www.incose.org

www.nafems.org

NAFEMS-INCOSE Systems Modeling & Simulation Working Group (SMSWG)

"Bridging the worlds of Systems Engineering and Engineering Simulation"

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/community/working-groups/systems-modeling-simulation/smstermsdefinitions/s-u/

V10 update

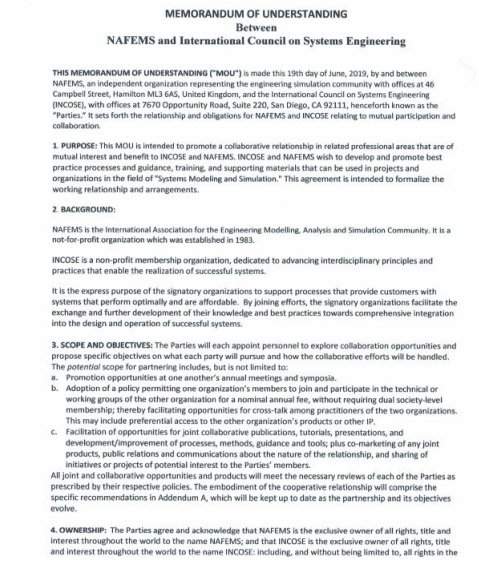
Systems Modeling & Simulation WG supporting INCOSE – NAFEMS collaboration

History & Governance

- Following 2011 agreement to develop a collaborative relationship, 1st Joint MoU signed at INCOSE Symposium in 2012 with announcement to form the NAFEMS-INCOSE SMSWG
- SMSWG launched in 2013 with founding steering committee to promote membership
- Joint MoU renewed at INCOSE Symposium in 2015 and NAFEMS World Congress in 2019
- Common INCOSE Charter & NAFEMS Terms of Reference established 2020 & updated end of 2021
- **10th Anniversary of collaboration and renewal of Joint MoU in June 2022**
- **2023 updates on MoU addendum A (joint activities) and B (certification)**

Collaboration

- Promotion of jointly developed products and opportunities for members to participate in each organisation's activities
- Mutual recognition of certifications offered by each organisation & reduced certification costs
- Mutual support for specific key events of each organisation, examples as follows
  - NAFEMS sponsorship at INCOSE IS 2021 and INCOSE sponsorship at NWC21
  - NWC19 special panel session "Systems Engineering meets Engineering Simulation"
  - NWC21 special panel session "Connecting Two Worlds Through Leadership" (inc SE vision & grand challenges)
  - IS 2024 special panel session "Building the digital bridge between MBSE and Engineering Simulation"
  - NWC25 paper "What simulation engineers need to know about systems engineering and MBSE"



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.**

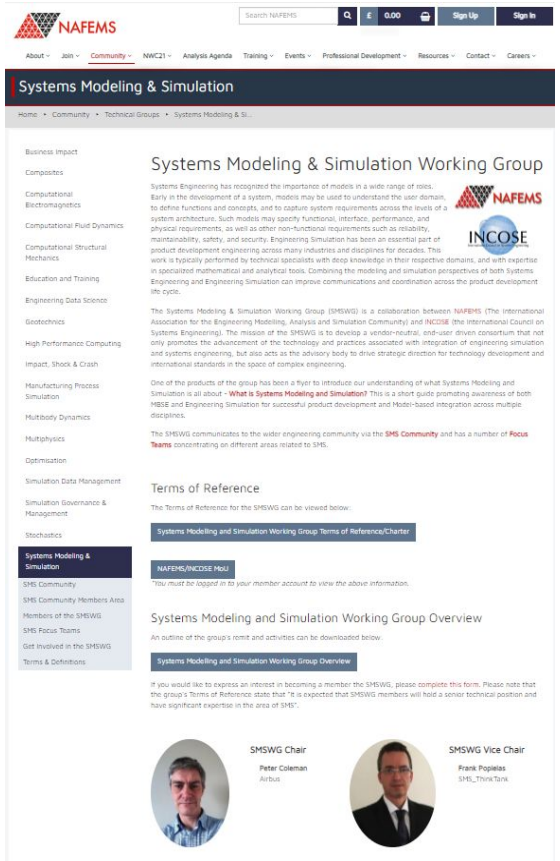
Mission & Goal

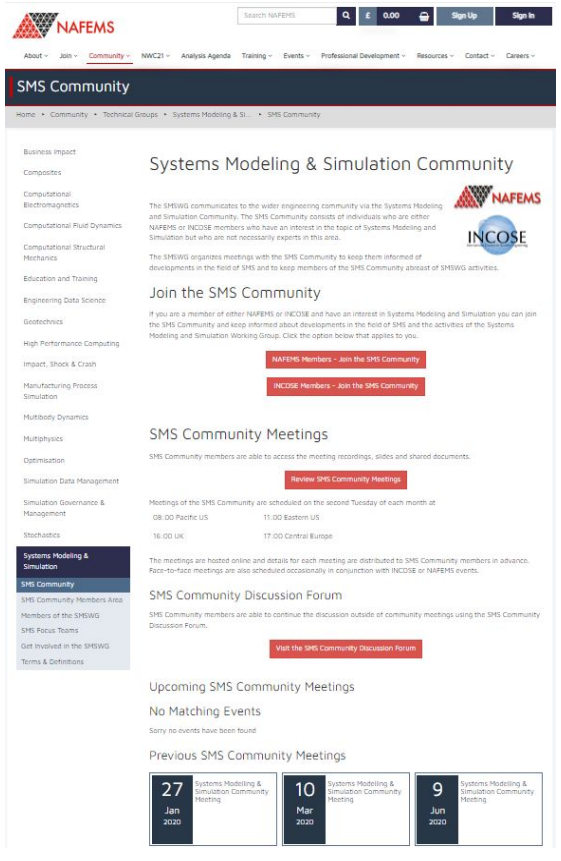
- To develop a **vendor-neutral, end-user driven** consortium that not only promotes the advancement of the technology and practices associated with **integration of engineering simulation and systems engineering**, but also acts as the advisory body to drive strategic direction for **technology development 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 Web Pages + SMS Community shared material

V5 update

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/

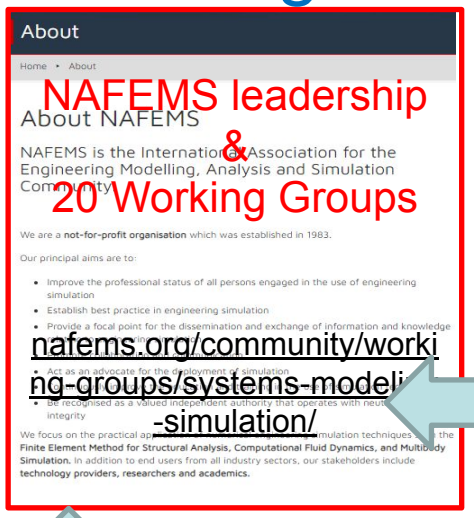
New SMSWG pages for INCOSE launched at IW2023

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

V10 update

SMS WG organisation (2025)

Contact nafems-incose@incose.net if interest to join any Focus Team

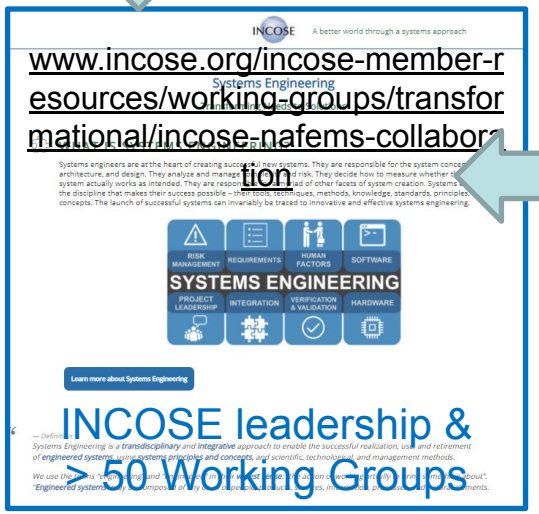


NAFEMS leadership & 20 Working Groups

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

14 SMSWG Members

- Roger Burkhart | Thematix
- Alexander Busch | Ansys
- Peter Coleman | Airbus (Chair)
- Hans Peter de Koning | DEKonsult
- Rodney Dreisbach | NAFEMS Technical Fellow
- Greg Garstecki | Garstecki Modeling Solutions
- Alexander Karl | Rolls-Royce & INCOSE relationship manager for NAFEMS
- Phyllis Marbach | INCOSE Assistant Director Transformational Enablers
- Sandeepak Natu | CIMData
- Frank Popielas | SMS_Thinktank (Co Chair)
- Ian Symington | NAFEMS Technical Officer
- Hubertus Tummescheit | Modelon Inc
- Mark Williams | PDES-LOTAR
- Kelly Zimmermann | Boeing

+

- NAFEMS TWG manager

Focus Team - **ACTIVE**

Roadmap & Best Practices

Frank Popielas

Focus Team - ***NEW in 2024***

Refining understanding of SMS

Alexander Busch

Focus Team - **restart 2025**

SMS Standards Ecosystem

HP de Koning

Focus Team - **on-hold since Feb'25**

Terms & Definitions

~~Greg Garstecki~~

Focus Team - ***NEW in 2024"**

SMA/PSE competencies mapping

A.Busch, R.Dreisbach

Focus Team - **completed**

SE Handbook 5E MA&S

HP de Koning

SMS Community

Open to all INCOSE or NAFEMS

631 registered (Jul'24)

* 547 NAFEMS
* 113 INCOSE
* 29 both NAFEMS & INCOSE

From >300 different organisations

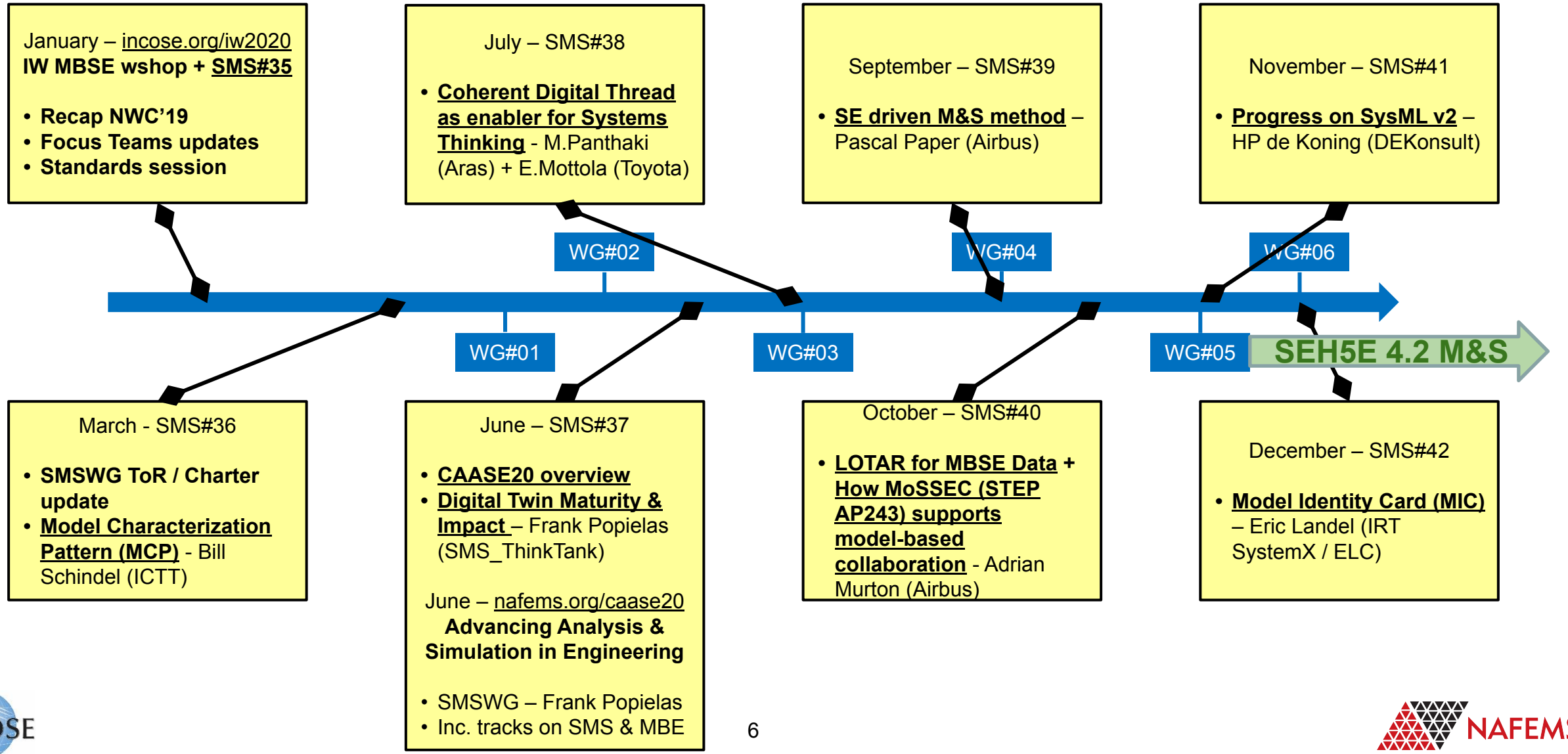
37 different countries

- US & Canada = 40%
- Europe = 43%
- Asia = 14%
- Rest of the world = 2%

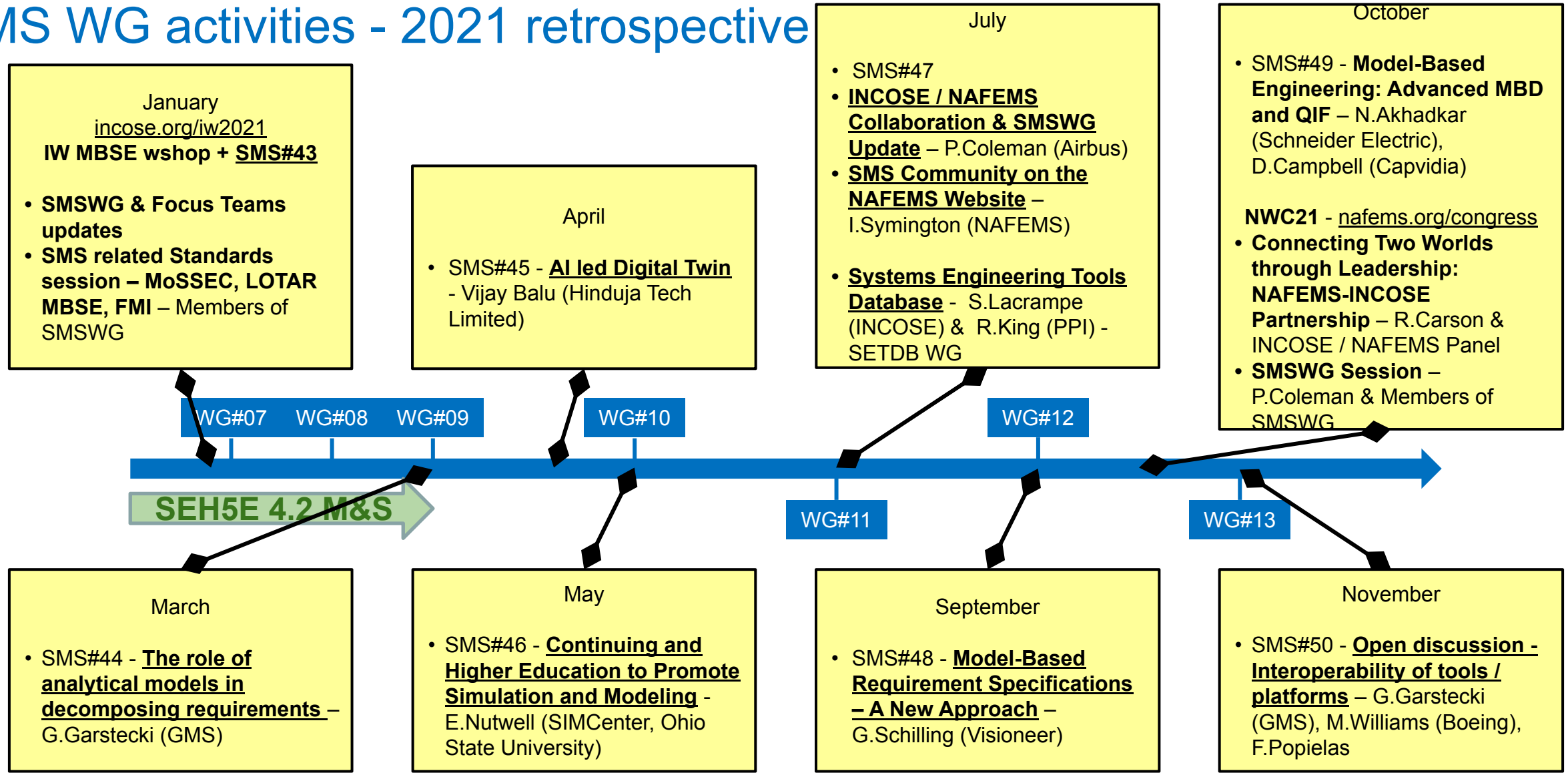
71 meetings from 2013 to 2025

Avg 30 participants (since Sep 2020)

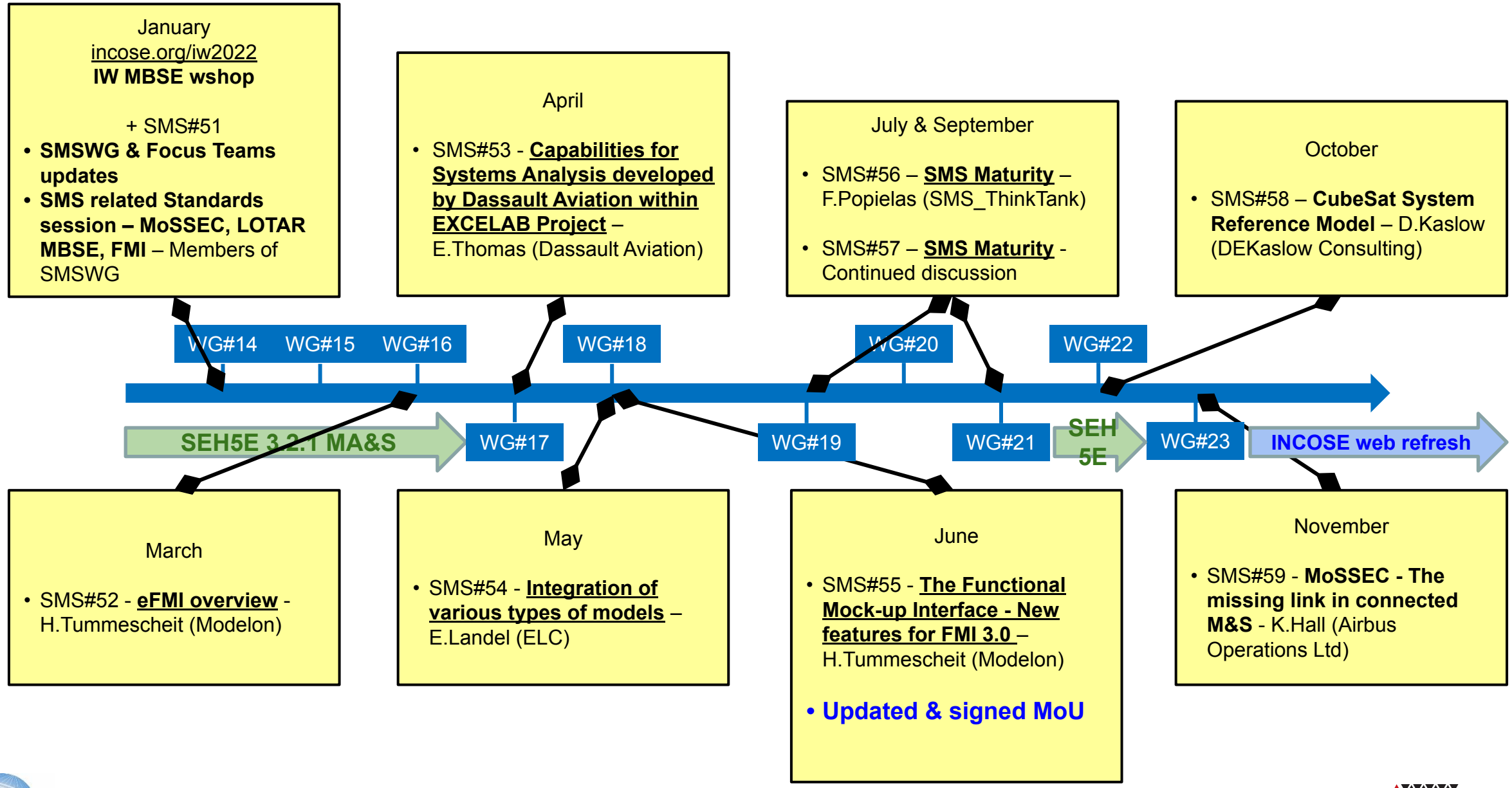
SMS WG activities - 2020 retrospective



SMS WG activities - 2021 retrospective

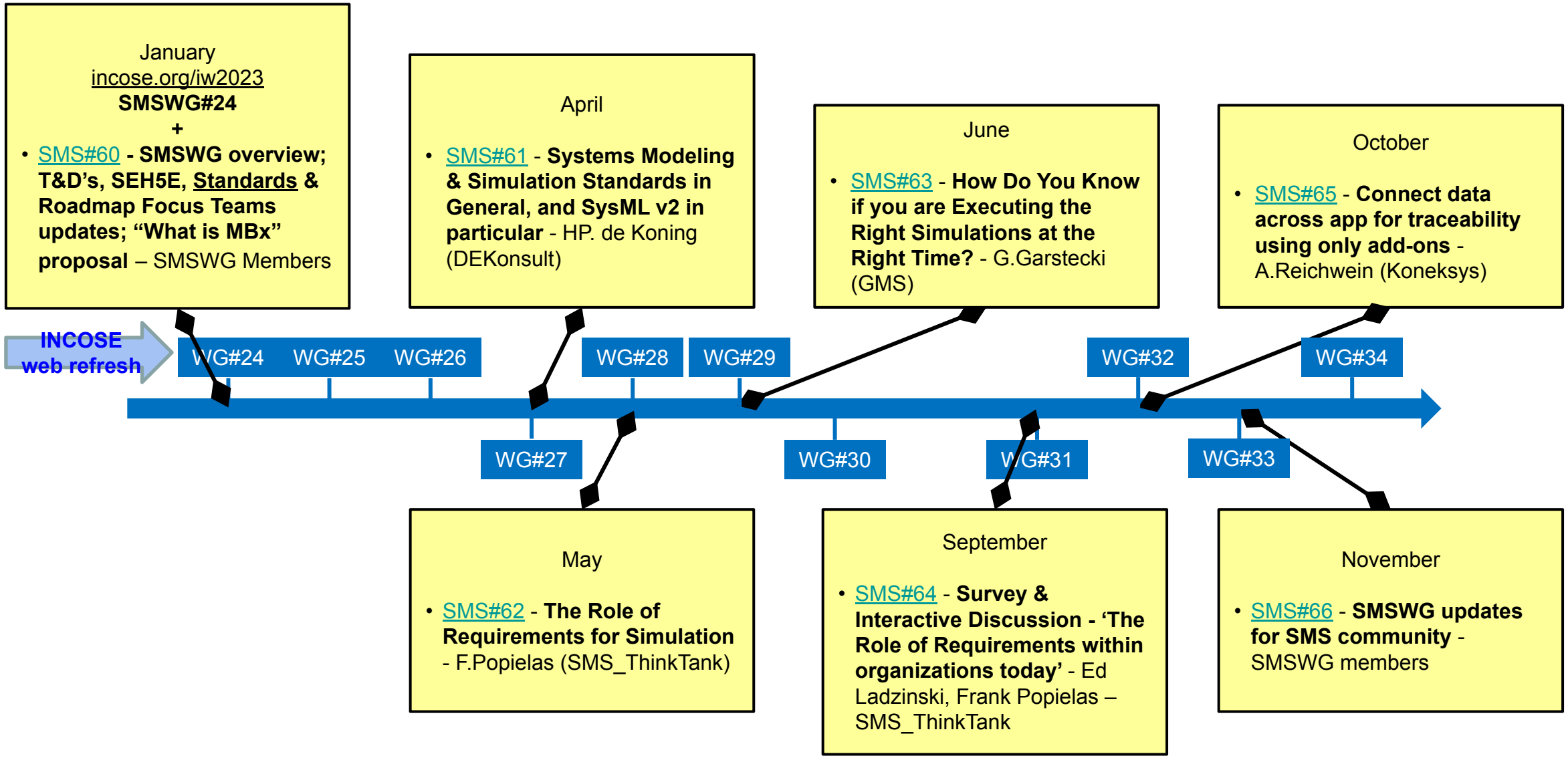


SMS WG activities - 2022 retrospective



SMS WG activities - 2023 retrospective

V7 update



SMS WG activities - 2024 retrospective

V9 update

28 & 29 January
incose.org/iw2024

2024 Annual INCOSE international workshop
HYBRID EVENT
Torrance, CA, USA
January 27 - 30, 2024

SMSWG#35 - products focus
+
SMS#67

- **SMSWG overview & plans** - P.Coleman (Airbus)
- **News from Modelica - FMI, eFMI, SSP** - H.Tummescheit (Modelon Inc)

5 July
incose.org/symp2024

34th Annual INCOSE international symposium
hybrid event
Dublin, Ireland
July 2 - 6, 2024

- **Panel - Building the digital bridge between MBSE and Engineering Simulation** - Moderator: P.Marbach (INCOSE); Panelists: I.Symington (NAFEMS); B.Delicado (INCOSE); HP.DeKoning (SMSWG); A.Busch (SMSWG)

INCOSE webpages refresh

WG#35 WG#36 WG#37 WG#38 WG#39 WG#40 WG#41 WG#42 WG#43 WG#44 WG#45

9 April

SMS#68

- **Archiving MBSE information, including new integration techniques** - M.Williams, JM Alvarez-Rodríguez, J. Gohl

11 June

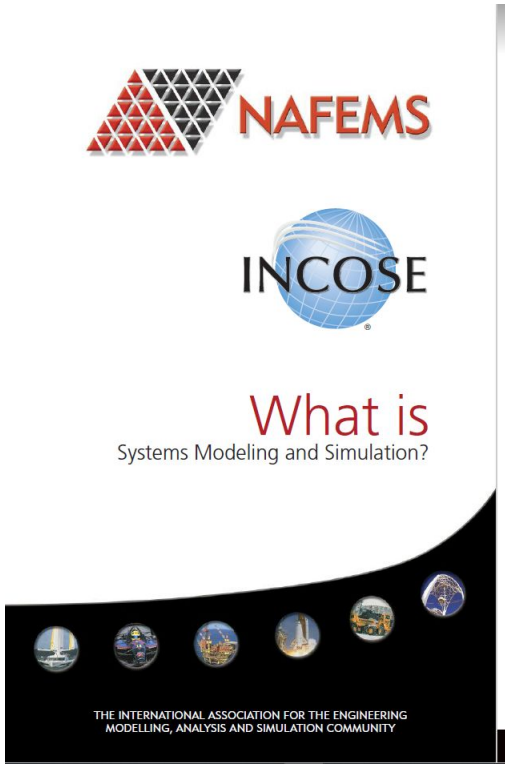
SMS#69

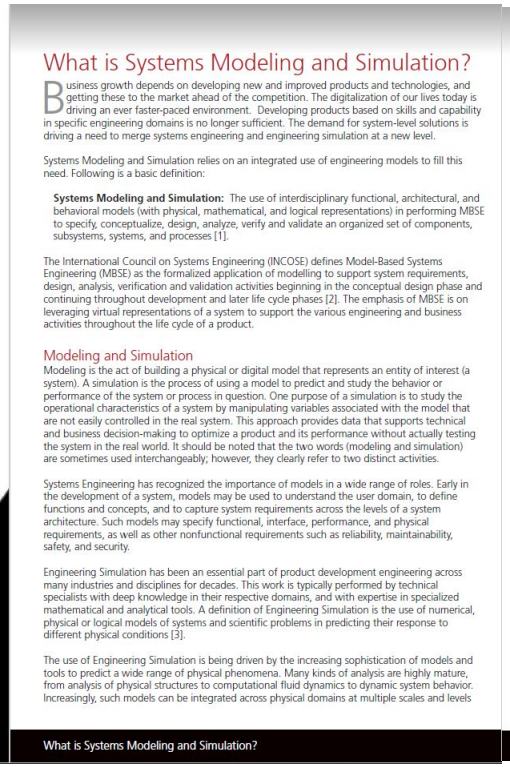
- **Discussion - Refining the Understanding of Systems Modeling and Simulation** - A.Busch (Ansys) & SMS community members

to be refreshed

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/





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

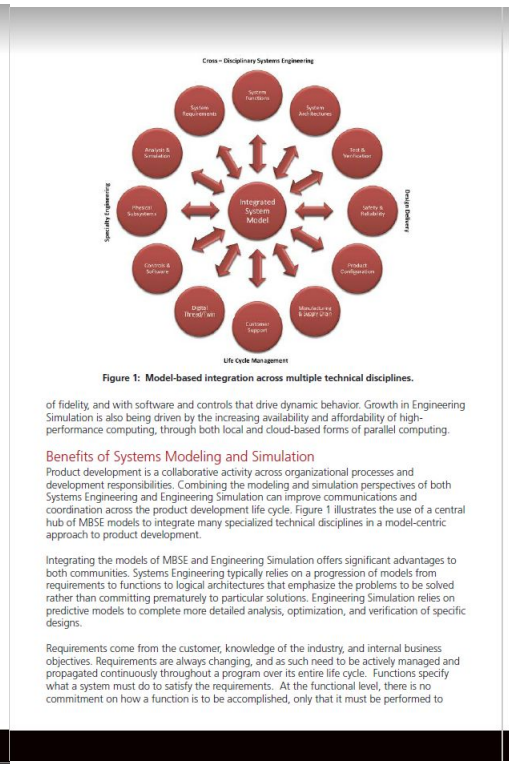


Figure 1: Model-based integration across multiple technical disciplines.

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

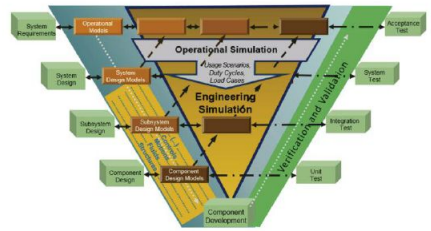


Figure 2: Iterative product development with systems engineering and simulation (derived from the NDIA MBE Final Report [4]).

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.

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**

to be refreshed

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.

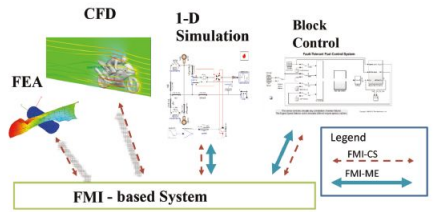


Figure 1: Integration of Multiple Models from Different Engineering Disciplines.

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 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.

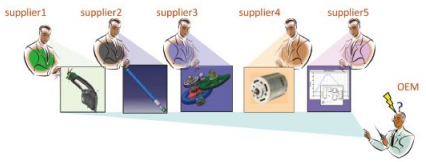


Figure 2: Integration of Independently-Developed Subsystem Models

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.

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-Mock-up-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

INCOSE

NAFEMS

SMSWG focus team - SMS Terms & Definitions

On-hold => Need new Focus Team lead!

V10 update

- First published 2016 with regular updates on dedicated pages hosted via NAFEMS website:
  - https://www.nafems.org/community/working-groups/systems-modeling-simulation/smstermsdefinitions/
  - 173 terms in total at end of 2023
- 12 additions in 2020:
  - Democratization of Simulation / Digital Twin / Engineering Simulation / Generative Design
  - Model-Based Definition (MBDef) / Model-Based Design (MBD) / Model Based Development (MBDev) / Model-Based Engineering (MBEng) /Model-Based Enterprise (MBEnt) / Model-Based Safety Analysis (MBSA) / Model-Based Systems Engineering (MBSE)
  - Simulation Governance
- Additions in 2022
  - Hardware, Software, Model, Human, Processor … “in the loop”
- Additions & updates in 2024 (also to be added to NAFEMS Glossary)
  - 12 model related terms i.e. behavioural model, conceptual model, descriptive model, empirical model, engineering simulation model, logical model, metamodel (revision), metadata (revision), physics-based model, physical model, surrogate model
- Collaborative reviews with other working groups or organisations e.g. Review T&D’s from NAFEMS SDMWG
  - NAFEMS SDMWG, related to existing terms within ISO 10303 and specific terms (such as simulation model, simulation state, and simulation step)
  - INCOSE SEBoK

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

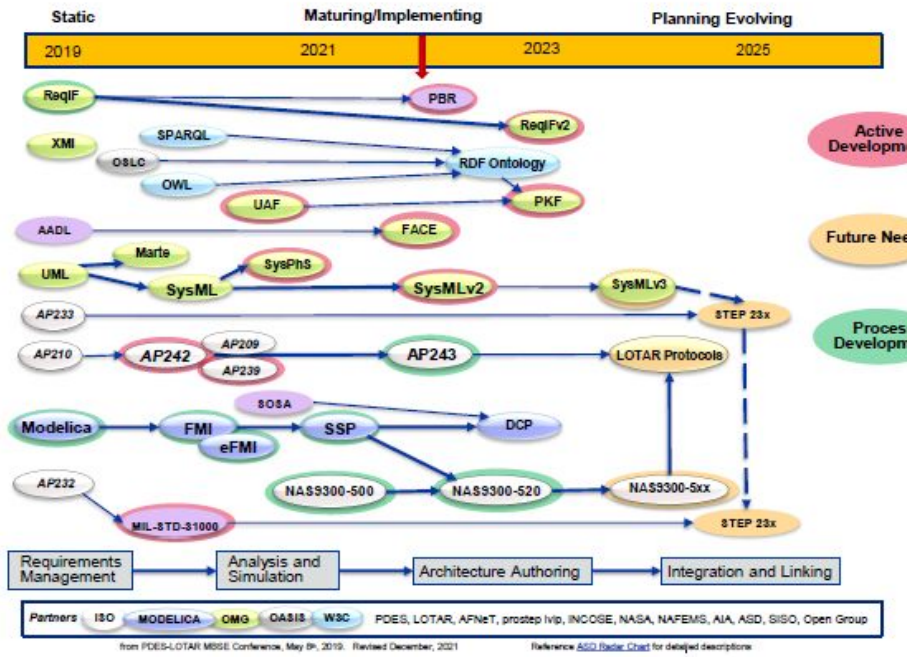
Terms & Definitions (M-O)

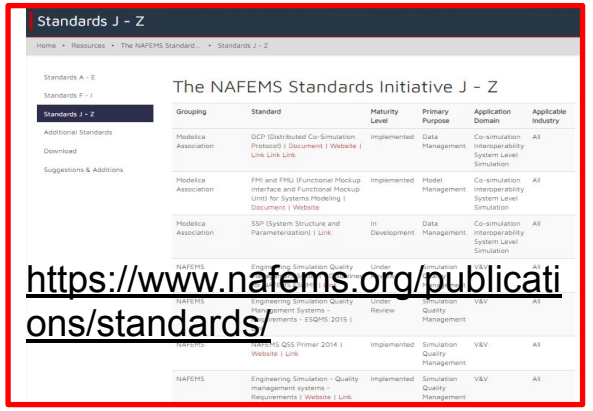
Term	Definition	Source	Comments
Mathematical Model	A symbolic model whose properties are expressed in mathematical symbols and relationships. (IEEE 610.3-1989)	Modeling & Simulation Coordination Office	
Measure Of Effectiveness (MOE)	A metric used to quantify the performance of a system, product or process 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 providing the characteristics of data.	NAFEMS SMSWG T&D Focus Team	
Metamodel	A representation of a model containing astractions of data types and classes along with their relationships.	NAFEMS SMSWG T&D Focus Team	

SMSWG focus team - SMS related standards

Restart 2025

- 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





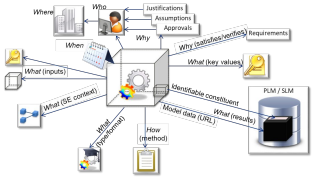
https://www.nafems.org/publications/standards/

SMSWG focus team - SMS model characterization & metadata

- Focus team launched in 2021, from discussions initiated at IW 2020
- Ten meetings up to May 2022
- 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
- Interface with NAFEMS SDMWG

on-hold

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

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

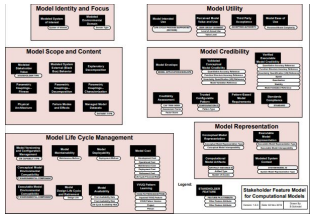
Model Identity Card (MIC)

- 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 focus team – INCOSE Systems Engineering Handbook 5th Edition

Completed

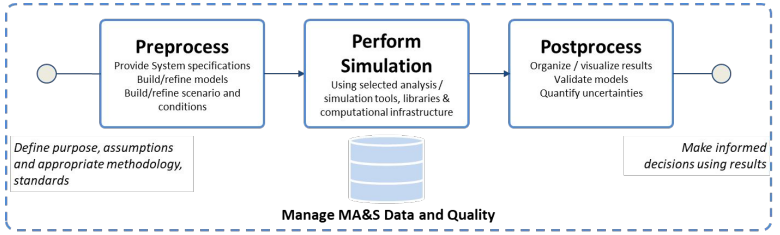
- SMSWG & Community team contributing to SEH5E revision:
  - Hans Peter de Koning + Peter Coleman, Alexander Karl, Maurice Theobald, Hubertus Tummescheit, Rod Dreisbach
- Adapted chapter title => Modeling, Analysis and Simulation
  - Modeling - the conception, creation and refinement of models
  - Analysis - 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
- Dec'20 to Apr'21 - Major re-write:
  - Streamlining content & narrative
  - Reference to "What is SMS" flyer
  - Proposed additional terms & definitions
  - Reviews & feedback with Editorial team
  - Overall prototype draft issued to reviewers
- Jan'22 to Mar'22 - Restructured SEH5E and MA&S revisions in response to reviewers comments for final draft submission
- Oct/Nov'22 and Jan'23 - Review significant reduction of text by Editorial team + Further revisions of System Development "vee" figure for final publisher ready version.

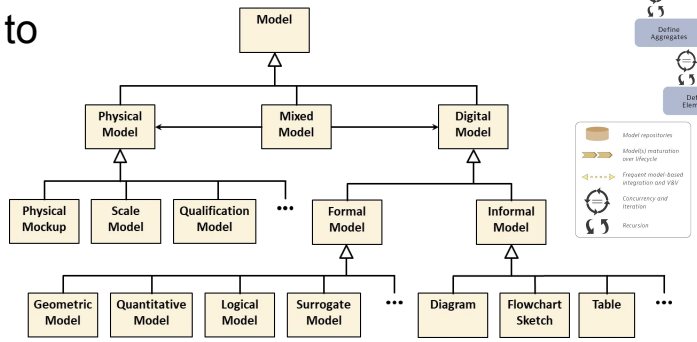
SEH5E - Part III - Life Cycle Analyses and Methods

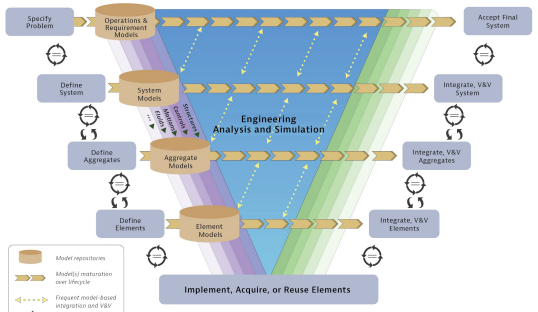
3.2 – Systems Engineering Analysis and Methods

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





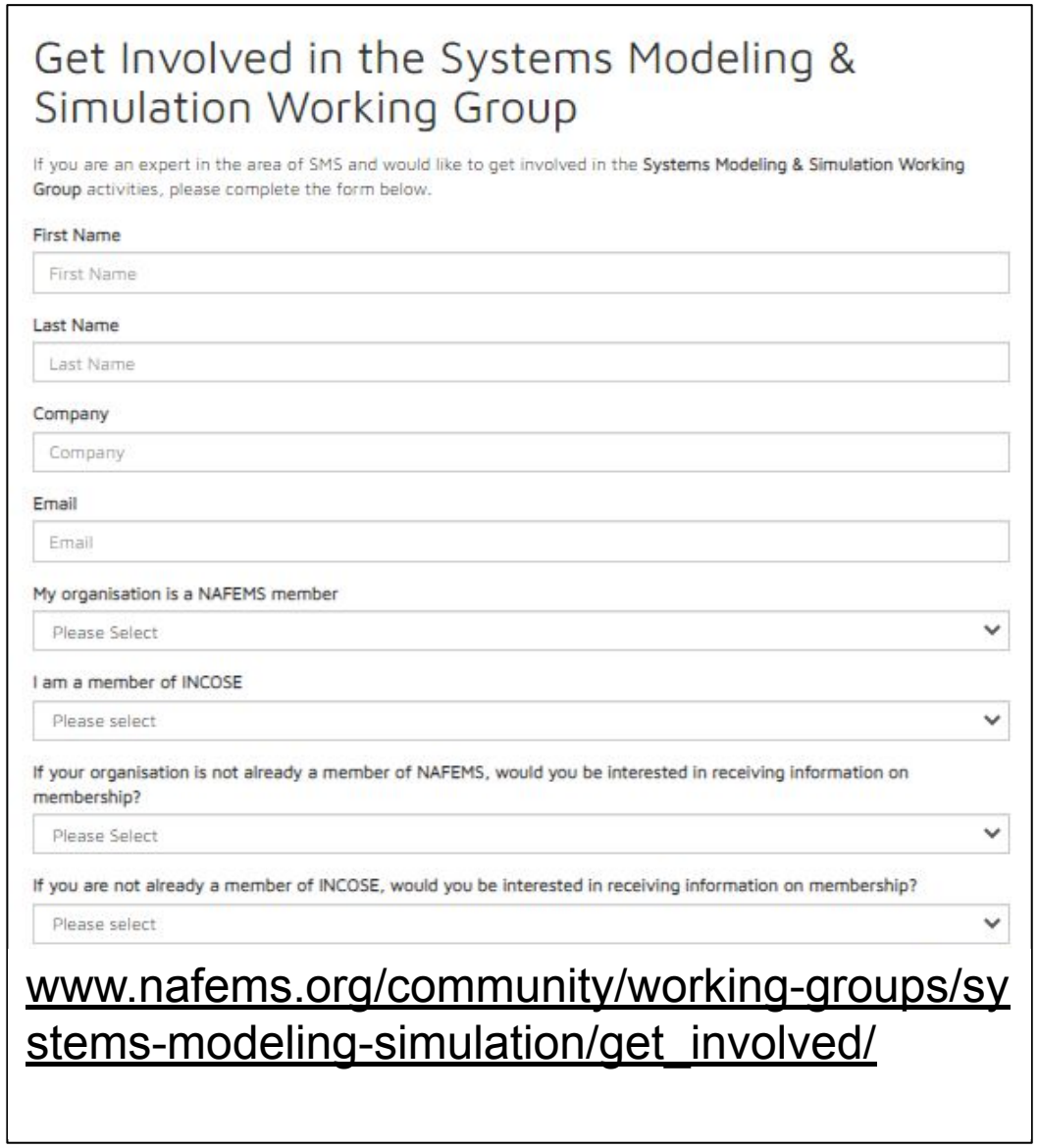


V10 update

SMSWG outlook for 2025 - work in progress

- Maintain & update SMS WG content on NAFEMS and INCOSE webpages - Continuous communication
- SMS WG management meetings - Usually 1st Monday each month, 17.00 CET / 11.00 ET
  - 2025 SMSWG#46 to #54 => 6-Jan, 24-Mar, 28-Apr, 2-Jun, 7-Jul, 1-Sep, 6-Oct, 3-Nov, 1-Dec
- SMS Community meetings - plan for 5 in 2025, each with ~1.5 hrs duration, usually 17.00 CET / 11.00 ET
  - Jan at IW25 (#70) + Apr (#71) + Jun (#72) + Sep (#73) + Nov (#74)
- SMS Roadmap focus team - Usually 3rd Tuesday each month =>
  - Ongoing - Plan SMS community sessions + SMS WG participation at other events + Identify & support emerging products
- INCOSE SMA / NAFEMS PSE competencies focus team (new in 2024) -
  - Continue to align
- SMS T&D's focus team meetings - On-hold since Feb'25 => need to identify new focus team leader
  - Waiting to restart activities to identify relevant SMS Terms & Definitions and integrate in next releases of T&D's website
- SMS Standards focus team - No meetings in 2024, plan to restart in 2025
  - Potential outputs - "How to develop effective engineering digitisation standards?" primer + revision "What is FMI" product
- Refining understanding SMS focus team (new in 2024) -
  - Potential output - revision of "What is SMS" product
  - Additional focus - MBSE "cheat sheet" product - review 'on hold' draft publication from 2024
- Support key events
  - NWC25 - Accepted paper (A.Busch, R.Dreisbach, F.Popielas)
  - IS25 panel (submitted) "Bridging the Divide: Linking Architectural Specification and Verification by System Simulation"
- Other potential topics
  - Restart from 2023 - INCOSE, NAFEMS & ASME collaboration with Prostep SmartSE standard for "Simulation Quality/Credibility"
  - Restart from 2023 - NAFEMS ESQMS (Engineering Simulation Quality Management Standard)

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

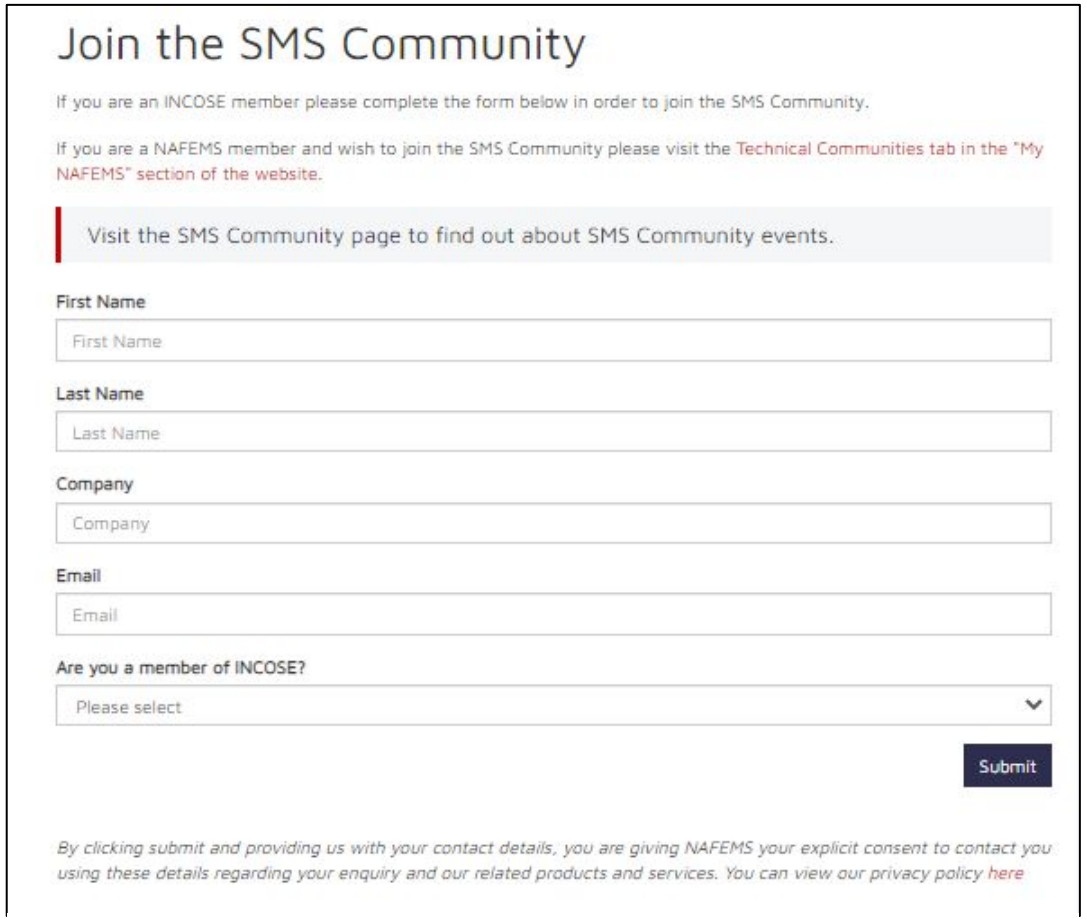
My organisation is a NAFEMS member
Please Select

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?
Please select

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
First Name

Last Name
Last Name

Company
Company

Email
Email

Are you a member of INCOSE?
Please select

Submit

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

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