

Transitioning Systems Engineering to a Model-based Discipline

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Systems engineers have always leveraged many kinds of models, including functional models to support requirements development, simulation models to analyze the behavior of systems, and other analytical models to analyze various aspects of the system such as reliability, safety, mass properties, power consumption, and cost. However, the discipline still relies heavily on document-based artifacts to capture much of the system specification and design information, such as requirements, interface control documentation, and system architecture design descriptions. This information is often spread across many different documents including text, informal drawings, and spreadsheets. This document-based approach to systems engineering suffers from a lack of precision, inconsistencies from one artifact to another, and difficulties in maintaining and reusing the information.



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Model-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 through development and later life cycle phases (INCOSE 2007). A distinguishing characteristic of an MBSE approach is that the model constitutes a primary artifact of the systems engineering process. The focus on developing, managing and controlling a model of the system is a shift from the traditional document-based approach to systems engineering, where the emphasis is on producing and controlling documentation about the system. By leveraging the system model as a primary artifact, MBSE offers the potential to enhance product quality, enhance reuse of the system modeling artifacts, and improve communications among the systems development team. This, in turn, offers the potential to reduce the time and cost to integrate and test the system, and significantly reduce cost, schedule, and risks in fielding a system.

MBSE includes a diverse set of descriptive and analytical models that can be applied throughout the life cycle, and from system of systems (SoS) modeling down to component modeling. Typical models may include descriptive models of the system architecture that are used to specify and design the system, and analytical models to analyze system performance, physical characteristics, and other quality characteristics such as reliability, maintainability, safety, and cost.

MBSE has been evolving for many years. The term MBSE was used by Wayne Wymore in his book by this name (Wymore 1993), that provided a state-based formalism for analyzing systems in terms of their input/output characteristics, and value functions for assessing utility of technology independent and technology dependent systems. Simulations have been extensively used across industry to provide high fidelity performance analysis of complex systems. The Standard for Integration Definition for Function Modeling (IDEF0 1993) was introduced in the 1990's to support basic functional modeling. A modeling formalism called the enhanced functional flow block diagram (Long 2000) has been used to model many different types of systems. The Object Management Group (OMG) introduced the concept of a Model Driven Architecture (MDA®) (OMG 2003) that leverages a standards-based approach to modeling. The Systems Modeling Language (OMG SysML™) (OMG 2015) was adopted by the OMG in 2006 as a general-purpose systems modeling language. In addition, the Unified Profile for DoDAF and MODAF (UPDM) (OMG 2013) was adopted by the OMG in 2008

to support enterprise modeling. Several other domain specific modeling languages have been introduced as well.

MBSE Transition

The INCOSE Systems Engineering Vision 2025 (INCOSE 2025, pg 38) describes the current state of MBSE as follows: “Model-based systems engineering has grown in popularity as a way to deal with the limitations of document-based approaches, but is still in an early stage of maturity similar to the early days of CAD/CAE.”

SE Vision 2025 also describes a continuing transition of SE to a model-based discipline in which: “Formal systems modeling is standard practice for specifying, analyzing, designing, and verifying systems, and is fully integrated with other engineering models. System models are adapted to the application domain, and include a broad spectrum of models for representing all aspects of systems. The use of internet driven knowledge representation and immersive technologies enable highly efficient and shared human understanding of systems in a virtual environment that span the full life cycle from concept through development, manufacturing, operations, and support.” The transition to a more model-based discipline is not without its challenges. This requires both advancements in the practice, and the need to achieve more widespread adoption of MBSE within organizations across industry sectors.

The INCOSE Systems Engineering Vision 2035 (INCOSE 2035, pg 33) states that "The Future of Systems Engineering Is Predominantly Model-Based". Further discussion goes on to project that "Systems engineers routinely compose task-specific virtual models using ontologically linked, digital twin-based model-assets. These connected models are updated in real-time providing a virtual reality-based, immersive design and exploration space. This virtual global collaboration space is cloud- based, enabled by modelling as a service and supports massive simulation leveraging cloud-based high-capacity compute infrastructure. Families of unified ModSim frameworks exist enabling small and medium businesses along with Government agencies to collaborate."

Advancing the practice requires improvements in the modeling languages, methods, and tools. The modeling languages must continue to improve in terms of their expressiveness, precision, and usability. MBSE methods, such as those highlighted in A Survey of Model-Based

Systems Engineering (MBSE) Methodologies (Estefan 2008), have continued to evolve, but require further advancements to provide a rigorous approach to modeling a system across the full system lifecycle, while being more adaptable to a diverse range of application domains. The modeling tools must also continue to evolve to support the modeling languages and methods, and to integrate with other multi-disciplinary engineering models and tools in support of the broader model-based engineering effort. The movement towards increased use of modeling standards, that are more widely available in commercial tools, and rigorous model-based methodologies, increase the promise of MBSE.

The adoption of MBSE requires a workforce that is skilled in the application of MBSE. This requires organizations to provide an infrastructure that includes MBSE methods, tools, and training, and a commitment to deploy this capability to their programs. As with any organizational change, this must be approached strategically to grow this capability and learn from their experiences.

Like other engineering disciplines, the transition of systems engineering to a model-based discipline is broadly recognized as essential to meet the challenges associated with increasing system complexity and achieving the productivity and quality improvements. The SEBoK will continue to reflect the growing body of knowledge to facilitate this transition.

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