THE INTERNATIONAL ASSOCIATION FOR THE ENGINEERING MODELLING, ANALYSIS AND SIMULATION COMMUNITY

THE INTERNATIONAL COUNCIL ON SYSTEMS ENGINEERING



# What is

# Systems Modeling and Simulation?

# What is Systems Modeling and Simulation (SMS)?

Business growth depends on developing new and improved products and technologies, and getting these to the market ahead of the competition. The digitalization of our lives today is driving an ever faster-paced environment. Developing products based on skills and capability in specific engineering domains is no longer sufficient. The demand for system-level solutions is driving a need to merge systems engineering and engineering simulation at a new level.

Systems Modeling and Simulation relies on an integrated use of engineering models to fill this need. Following is a basic definition:

> **Systems Modeling and Simulation:** The use of interdisciplinary functional, architectural, and behavioral models (with physical, mathematical, and logical representations) in performing MBSE to specify, conceptualize, design, analyze, verify and validate an organized set of components, subsystems, systems, and processes [1].

The International Council on Systems Engineering (INCOSE) defines Model-Based Systems Engineering (MBSE) as the formalized application of modelling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later lifecycle phases. The emphasis of MBSE is on leveraging virtual representations of a system to support the various engineering and business activities throughout the lifecycle of a product [2].

## Modeling and Simulation

Modeling is the act of building a physical or digital model that represents an entity of interest (a system). A simulation is the process of using a model to predict and study the behavior or performance of the system or process in question. One purpose of a simulation is to study the operational characteristics of a system by manipulating variables associated with the model that are not easily controlled in the real system. This approach provides data that supports technical and business decision-making to optimize a product and its performance without actually testing the system in the real world. It should be noted that the two words (modeling and simulation) are sometimes used interchangeably; however, they clearly refer to two distinct activities.

Systems Engineering has recognized the importance of models in a wide range of roles. Early in the development of a system, models may be used to understand the user domain, to define functions and concepts, and to capture system requirements across the levels of a system architecture. Such models may specify functional, interface, performance, and physical requirements, as well as other nonfunctional requirements such as reliability, maintainability, safety, and security.

Engineering Simulation has been an essential part of product development engineering across many industries and disciplines for decades. This work is typically performed by technical specialists with deep knowledge in their respective domains, and with expertise in specialized mathematical and analytical tools. A definition of Engineering Simulation is the use of numerical, physical or logical models of systems and scientific problems in predicting their response to different physical conditions [3].

The use of engineering simulation is being driven by the increasing sophistication of models and tools to predict a wide range of physical phenomena. Many kinds of analysis are highly mature, from analysis of physical structures to computational fluid dynamics to dynamic system behavior. Increasingly, such models can be integrated across physical domains at multiple scales and levels of fidelity, and with software and controls that drive dynamic behavior. Growth in engineering simulation is also being driven by the increasing availability and affordability of high-performance computing, through both local and cloud-based forms of parallel computing.

## Benefits of Systems Modeling and Simulation

Product development is a collaborative activity across organizational processes and development responsibilities. Combining the modeling and simulation perspectives of both Systems Engineering and Engineering Simulation can improve communications and coordination across the product development lifecycle. Figure 1 illustrates the use of a central hub of MBSE models to integrate many specialized technical disciplines in a model-centric approach to product development.

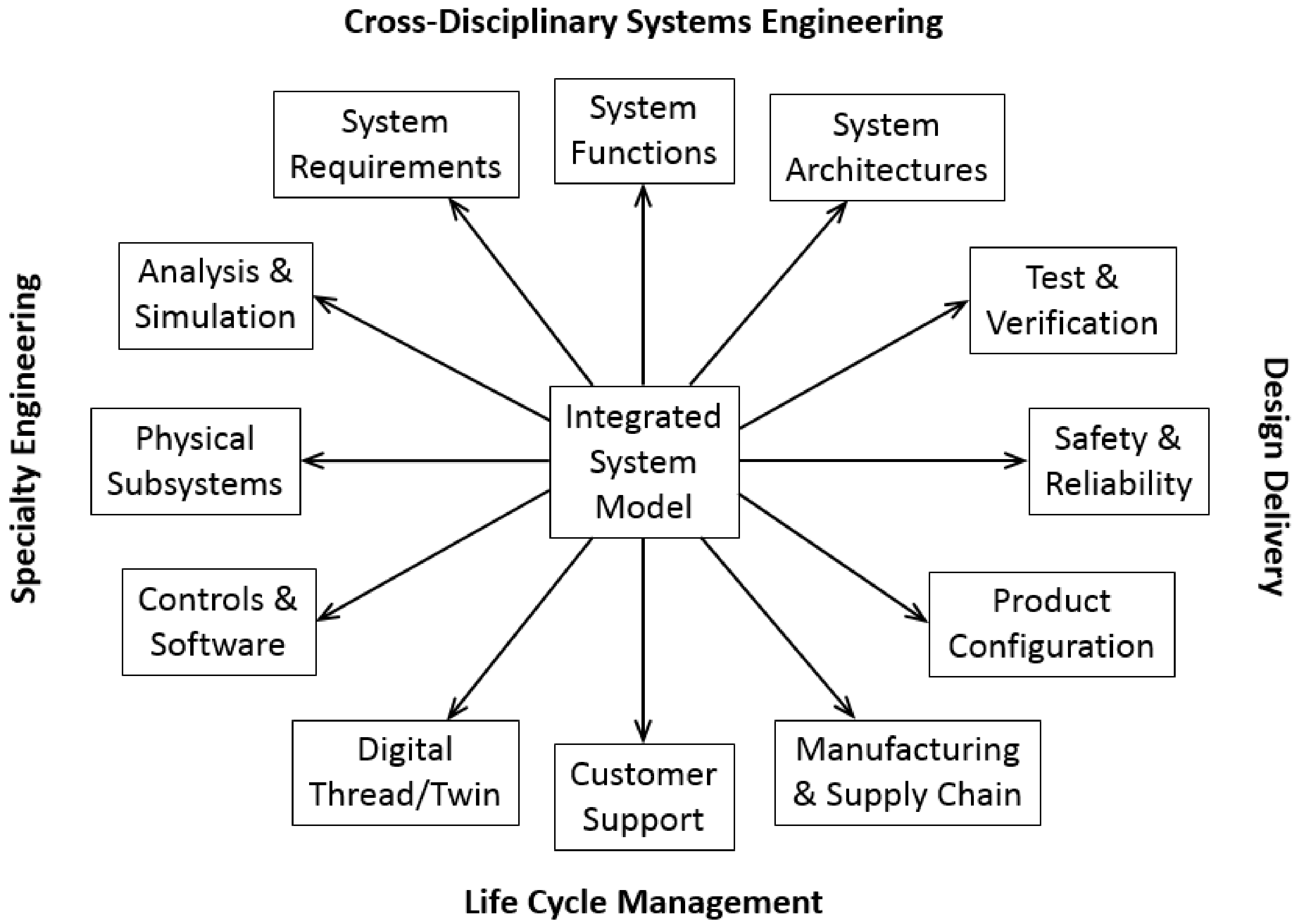


**Figure 1. Model-based integration across multiple technical disciplines.**

Integrating the models of MBSE and engineering simulation offers significant advantages to both communities. Systems engineering typically relies on a progression of models from requirements to functions to logical architectures that emphasize the problems to be solved rather than committing prematurely to particular solutions. Engineering simulation relies on predictive models to complete more detailed analysis, optimization, and verification of specific designs.

Requirements come from the customer, knowledge of the industry, and internal business objectives. Requirements are always changing, and as such need to be actively managed and propagated continuously throughout a program over its entire life cycle. Functions specify what a system must do to satisfy the requirements. At the functional level, there is no commitment on how a function is to be accomplished, only that it must be performed to meet the program requirements. The decomposed functions can then be allocated to the elements of proposed solutions, and to their corresponding engineering disciplines, to create and apply a variety of architectural models. MBSE recognizes that all these kinds of specifications can be captured in formalized models, even when this information is purely descriptive.

Once proposed solutions are sufficiently detailed, a further step is the creation of engineering models that are comprised of mathematical and physical descriptions of the system. These models could include the CAD geometry of each component in an assembly, as well as the system response characterized, for example, by FEA, CFD, or dynamic system models, and possibly enhanced with software and control logic.

For technical specialists who develop and verify detailed designs of subsystems and components, systems engineering can offer clear boundaries of problems to be solved without overly constraining the freedom of possible designs. Both systems engineers and designers can explore combinations of technologies and solutions that map to capabilities of a system in effective and flexible ways. As systems engineering becomes more widely adopted for the development of complex products, larger numbers of discipline-specific engineers will need a basic familiarity and literacy of MBSE models to integrate their work into a larger whole.

System engineers will need to develop a familiarity with a wide variety of system simulation capabilities, including those of engineering simulation. An early reliance on simulation can enable agile approaches in which prototypes and visualizations contribute to elicitation and refinement of expectations and alternatives in collaboration with system stakeholders. Simulation throughout the product lifecycle can reduce risk, more thoroughly explore alternative solutions, and reduce costs over physical testing.

The Systems Engineering Vee Diagram is widely used to depict the process of decomposing a system into subsystems and then validating the successful integration of partial solutions back into the larger whole. Figure 2 illustrates how simulation can contribute to rapid iteration at each stage in this process.

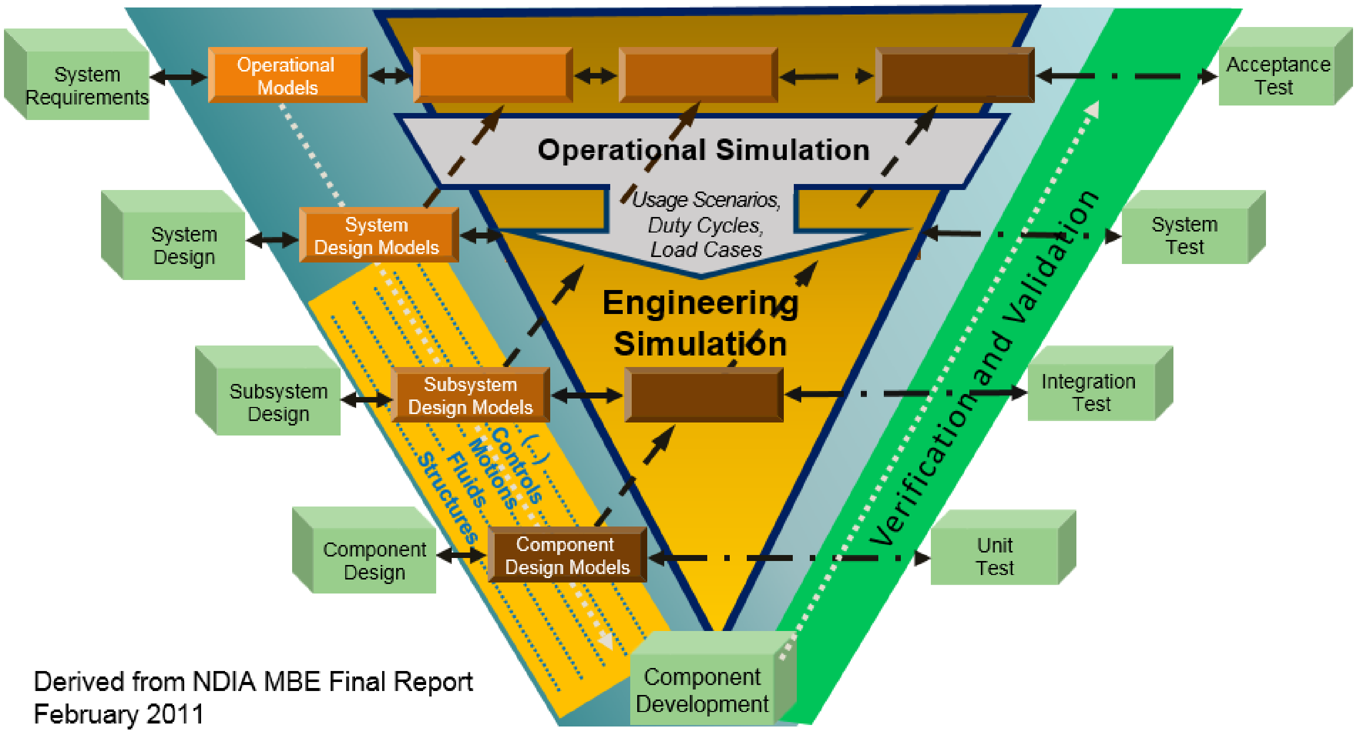


**Figure 2. Iterative product development with systems engineering and simulation.**

Systems Engineering encourages the use of modeling and simulation throughout the early stages of the specification and development of a system [4]. At these early stages, simulation can provide a means to analyze complex dynamic behavior of systems, software, hardware, people, and physical phenomena. These early-stage simulations may take many different forms, such as agent-based, discrete-behavior, stochastic, and interactive simulations, and the integration of many such simulations may occur [5].

These operational simulations of a system can provide key inputs to the purely physical layers of a system. Data specific to different usage scenarios and operating conditions can be fed into engineering simulations of physical structures and components. Duty cycles from either requirements or other simulations can provide time histories of loads and other boundary conditions. At the physical layers, coupling of simulations across multiple kinds of physics, and at different scales and levels of fidelity, may be required for detailed analysis, and to optimize designs across multiple alternatives.

## Systems Modeling and Simulation Working Group (SMSWG)

To explore the benefits of Systems Modeling and Simulation, and to promote specific technologies, practices, and standards which enable them, NAFEMS, the International Association for the Engineering Modelling, Analysis and Simulation Community, and INCOSE, the International Council for Systems Engineering, launched a joint working group on Systems Modeling and Simulation under an Memorandum of Understanding in 2012.

The mission of the NAFEMS / INCOSE Systems Modeling & Simulation Working Group (SMSWG) is to develop a vendor-neutral, end-user driven consortium that not only promotes the advancement of the technology and practices associated with integration of engineering simulation and systems engineering, but also act as an advisory body to drive a strategic direction for technology development and standards in the space of complex engineering.

The Further Reading links below serve as a living document to cover more detailed activities and focus areas of the SMSWG in support of Systems Modeling and Simulation.

## Further Reading

Home page for NAFEMS-INCOSE Systems Modeling and Simulation WG at NAFEMS: https://www.nafems.org/about/technical-working-groups/systems_modeling/

Home page for NAFEMS-INCOSE Systems Modeling and Simulation WG at INCOSE: http://wiki.omg.org/MBSE/doku.php?id=mbse:smswg

## References


[1] https://www.nafems.org/about/technical-working-groups/systems_modeling/smstermsdefinitions
[2] http://wiki.omg.org/MBSE
[3] https://www.nafems.org/publications/glossary
[4] https://www.sebokwiki.org/wiki/Representing_Systems_with_Models
[5] https://www.sebokwiki.org/wiki/Types_of_Models