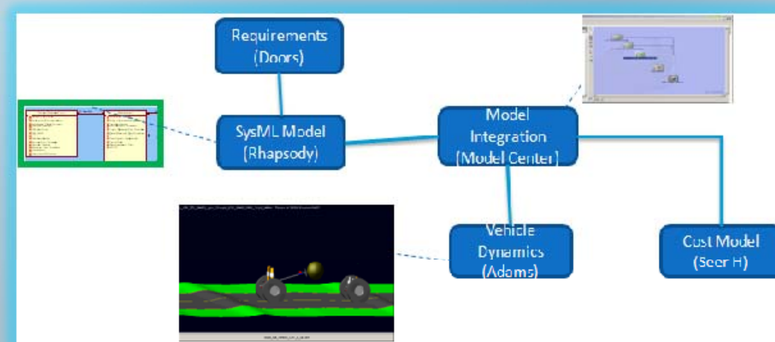
- **Determine the purpose of the system model prior to developing the model**
- **Define which portions of the system model that you need to model, make executable, or simulate**
- **Only model what is necessary**
  - Dependent on how the system model is being used in development
    - Generating code from the system model requires extensive/precise modeling
  - Complex system behaviors and interfaces
  - High technical risk areas
- **Only model the fidelity that meets the intended use**
  - M&S decision making experience applied to MBSE -- How much fidelity is enough?
- **Design system models with loose coupling and high cohesion**
  - Enables better reuse
  - Results in a better architectural design and system performance

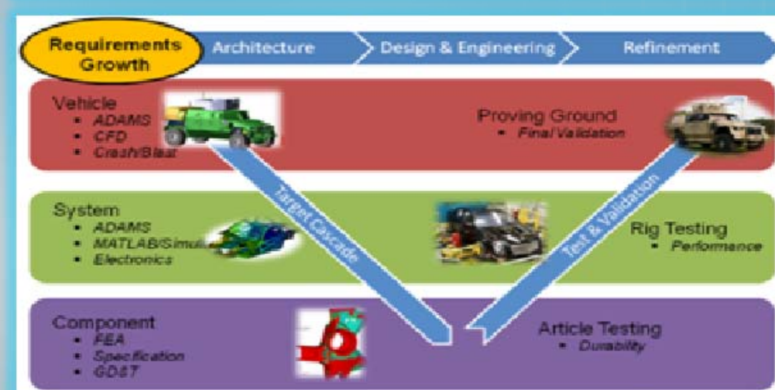
Lockheed Martin Case Study:
SysML Driven Subsystem Optimization

- **Pilot Objective**
  - Elaborate the modeling capability to demonstrate robust integration of requirements, analysis and design
  - Leverage Design of Experimentation techniques to analyze the design trade space
- **Pilot Challenges**
  - Developing a Suspension System that meets ride and handling qualities under the full range of loading conditions at minimum cost and weight
  - Considering conventional, adjustable, active and position dependent shock absorber designs
- **Demonstrated integration of the following tools**
  - Rhapsody, SEER, Matlab, Excel and MSC.Adams using Model Center
- **Focused on verifying an enhanced ability to investigate performance**

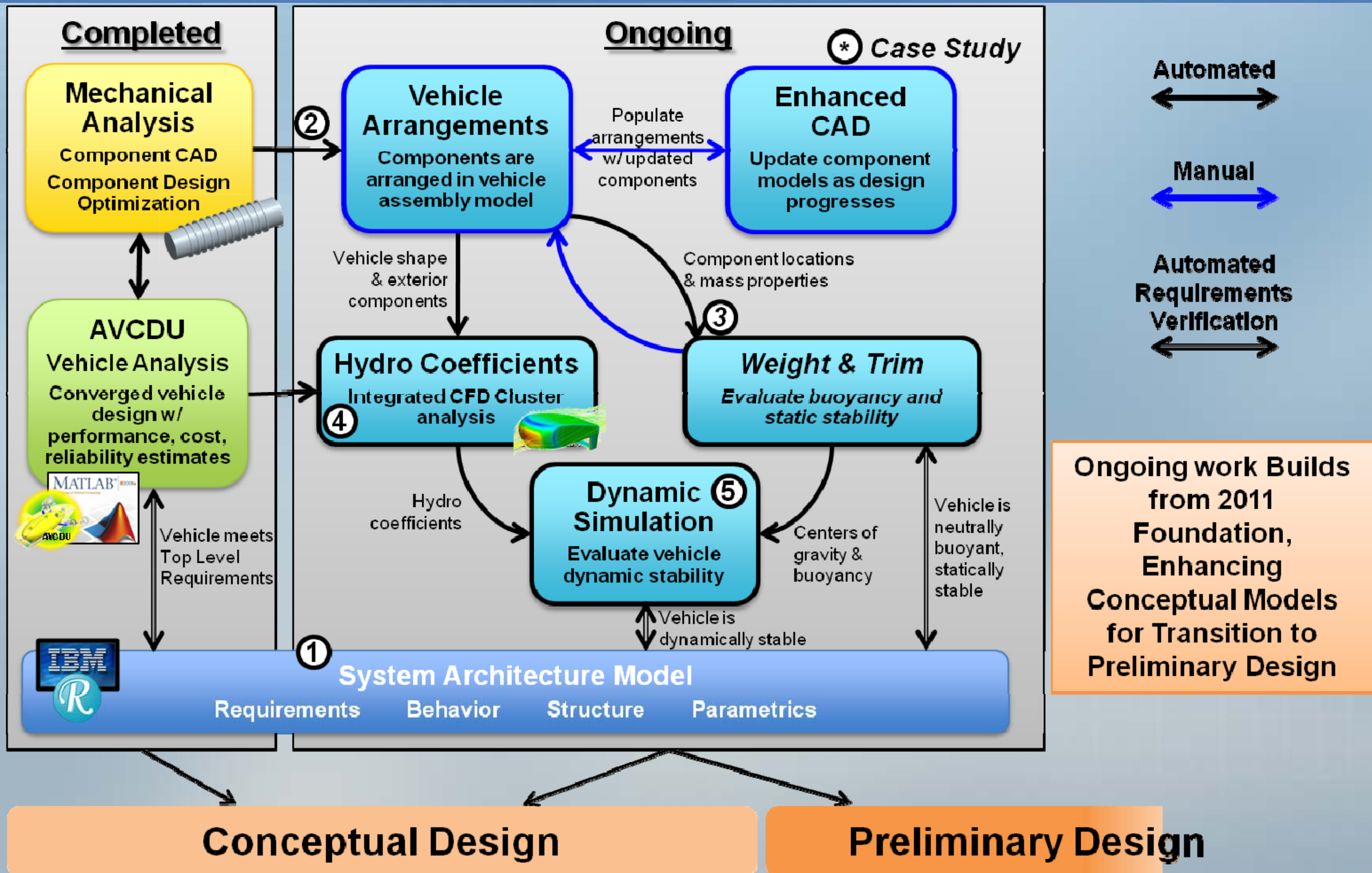








Integrated Analysis for Improved Trades: Conceptual Design through PDR



Conclusion

- **Modeling and simulation is becoming more widely used as the ever increasing complex problems drive more complex solutions**
- **As modeling tools, methods and languages mature, the worlds of M&S and MBSE continue to converge**
- **This convergence drives a need for expertise and proficiency in**
  - The basics: M&S and MBSE
  - The specialties: Tools, Methods, Languages
- **Much of the traditional M&S principles and experiences are transferrable and beneficial to MBSE**

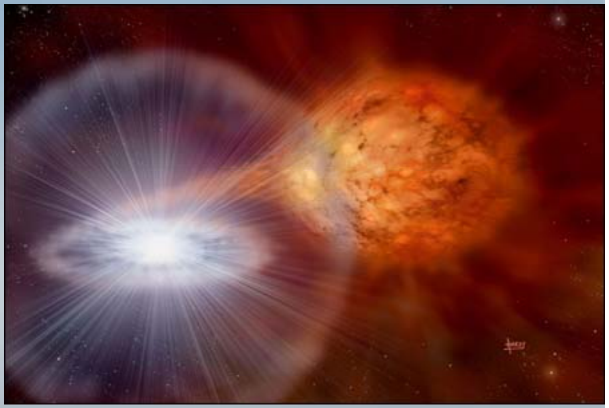


Image Credit: http://www.news.harvard.edu/gazette/2006/07.20/photos/19-supernova-1.jpg

Both worlds are needed for the effective, efficient development of a complex system

Questions and/or Comments?