INCOSE International Council on Systems Engineering

www.incose.org

NAFEMS

www.nafems.org

Systems Modeling & Simulation (SMS) Working Group

MBSE:	*Systems Modeling and Simulation:*	*Engineering Simulation:*
The formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.	*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.*	*The use of physics-based mathematical (numerical) models and/or logical models, including relevant data derived from their physical model counterparts, as representations of a conceptual or real-world system, phenomenon, or process in studying its technical requirements and operational behaviour.*

SMSWG – Terms & Definitions: https://www.nafems.org/about/technical-working-groups/systems_modeling/smstermsdefinitions/s-u/

Systems Modeling & Simulation WG supporting INCOSE – NAFEMS collaboration

History

- 2011 agreement to develop a collaborative relationship that benefits both organizations
- Joint MoU signed at INCOSE International Symposium in 2012 and announcement to form the INCOSE/NAFEMS SMSWG
- SMSWG launched in 2013 with founding steering committee to promote membership
- Joint MoU renewed at NAFEMS World Congress in 2019 alongside special “Systems Engineering meets Engineering Simulation” session
- 2020 & 2021 : Common INCOSE Charter & NAFEMS Terms of Reference refreshed for SMSWG

Collaboration

- Mutual recognition of the certifications offered by each organisation
- Promotion of joint collaborative products and opportunities for members to participate in each organisation’s activities
- Mutual support for specific events of each organisation
  - E.g. NAFEMS sponsorship at INCOSE IS 2021 and IW 2022
  - E.g. INCOSE sponsorship at NWC 2021 + dedicated sessions

MEMORANDUM OF UNDERSTANDING
Between
NAFEMS and International Council on Systems Engineering

THIS MEMORANDUM OF UNDERSTANDING ("MOU") is made this 19th day of June, 2019, by and between NAFEMS, an independent organization representing the engineering simulation community with offices at 46 Campbell Street, Hamilton ML3 6AS, United Kingdom, and the International Council on Systems Engineering (INCOSE), with offices at 7670 Opportunity Road, Suite 220, San Diego, CA 92111, henceforth known as the “Parties.” It sets forth the relationship and obligations for NAFEMS and INCOSE relating to mutual participation and collaboration.

1. **PURPOSE:** This MOU is intended to promote a collaborative relationship in related professional areas that are of mutual interest and benefit to INCOSE and NAFEMS. INCOSE and NAFEMS wish to develop and promote best practice processes and guidance, training, and supporting materials that can be used in projects and organizations in the field of "Systems Modeling and Simulation." This agreement is intended to formalize the working relationship and arrangements.

2. **BACKGROUND:**

NAFEMS is the International Association for the Engineering Modelling, Analysis and Simulation Community. It is a not-for-profit organization which was established in 1983.

INCOSE is a non-profit membership organization, dedicated to advancing interdisciplinary principles and practices that enable the realization of successful systems.

It is the express purpose of the signatory organizations to support processes that provide customers with systems that perform optimally and are affordable. By joining efforts, the signatory organizations facilitate the exchange and further development of their knowledge and best practices towards comprehensive integration into the design and operation of successful systems.

3. **SCOPE AND OBJECTIVES:** The Parties will each appoint personnel to explore collaboration opportunities and propose specific objectives on what each party will pursue and how the collaborative efforts will be handled. The *potential* scope for partnering includes, but is not limited to:

a. Promotion opportunities at one another’s annual meetings and symposia.
b. Adoption of a policy permitting one organization’s members to join and participate in the technical or working groups of the other organization for a nominal annual fee, without requiring dual society-level membership; thereby facilitating opportunities for cross-talk among practitioners of the two organizations. This may include preferential access to the other organization’s products or other IP.
c. Facilitation of opportunities for joint collaborative publications, tutorials, presentations, and development/improvement of processes, methods, guidance and tools; plus co-marketing of any joint products, public relations and communications about the nature of the relationship, and sharing of initiatives or projects of potential interest to the Parties’ members.

All joint and collaborative opportunities and products will meet the necessary reviews of each of the Parties as prescribed by their respective policies. The embodiment of the cooperative relationship will comprise the specific recommendations in Addendum A, which will be kept up to date as the partnership and its objectives evolve.

4. **OWNERSHIP:** The Parties agree and acknowledge that NAFEMS is the exclusive owner of all rights, title and interest throughout the world to the name NAFEMS; and that INCOSE is the exclusive owner of all rights, title and interest throughout the world to the name INCOSE: including, and without being limited to, all rights in the

SMSWG Purpose & Mission

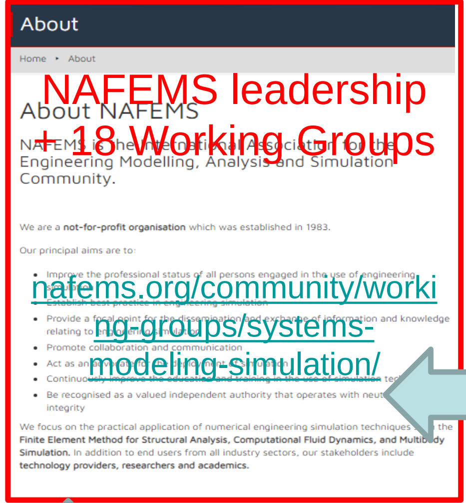
Purpose

- **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 non-functional 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.
- **Combining the Modelling and Simulation perspectives of both Systems Engineering and Engineering Simulation can improve communications and coordination across the product development life cycle.**

Mission & Goal

- 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 acts as the advisory body to drive strategic direction for **technology development and international standards** in the space of complex engineering.
- **The SMSWG supports activities that bridge engineering simulation and systems engineering to optimize the integration of Systems Engineering and Engineering Simulation solutions for both OEM and supplier. This includes education, communication, promotion of international standards, and development of requirements that will have general benefits to the Engineering Simulation and Systems Engineering communities.**

SMSWG organisation (2022)



NAFEMS leadership
+ 18 Working Groups

nafems.org/community/working-groups/systems-modeling-simulation/

Collaboration MoU

+ SMSWG Charter / ToR

www.incose.org/incose-member-resources/working-groups/transformational/incose-nafems-collaboration

INCOSE leadership
+ >50 Working Groups

SMS WG Members

- Roger Burkhart | INCOSE
- **Ron Carson | INCOSE Relationship Manager for NAFEMS**
- **Peter Coleman | Airbus (Chair)**
- Hans Peter de Koning | DEKonsult
- Rodney Dreisbach | NAFEMS Technical Fellow
- Greg Garstecki | Garstecki Modeling Solutions
- David Kaslow | DEKaslow Consulting
- Edward Ladzinski | SMS_Thinktank
- Eric Landel | IRT SystemX / ELC
- Phyllis Marbach | INCOSE Assistant Director Transformational Enablers
- Frank Popielas | SMS_Thinktank (Vice Chair)
- Ian Symington | NAFEMS Technical Officer
- Don Tolle | CIMData
- Hubertus Tummescheit | Modelon
- Mark Williams | The Boeing Company

+

- Trudy Hoye | NAFEMS TWG manager

Focus Team
Roadmap & Best Practices
Frank Popielas ++

Focus Team
SMS Standards Ecosystem
HP de Koning ++

Focus Team
Terms & Definitions
G Garstecki ++

Focus Team
SE Handbook 5E MA&S
HP de Koning ++

Focus Team
SMS Models & Metadata
P Coleman ++

Affiliated
AFIS-NAFEMS SMSWG
Eric Landel ++

SMS Community

Open to all INCOSE or NAFEMS

396 members (Oct'21)

* 331 NAFEMS
* 36 INCOSE
* 29 both NAFEMS & INCOSE

215 different organisations

30 different countries

- Americas = 40%
- Europe = 49%
- Asia = 8%
- Rest of the world = 3%

2020 retrospective

January – incose.org/iw2020
IW MBSE wshop + SMS#35

- **Recap NWC'19**
- **Focus Teams updates**
- **Standards session**

March - SMS#36

- **SMSWG ToR / Charter update**
- **Model Characterization Pattern (MCP)** - Bill Schindel (ICTT)

June – SMS#37

- CAASE20 overview
- **Digital Twin Maturity & Impact** – Frank Popielas (SMS_ThinkTank)

June – nafems.org/caase20
Advancing Analysis & Simulation in Engineering

- SMSWG – Frank Popielas
- Inc. tracks on SMS & MBE

July – SMS#38

- **Coherent Digital Thread as enabler for Systems Thinking** - M.Panthaki (Aras) + R.Mottola (Toyota)

September – SMS#39

- **SE driven M&S method** – Pascal Paper (Airbus)

October – SMS#40

- **LOTAR for MBSE Data + How MoSSEC (STEP AP243) supports model-based collaboration** - Adrian Murton (Airbus)

November – SMS#41

- **Progress on SysML v2** – HP de Koning (DEKonsult)

December – SMS#42

- **Model Identity Card (MIC)** – Eric Landel (IRT SystemX / ELC)

WG#01 WG#02 WG#03 WG#04 WG#05 WG#06

SEH-E5 4.2 M&S

2021 retrospective

January
incose.org/iw2021
IW MBSE wshop + SMS#43

- **SMSWG & Focus Teams updates**
- **SMS related Standards session – MoSSEC, LOTAR MBSE, FMI** – Members of SMSWG

March

- SMS#44 - **The role of analytical models in decomposing requirements** – G.Garstecki (GMS)

April

- SMS#45 - **AI led Digital Twin** - Vijay Balu (Hinduja Tech Limited)

May

- SMS#46 - **Continuing and Higher Education to Promote Simulation and Modeling** - E.Nutwell (SIMCenter, Ohio State University)

July

- SMS#47
- **INCOSE / NAFEMS Collaboration & SMSWG Update** – P.Coleman (Airbus)
- **SMS Community on the NAFEMS Website** – I.Symington (NAFEMS)
- **Systems Engineering Tools Database** - S.Lacrampe (INCOSE) & R.King (PPI) - SETDB WG

September

- SMS#48 - **Model-Based Requirement Specifications – A New Approach** – G.Schilling (Visioneer)

October

- SMS#49 - **Model-Based Engineering: Advanced MBD and QIF** – N.Akhadkar (Schneider Electric), D.Campbell (Capvidia)

NWC21 - nafems.org/congress

- **Connecting Two Worlds through Leadership: NAFEMS-INCOSE Partnership** – R.Carson & INCOSE / NAFEMS Panel
- **SMSWG Session** – P.Coleman & Members of SMSWG

November

- SMS#50 - **Open discussion - Interoperability of tools / platforms** – G.Garstecki (GMS), M.Williams (Boeing), F.Popielas

WG#07 WG#08 WG#09 WG#10 WG#11 WG#12 WG#13

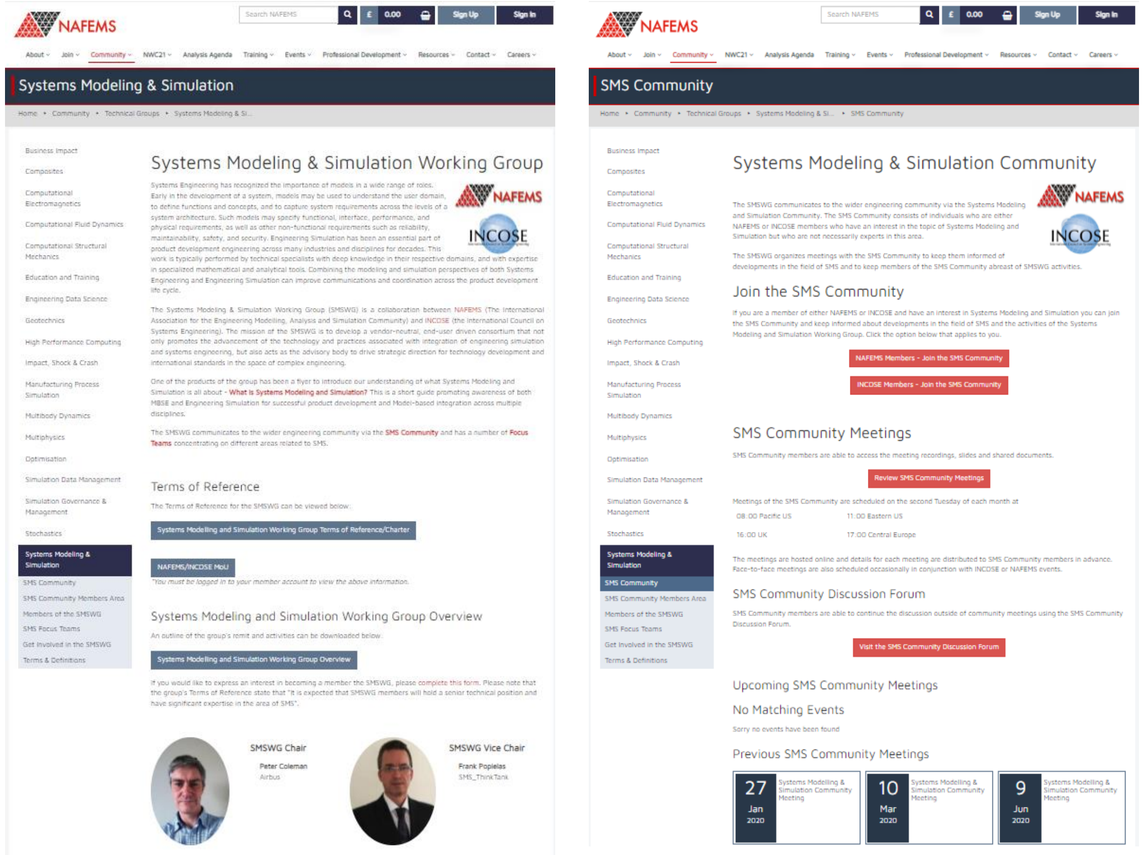
SEH-E5 4.2 M&S

INCOSE International Council on Systems Engineering

NAFEMS

SMSWG Web Pages + SMS Community shared material

Ensure you are signed up to the SMS Community via the NAFEMS website in order to access the SMS Community Members' Area and to receive future event notifications and SMS Community correspondence



https://www.nafems.org/community/working-groups/systems-modeling-simulation/

https://www.incose.org/incose-member-resources/working-groups/transformational/incose-nafems-collaboration

NOTE - SMSWG archive material on OMG MBSE wiki pages - not maintained since March 2020

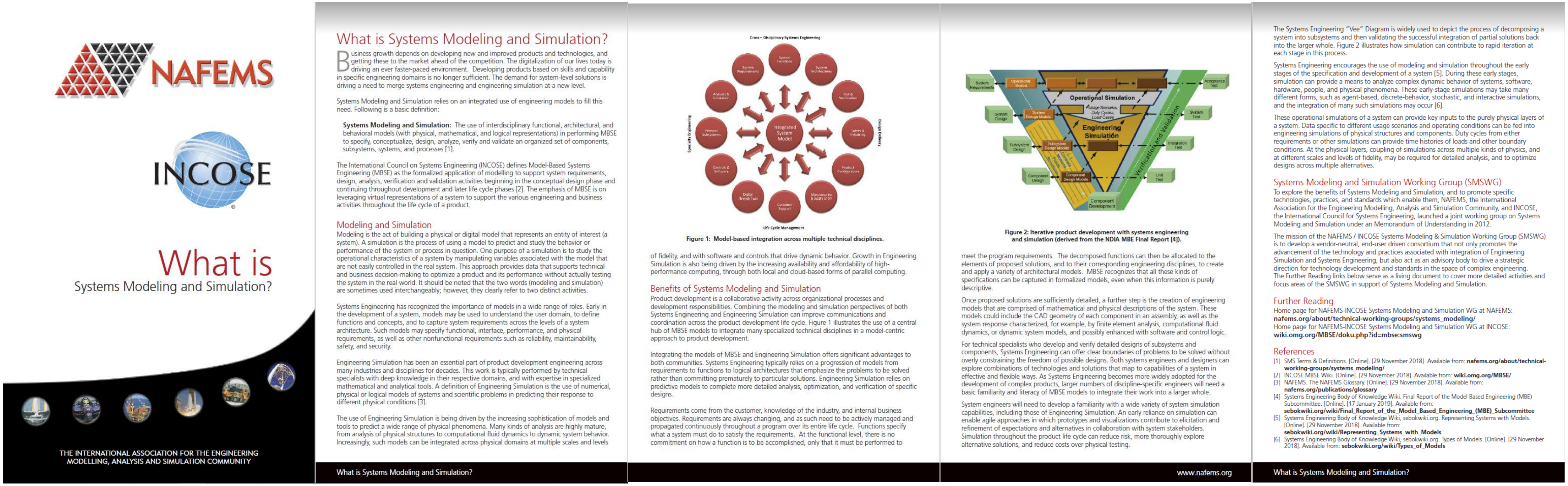
http://www.omgwiki.org/MBSE/doku.php?id=mbse:smswg

INCOSE International Council on Systems Engineering

NAFEMS

SMSWG “What is SMS?” publication 2019

- Short guide promoting awareness of both MBSE and Engineering Simulation for successful product development and Model-based integration across multiple disciplines
- First co-branded product available for INCOSE or NAFEMS members via:
- https://connect.incose.org/Pages/Product-Details.aspx?ProductCode=what_is_sms
- https://www.nafems.org/publications/resource_center/bm_apr_19_11/



NAFEMS

INCOSE

What is
Systems Modeling and Simulation?

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

What is Systems Modeling and Simulation?

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 life cycle phases [2]. The emphasis of MBSE is on leveraging virtual representations of a system to support the various engineering and business activities throughout the life cycle of a product.

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

What is Systems Modeling and Simulation?

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

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 life cycle. 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.

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

Figure 2: Iterative product development with systems engineering and simulation (derived from the NDIA MBE Final Report [4]).

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 finite element analysis, computational fluid dynamics, 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 life cycle can reduce risk, more thoroughly explore alternative solutions, and reduce costs over physical testing.

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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.

Systems Engineering encourages the use of modeling and simulation throughout the early stages of the specification and development of a system [5]. During 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 [6].

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:
nafems.org/about/technical-working-groups/systems_modeling/
Home page for NAFEMS-INCOSE Systems Modeling and Simulation WG at INCOSE:
wiki.omg.org/MBSE/doku.php?id=mbse:smswg

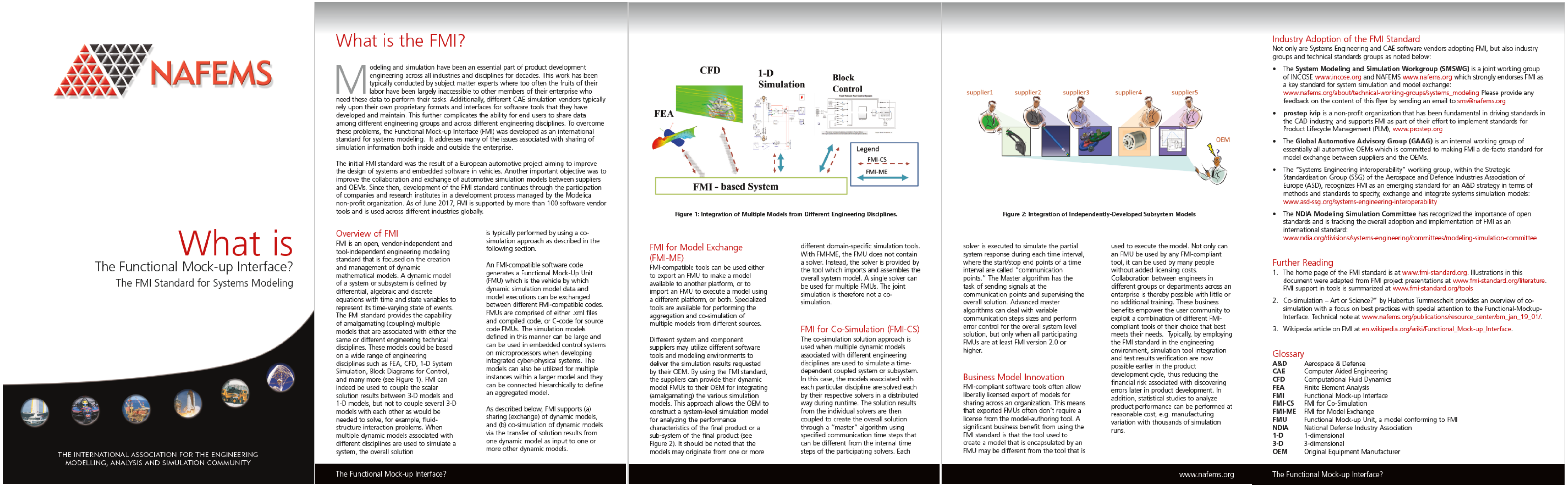
References

[1] SMS Terms & Definitions. [Online]. [29 November 2018]. Available from: **nafems.org/about/technical-working-groups/systems_modeling/**
[2] INCOSE MBSE Wiki. [Online]. [29 November 2018]. Available from: **wiki.omg.org/MBSE/**
[3] NAFEMS. The NAFEMS Glossary. [Online]. [29 November 2018]. Available from: **nafems.org/publications/glossary**
[4] Systems Engineering Body of Knowledge Wiki. Final Report of the Model Based Engineering (MBE) Subcommittee. [Online]. [17 January 2019]. Available from: **sebokwiki.org/wiki/Final_Report_of_the_Model_Based_Engineering_(MBE)_Subcommittee**
[5] Systems Engineering Body of Knowledge Wiki, sebokwiki.org. Representing Systems with Models. [Online]. [29 November 2018]. Available from: **sebokwiki.org/wiki/Representing_Systems_with_Models**
[6] Systems Engineering Body of Knowledge Wiki, sebokwiki.org. Types of Models. [Online]. [29 November 2018]. Available from: **sebokwiki.org/wiki/Types_of_Models**

What is Systems Modeling and Simulation?

SMSWG “What is FMI?” publication 2018

- Short guide promoting awareness on the Modelica FMI standard for Model Exchange and Co-simulation
- NAFEMS branded product freely available via: https://www.nafems.org/publications/resource_center/wt06/



NAFEMS

What is
The Functional Mock-up Interface?
The FMI Standard for Systems Modeling

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

What is the FMI?

Modeling and simulation have been an essential part of product development engineering across all industries and disciplines for decades. This work has been typically conducted by subject matter experts where too often the fruits of their labor have been largely inaccessible to other members of their enterprise who need these data to perform their tasks. Additionally, different CAE simulation vendors typically rely upon their own proprietary formats and interfaces for software tools that they have developed and maintain. This further complicates the ability for end users to share data among different engineering groups and across different engineering disciplines. To overcome these problems, the Functional Mock-up Interface (FMI) was developed as an international standard for systems modeling. It addresses many of the issues associated with sharing of simulation information both inside and outside the enterprise.

The initial FMI standard was the result of a European automotive project aiming to improve the design of systems and embedded software in vehicles. Another important objective was to improve the collaboration and exchange of automotive simulation models between suppliers and OEMs. Since then, development of the FMI standard continues through the participation of companies and research institutes in a development process managed by the Modelica non-profit organization. As of June 2017, FMI is supported by more than 100 software vendor tools and is used across different industries globally.

Overview of FMI

FMI is an open, vendor-independent and tool-independent engineering modeling standard that is focused on the creation and management of dynamic mathematical models. A dynamic model of a system or subsystem is defined by differential, algebraic and discrete equations with time and state variables to represent its time-varying state of events. The FMI standard provides the capability of amalgamating (coupling) multiple models that are associated with either the same or different engineering technical disciplines. These models could be based on a wide range of engineering disciplines such as FEA, CFD, 1-D System Simulation, Block Diagrams for Control, and many more (see Figure 1). FMI can indeed be used to couple the scalar solution results between 3-D models and 1-D models, but not to couple several 3-D models with each other as would be needed to solve, for example, fluid-structure interaction problems. When multiple dynamic models associated with different disciplines are used to simulate a system, the overall solution is typically performed by using a co-simulation approach as described in the following section.

An FMI-compatible software code generates a Functional Mock-Up Unit (FMU) which is the vehicle by which dynamic simulation model data and model executions can be exchanged between different FMI-compatible codes. FMUs are comprised of either .xml files and compiled code, or C-code for source code FMUs. The simulation models defined in this manner can be large and can be used in embedded control systems on microprocessors when developing integrated cyber-physical systems. The models can also be utilized for multiple instances within a larger model and they can be connected hierarchically to define an aggregated model.

As described below, FMI supports (a) sharing (exchange) of dynamic models, and (b) co-simulation of dynamic models via the transfer of solution results from one dynamic model as input to one or more other dynamic models.

The Functional Mock-up Interface?

Figure 1: Integration of Multiple Models from Different Engineering Disciplines.

FMI for Model Exchange (FMI-ME)

FMI-compatible tools can be used either to export an FMU to make a model available to another platform, or to import an FMU to execute a model using a different platform, or both. Specialized tools are available for performing the aggregation and co-simulation of multiple models from different sources.

Different system and component suppliers may utilize different software tools and modeling environments to deliver the simulation results requested by their OEM. By using the FMI standard, the suppliers can provide their dynamic model FMUs to their OEM for integrating (amalgamating) the various simulation models. This approach allows the OEM to construct a system-level simulation model for analyzing the performance characteristics of the final product or a sub-system of the final product (see Figure 2). It should be noted that the models may originate from one or more different domain-specific simulation tools. With FMI-ME, the FMU does not contain a solver. Instead, the solver is provided by the tool which imports and assembles the overall system model. A single solver can be used for multiple FMUs. The joint simulation is therefore not a co-simulation.

FMI for Co-Simulation (FMI-CS)

The co-simulation solution approach is used when multiple dynamic models associated with different engineering disciplines are used to simulate a time-dependent coupled system or subsystem. In this case, the models associated with each particular discipline are solved each by their respective solvers in a distributed way during runtime. The solution results from the individual solvers are then coupled to create the overall solution through a "master" algorithm using specified communication time steps that can be different from the internal time steps of the participating solvers. Each

Figure 2: Integration of Independently-Developed Subsystem Models

solver is executed to simulate the partial system response during each time interval, where the start/stop end points of a time interval are called "communication points." The Master algorithm has the task of sending signals at the communication points and supervising the overall solution. Advanced master algorithms can deal with variable communication steps sizes and perform error control for the overall system level solution, but only when all participating FMUs are at least FMI version 2.0 or higher.

Business Model Innovation

FMI-compliant software tools often allow liberally licensed export of models for sharing across an organization. This means that exported FMUs often don't require a license from the model-authoring tool. A significant business benefit from using the FMI standard is that the tool used to create a model that is encapsulated by an FMU may be different from the tool that is used to execute the model. Not only can an FMU be used by any FMI-compliant tool, it can be used by many people without added licensing costs. Collaboration between engineers in different groups or departments across an enterprise is thereby possible with little or no additional training. These business benefits empower the user community to exploit a combination of different FMI-compliant tools of their choice that best meets their needs. Typically, by employing the FMI standard in the engineering environment, simulation tool integration and test results verification are now possible earlier in the product development cycle, thus reducing the financial risk associated with discovering errors later in product development. In addition, statistical studies to analyze product performance can be performed at reasonable cost, e.g. manufacturing variation with thousands of simulation runs.

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Industry Adoption of the FMI Standard

Not only are Systems Engineering and CAE software vendors adopting FMI, but also industry groups and technical standards groups as noted below:

- The **System Modeling and Simulation Workgroup (SMSWG)** is a joint working group of INCOSE www.incose.org and NAFEMS www.nafems.org which strongly endorses FMI as a key standard for system simulation and model exchange: www.nafems.org/about/technical-working-groups/systems_modeling Please provide any feedback on the content of this flyer by sending an email to sms@nafems.org
- **prostep ivip** is a non-profit organization that has been fundamental in driving standards in the CAD industry, and supports FMI as part of their effort to implement standards for Product Lifecycle Management (PLM), www.prostep.org
- The **Global Automotive Advisory Group (GAAG)** is an internal working group of essentially all automotive OEMs which is committed to making FMI a de-facto standard for model exchange between suppliers and the OEMs.
- The "Systems Engineering interoperability" working group, within the Strategic Standardisation Group (SSG) of the Aerospace and Defence Industries Association of Europe (ASD), recognizes FMI as an emerging standard for an A&D strategy in terms of methods and standards to specify, exchange and integrate systems simulation models: www.asd-ssg.org/systems-engineering-interoperability
- The **NDIA Modeling Simulation Committee** has recognized the importance of open standards and is tracking the overall adoption and implementation of FMI as an international standard: www.ndia.org/divisions/systems-engineering/committees/modeling-simulation-committee

Further Reading

1. The home page of the FMI standard is at www.fmi-standard.org. Illustrations in this document were adapted from FMI project presentations at www.fmi-standard.org/literature. FMI support in tools is summarized at www.fmi-standard.org/tools
2. Co-simulation – Art or Science?" by Hubertus Tummescheit provides an overview of co-simulation with a focus on best practices with special attention to the Functional-Mockup-Interface. Technical note at www.nafems.org/publications/resource_center/bm_jan_19_01/.
3. Wikipedia article on FMI at en.wikipedia.org/wiki/Functional_Mock-up_Interface.

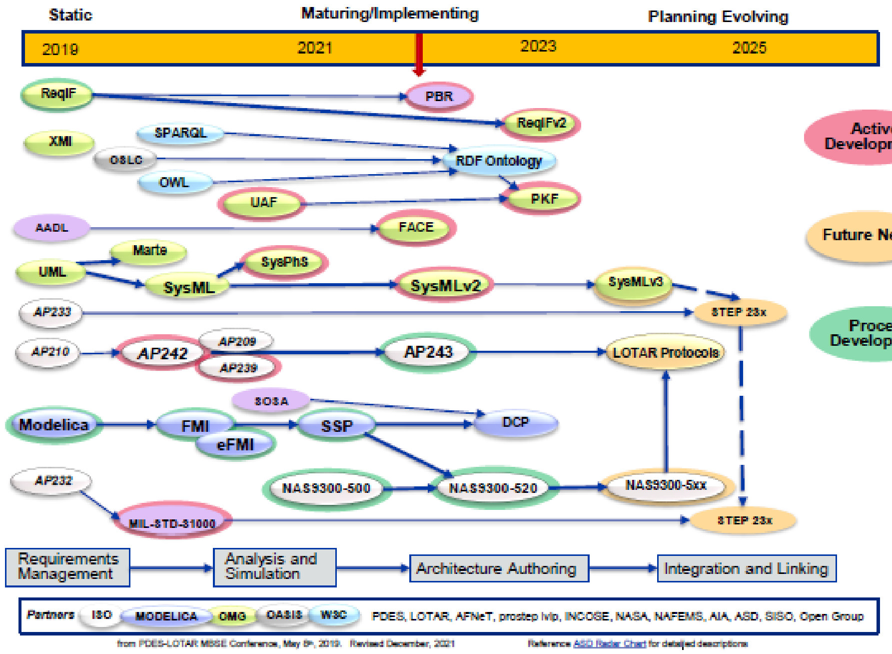
Glossary

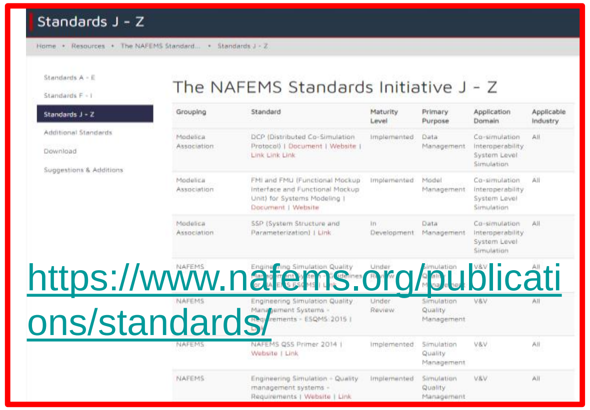
A&D	Aerospace & Defense
CAE	Computer Aided Engineering
CFD	Computational Fluid Dynamics
FEA	Finite Element Analysis
FMI	Functional Mock-up Interface
FMI-CS	FMI for Co-Simulation
FMI-ME	FMI for Model Exchange
FMU	Functional Mock-up Unit, a model conforming to FMI
NDIA	National Defense Industry Association
1-D	1-dimensional
3-D	3-dimensional
OEM	Original Equipment Manufacturer

The Functional Mock-up Interface?

SMSWG identify and promote SMS related standards

- SMSWG aim to identify and promote the maturity and industry adoption of relevant international standards that enable Systems M&S and the integration of MBSE with engineering simulation
- “Unknown or no standards” identified as major gap in survey from MBSE workshop at 2018 GPDIS
- Need for improved model/data interoperability and cross-domain engineering collaboration
- Connect with industry groups working on developing or promoting adoption of standards for MBSE and Engineering Simulation
- Ongoing liaison with NAFEMS Standards Initiative
- Examples:
  - Modelica Assoc. standards e.g. FMI/FMU, SSP …
  - ISO STEP standards e.g. AP209ed2, AP243 (MoSSEC), link with LOTAR
  - Web standards e.g. OSLC, RDF, XML/XMI, UML
  - OMG standards e.g. ReqIF, SysML v2, UAF





https://www.nafems.org/publications/standards/

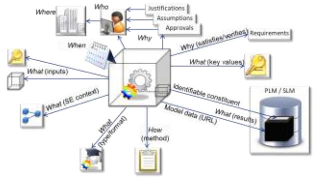
SMS model characterization & metadata

- Focus team launched in 2021, from discussions initiated at IW 2020
  - P.Coleman, M.Williams, R.Dreisbach, R.Burkhart, E.Landel, J.Walsh, W.Schindel, D.Leal
- Six meetings up to Sept 2021
- How to characterise SE (systems engineering) and ES (engineering simulation) models together?
- How to harmonise on common and specific categories and types of metadata across types of models?
- Metadata compared to metamodels?
- How to join-up common interests and initiatives?
- Supporting comparison and mapping of model characterisation categories and metadata from multiple sources
  - UMC4ES (ASSESS), NAS9300-5xx (LOTAR), MIC, OAIS, MCP, MoSSEC
- Progress on interface with NAFEMS SDMWG

ASSESS

- **UMC4ES** - Unified Model Characterization for Engineering Simulation
- Feature Groups - Model Identity and Focus; Model Scope of Content; Model Representation; Model Utility; Model Confidence/Credibility; Model Lifecycle Management

MoSSEC



- **Modelling and Simulation in a collaborative Systems Engineering Context**
- ISO 10303-243:2021
- Business objects covering Study management; Models management; Methodology; Architecture & interfaces; Optimisation; Requirements & quality; Value generation; Actors & organisation; Security & trust

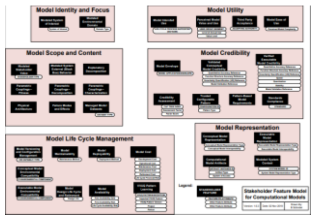
Model Identity Card (MIC)

- General Information; Integration; Content and computation; Ports, internal variable and parameters; Verification and validation

LOTAR MBSE

- NAS9300-520 - analytical models
- Categories - PLM General Info; Model Development-Execution; Physics; Model Variables; V&V;

Model Characterization Pattern (MCP)



- INCOSE MBSE Patterns WG
- Feature groups - Model identity & focus; Model utility; Model scope & content; Model credibility; Model life cycle management; Model representation

SMSWG maintain and evolve the SMS Terms & Definitions

- First published 2016 with regular updates on dedicated pages hosted via NAFEMS website:
  - https://www.nafems.org/community/working-groups/systems-modeling-simulation/smstermsdefinitions/
- 12 additions in 2020:
  - Democratization of Simulation
  - Digital Twin
  - Engineering Simulation
  - Generative Design
  - Model-Based Definition (MBD)/(MBDef)
  - Model-Based Design (MBD)
  - Model Based Development (MBDev)
  - Model-Based Engineering (MBE)
  - Model-Based Enterprise (MBE)
  - Model-Based Safety Analysis (MBSA)
  - Model-Based Systems Engineering (MBSE)
  - Simulation Governance
- Next Terms to be finalised
  - Hardware, Software, Model, Human … "in the loop"
- Review T&D's from NAFEMS SDMWG
  - Definitions related to existing terms within ISO 10303
  - Simulation model, simulation state, and simulation step

Systems Modeling & Simulation Working Group

The following was compiled by members of the Systems Modeling & Simulation Working Group to provide the model-based systems engineering community with a common set of shared terms and definitions.

A-C | D-F | G-I | J-L | M-O | P-R | S-U| V-X | Y-Z

Terms & Definitions (M-O)

Term	Definition	Source	Comments
Mathematical Model	A symbolic model whose properties are expressed in mathematical symbols and relationships. (IEEE 610.3-1989)	Modeling & Simulation Coordination Office	
Measure Of Effectiveness (MOE)	A metric used to quantify the performance of a system, product or process in terms that describe a measure to what degree the real objective is achieved.	Modeling & Simulation Coordination Office	
Measure Of Outcome (MOO)	A qualitative or quantitative measure that defines how operational requirements contribute to end results at higher levels, such as campaign or national strategic outcomes.	Modeling & Simulation Coordination Office	
Measure Of Performance (MOP)	A qualitative or quantitative measure of how the system/individual performs its functions in a given environment (i.e., number of targets detected, reaction time, number of targets nominated, susceptibility of deception, task completion time). It is closely related to inherent parameters (physical and structural) but measures attributes of system behavior.	Modeling & Simulation Coordination Office	
Measures of Effectiveness Data	Data provided to quantify Measures of Effectiveness.	INCOSE	
Measures of Effectiveness Needs	The "operational" measures of success that are closely related to the achievement of the mission or operational objective being evaluated, in the intended operational environment under a specified set of conditions (i.e., how well the solution achieves the intended purpose).	INCOSE	
Measures of Performance Data	Data provided to quantify the Measures of Performance.	INCOSE	
Measures of Performance Needs	Key performance characteristics the system should have when fielded and operated in its intended operating environment.	INCOSE	
Metadata	Information describing the characteristics of data; data or information about data; descriptive information about an organization's data, data activities, systems, and holdings. For example, discovery metadata is a type of metadata that allows data assets to be found using enterprise search capabilities. (DoDD 8320.02)	Modeling & Simulation Coordination Office	
Metamodel	A model of a model or simulation. Metamodels are abstractions which use functional decomposition to show relationships, paths of data and algorithms, ordering, and interactions between model components and subcomponents. Metamodels allow the developer to abstract details to a level that subject matter experts can validate.	Modeling & Simulation Coordination Office	

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SMSWG input for INCOSE Systems Engineering Handbook 5th Edition

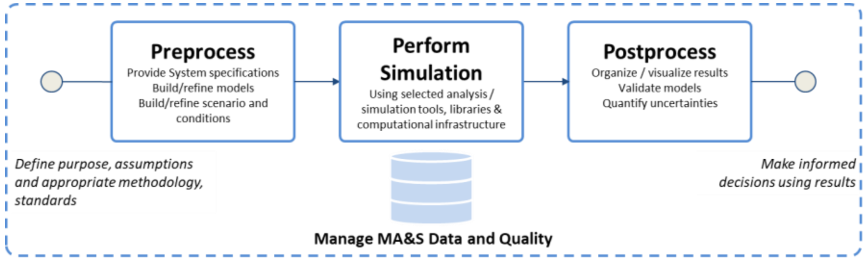
- SMSWG & Community team contributing to SEH5E revision:
  - Hans Peter de Koning + Peter Coleman, Alexander Karl, Maurice Theobald, Hubertus Tummescheit, Rod Dreisbach
- Dec'20 to Mar'21 inc. reviews & feedback with Editorial team:
  - Major re-write – streamlining content & narrative
  - Reference to "What is SMS" flyer
  - Proposed additional terms & definitions
- Adapted chapter title => Modeling, Analysis and Simulation
  - Modeling - the conception, creation and refinement of models
  - Analysis - the process of systematic, reproducible examination to gain insight
  - Simulation - the process of using a model to predict and study the behavior or performance of the system-of-interest
- Overall prototype draft issued to reviewers in Apr'21
- Restructured SEH5E to authors with comments in Jan'22
- Further revisions for final draft submission at end of Mar'22

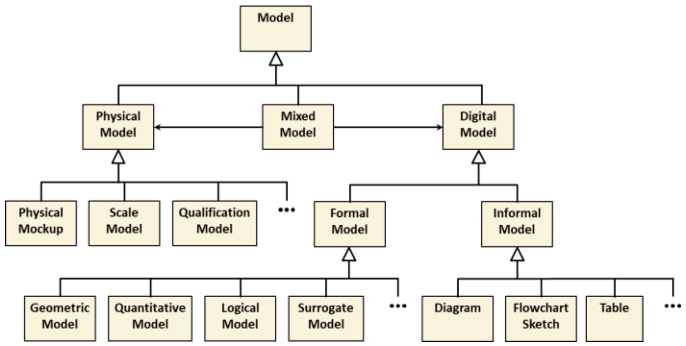
SEH5E - Part III - Life Cycle Analyses and Methods

3.2 – Systems Engineering Analysis and Methods

3.2.1 – Modeling, Analysis and Simulation

- Overview and Purpose
- Benefits
- Classifying and Characterizing Models
- Model Interoperability
- Tools
- Modeling Quality and Metrics
- MA&S Industrial Practice





Interested to join the SMSWG or SMS Community?

Get Involved in the Systems Modeling & Simulation Working Group

If you are an expert in the area of SMS and would like to get involved in the **Systems Modeling & Simulation Working Group** activities, please complete the form below.

First Name

First Name

Last Name

Last Name

Company

Company

Email

Email

My organisation is a NAFEMS member

Please Select

I am a member of INCOSE

Please select

If your organisation is not already a member of NAFEMS, would you be interested in receiving information on membership?

Please Select

If you are not already a member of INCOSE, would you be interested in receiving information on membership?

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www.nafems.org/community/working-groups/systems-modeling-simulation/get_involved/

Join the SMS Community

If you are an INCOSE member please complete the form below in order to join the SMS Community.

If you are a NAFEMS member and wish to join the SMS Community please visit the Technical Communities tab in the "My NAFEMS" section of the website.

Visit the SMS Community page to find out about SMS Community events.

First Name

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By clicking submit and providing us with your contact details, you are giving NAFEMS your explicit consent to contact you using these details regarding your enquiry and our related products and services. You can view our privacy policy here

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