Model-Based Systems Engineering in an Integrated Environment

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Presented by Kevin Knudsen

System-of-Systems: *An NIE Experience* and The R&D "Use" of Propulsion Vehicles Workshops

Boeing at a Glance

- **Customers and customer support in 150 countries**
  - Total revenue in 2011: $68.7 billion
  - 70 percent of commercial airplane revenue historically from customers outside the United States
- **Manufacturing, service, and technology partnerships with companies around the world**
  - Contracts with 22,000 suppliers and partners globally
- **Research, design, and technology development centers and programs in multiple countries**
- **More than 170,000 Boeing employees in 50 states and 70 countries**

Introduction

- Model-Based Systems Engineering (MBSE) is key to development and sustainment of high-quality integrated systems.
- MBSE can be accomplished in a variety of ways leveraging different modeling techniques, such as SysML, IDEF0, and others.
- Organization and system development characteristics such as product type, lifecycle dependency and complexity, need different approaches to make MBSE attractive.
- The integration and management of product data is critical to MBSE.

This paper identifies the conditions under which different approaches may be most appropriate to realize the full potential of MBSE.

What is MBSE?

- "Model-based systems engineering (MBSE):
  - is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities.
  - begins in the conceptual design phase and continues throughout development and later life cycle phases.
- "In particular, MBSE is expected to replace the document-centric approach that has been practiced by systems engineers in the past and influence the future practice of systems engineering by being fully integrated into the definition of systems engineering processes."

INCOSE Vision 2020 (Reference: "International Council on Systems Engineering, Systems Engineering Vision 2020," INCOSE-TP-2004-004-02, Version/Revision: 2.03, Dated September 2007)

MBSE Elements

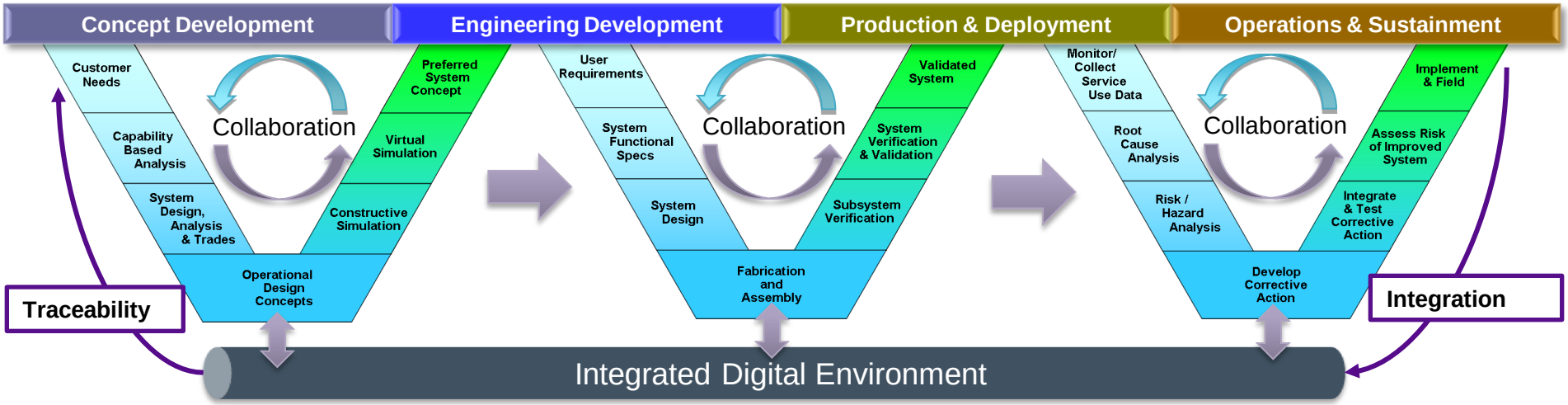
- **Elements of MBSE include:**
  - Operational and system models and simulations, from the concept development phase through disposal.
  - The structure of requirements based on functional components.
  - The organization of requirements into specifications for logical elements.
  - A specification tree that organizes specifications for all logical elements.
  - The definition and control of interfaces.
  - The relationships of requirements and functional/logical elements to the verification and validation artifacts and activities.
  - Integration of these elements with the system design and system performance analyses and trade studies.

System Architecture

- The framework that includes and links these MBSE elements is called a system architecture.
- When the system architecture data (e.g., requirements architecture, functional architecture, logical architecture and their relationships) is contained in an integrated database environment, Boeing refers to this as an Integrated Product Architecture (IPA).
- The use of an integrated database environment results in a single source of information, from which architecture artifacts can be generated as by-products.
- A single source of information contained in an architecture-based integrated database environment is a very effective Model-Based System Engineering approach.

MBSE Across the Lifecycle

- An integrated database approach to MBSE maintains information throughout the product life cycle – ConOps to requirements to design to production…



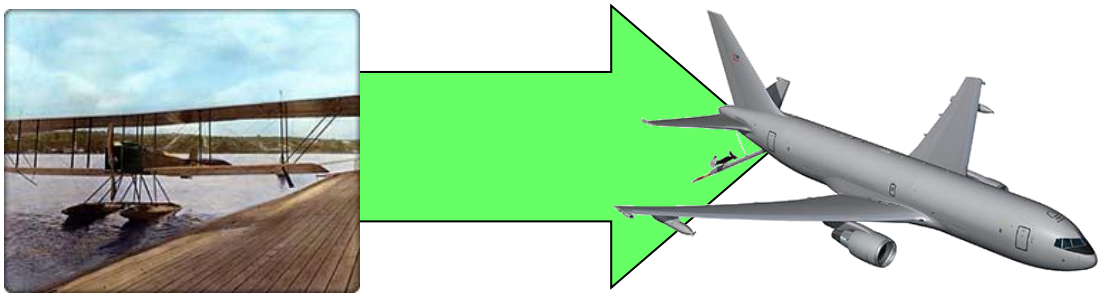
- …providing the ability for more effective downstream performance, logistics, and cost analyses.

Why MBSE now?

- System definitions have moved from simple to highly integrated and complex.
- Customers' drive to open architectures and increased affordability.
- Faster delivery of adaptable, interoperable systems.

Streamlined system engineering and integration, higher design efficiency, and fewer errors in complex design efforts

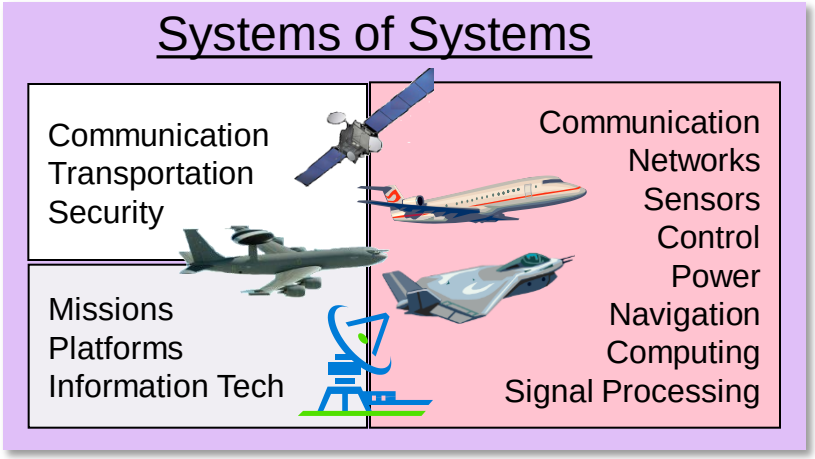
System Definition Evolution

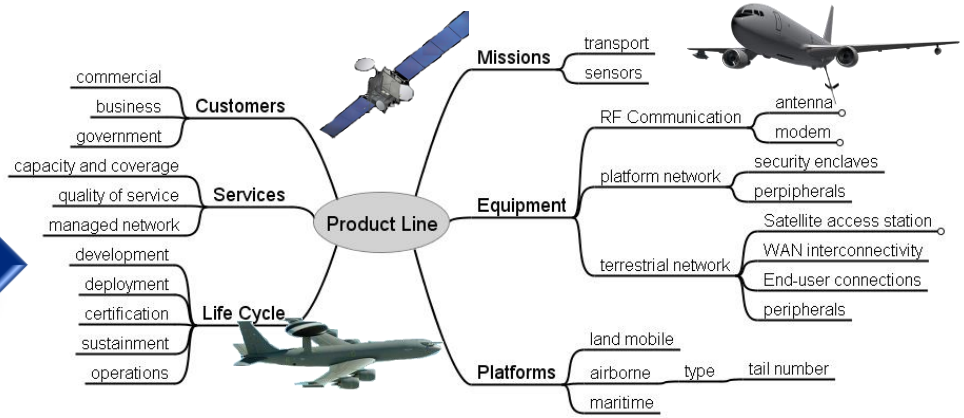


	Federated	Integrated, Distributed
Functional interactions	Isolated, system of subsystems	Strongly interacting subsystems with shared common resources
Interface definition	Functional cohesion, loose coupling	Highly integrated, complex, tightly coupled interfaces
Integration effort	Simpler	More complex functionality
Interconnections	Discrete wiring possible	Highly networked interconnections required
Failure behavior	Causes of failures more transparent	Complicated integrated behavior; causes of failures more “opaque”

MBSE Enables Product Development Needs

- **System of Systems**
  - Multiple system architectures integrated into an SOS architecture
- **Open Architectures**
  - Modular, interchangeable architecture elements to provide best value and interoperability
- **Product Lines**
  - Reuse of architecture elements
  - Affordable systems
  - Consistency and quality across product lines





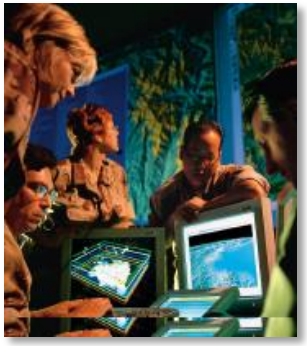
Disciplines Required for MBSE

Organize to support the use of MBSE

- The model is the authority (i.e., not the documents).
- Ensure appropriate access to the data.
- Training, training, training.

Use the model (architecture) to perform Systems Engineering

- Use data elements for functional and operational analysis to derive requirements.
- Use data elements to determine system trade studies to meet evolving needs.
- Derive verification activities from data elements.
- Apply design features directly from the model.
- Generate customer artifacts directly from the model.



Use the data to ensure quality (i.e., “the right design”)

- Query the model early and continuously to identify missing design elements.
- Query the model to prevent overdesign and unnecessary costs.

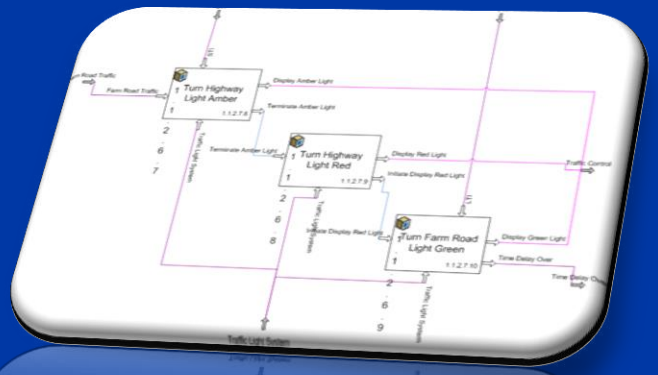
Use the model throughout the entire life cycle

- Share across various development and support organizations.

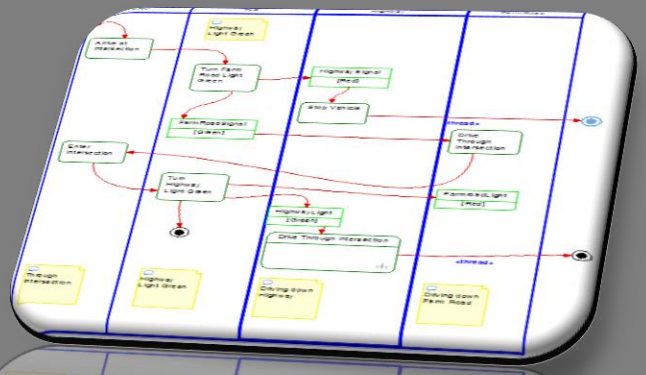
Modeling Processes and Tools Options

Legacy approach : document-based with the aid of a requirements tool, where information is textual and manually integrated by the user.

An MBSE approach using structured analysis in an integrated environment with an associated tool, e.g., Siemens Teamcenter® for Systems Engineering (TcSE)



An MBSE approach using Systems Modeling Language (SysML) with an associated tool, e.g., IBM® Rational® Rhapsody®



Evaluation Criteria for Successful MBSE

Effectiveness

- Model precision
- Model semantics
- Data queries
- Configuration and change management

Data Type and Quantity Needs

- Integration complexity
- Size limits

Organization Suitability

- Business rules
- Organization process compatibility
- Skill compatibility

Modeling Alternative Evaluation (1/2)

	MBSE Methodology Approach		
Criterion	**Traditional SE (non-MBSE)**	**MBSE using SysML**	**MBSE using Structured Analysis/Integrated Environment**
Model Precision	• Low – separate requirements management tool, independent diagrams	• Inherently high	• Can be high (depends on meta-model)
Model Semantics	• Loosely defined set of customizable semantics	• Integrated, complex but defined set of extensible semantics	• Customizable semantics (depends on meta-model)
Business Rules	• Process-enforced	• Tool-aided	• Tool-aided • Enforces standardized use of processes
Process Compatibility	• Consistent with IEEE 1220 language	• Less Consistent with IEEE 1220 language	• Consistent with IEEE 1220 language
Skill Compatibility	• Consistent with engineering skills	• Adaption of SW-based methods can be a steep learning curve for systems engineers (Eisenmann, et al., 2009)	• Consistent with engineering skill base

Modeling Alternative Evaluation (2/2)

	MBSE Implementation Approach		
Criterion	**Traditional SE (non-MBSE)**	**MBSE using SysML tool**	**MBSE using Structured Analysis/ Integrated Environment tool**
Integration Complexity	• No integrated data • Engineers tend to work independently; federated tools and data do not enforce integration	• Integrated model, not necessarily integrated to other data • May not be a database, but a single file accessible to a single user; each model enforces internal cohesion and integration among users	• All SE data integrated in one database • Multiuser distributed environment • Web-based client-server architecture
Size Limits	• Management problem with large data sets	• Models limited in size by local memory	• Effectively unlimited model size
Data Queries	• Not possible across architecture views	• Complex queries require coding	• Query Wizard supports complex queries
Configuration and Change Management	• Manual development and integration • Document- based • Copy for variants	• Accommodates check-out/check-in, branch, merge • Model-level management; synchronization dependent on check-in	• All SE data managed in single database • Residual risk of data overwrite without check-out or process control • Object-level management; immediate synchronization is possible

Benefits of MBSE in an Integrated Environment

PROVIDING A NETWORKED ENVIRONMENT TO FULFILL CUSTOMER GOALS

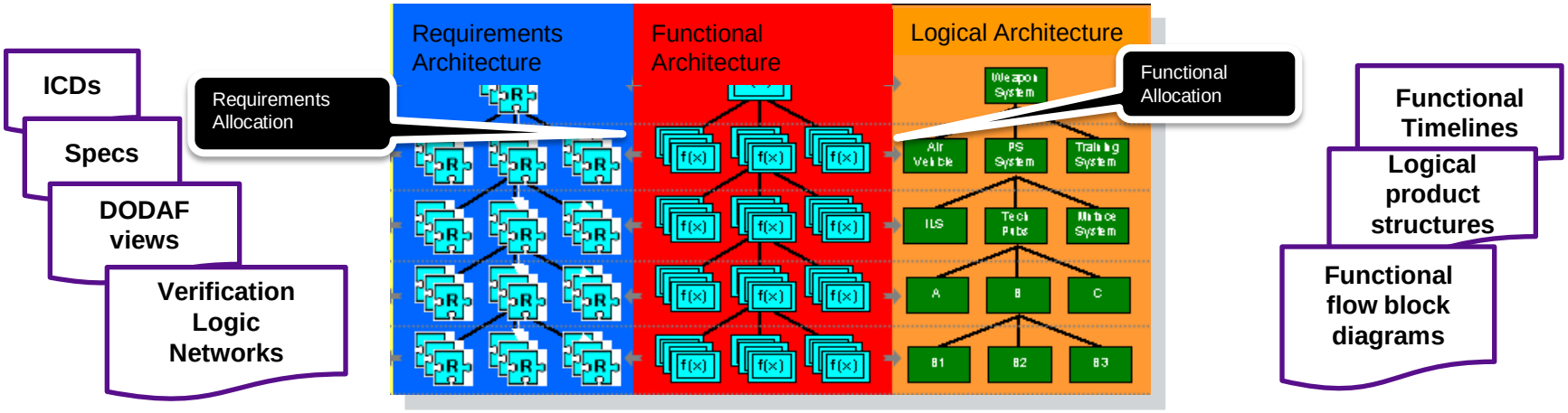
- Single data environment ensures completeness and consistency of design data.
- Rich database permits multiuser input and immediate synchronization, improving efficiency and productivity.
- Use of a single data environment results in data availability throughout program life cycles.
- Traceability through model elements enables efficient change and impact analysis, enabling a more adaptable system.
- Robust query engine allows rapid assessment of the integrated database, finding anomalies early, preventing rework.

Additional Thoughts when Applying MBSE in an Integrated Database Environment

- Model semantics must be defined and controlled to align with organization processes.
- Multiuser effects and data configuration control must be managed.
- Various representation formats; e.g., SysML and DODAF artifacts can be incorporated into the integrated environment.

Integrated Product Architectures at The Boeing Company

- IPA is an enterprise effort to develop and deploy a common capability, enabling Boeing engineers to integrate requirements, architectures, and analyses.
- IPA uses an MBSE approach in an integrated data environment.
- The Integrated environment architectures enable consistent, seamless generation of SE artifacts, and enables more effective system trades.



Architecture data captured and managed in a single data environment ensures product quality and enables affordability.

MBSE at Boeing - Now and in the Future

Boeing has had success in implementing Model Based Systems Engineering on a variety of product development efforts

Success = improved program cost and schedule impacts

- Comprehensive integrated architectures resulted in a significant reduction in interface definition changes after initial design.
- Detailed functional architectures resulted in reductions of actual program test hours.
- MBSE used for early identification of system performance impacts, resulting in a more effective network performance.
- Potential design issues were identified early in the life cycle.

As we continue to evolve with more complex systems, Boeing is moving forward in the development and application of MBSE capabilities and approaches.

Thank You!