SIMPLIFYING MODEL-BASED SYSTEMS ENGINEERING

AN IMPLEMENTATION JOURNEY

New Frontiers

New Cultures

New Thinking

SMS_ThinkTank™

This white paper is sponsored by Dassault Systèmes.

CONTENTS

EXECUTIVE SUMMARY

Model-Based Systems Engineering (MBSE) is perhaps one of the most misunderstood and often abused acronyms in the engineering vernacular. Many companies struggle to understand how it will improve their entire product lifecycle and address the ever-increasing complexity of products. In many companies, executives and middle management experience a lack of understanding regarding the rapid pace of today's technology and its impact on organizations and processes. Technical practitioners may gain additional insight as they focus their energies on establishing strong MBSE practices. The successful implementation of MBSE includes transformations and enhancements in three key areas: organization, process and technology.

This white paper shares proper planning and implementation considerations in adopting an MBSE practice. It provides a high-level view, defines critical components to help success and identifies many problematic areas to avoid in an implementation journey.

INTRODUCTION TO MBSE

The complexity of systems is rapidly increasing across all industries. Embedded systems and interactive environments account for an increasing share of a product's features and its total cost. Through Digital Transformation, companies seek to stay competitive and lead in their market segments. In an engineering driven environment, MBSE is widely regarded as a critical component in this digital transformation.

MBSE is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later lifecycle phases.[1]

Many white papers highlight the benefits of implementing an MBSE way of thinking. This white paper uses the phrase, "way of thinking'' because the journey spans the entire product lifecycle from product development, manufacturing, in-use, maintenance and retirement. The MBSE journey takes leadership, resources and patience.

How do you quantify good engineering? The direct benefits for MBSE can be a bit hard to measure. Some companies have developed complex measurements relating to schedule slips, field recalls, risk analysis and more. This white paper argues that the greatest benefit will be the ability to address the exponentially raising product complexity as a result of greater stakeholder demands. Though a challenge to quantify, tracking improvements as part of a company's MBSE program helps keep management and the wider team remain engaged. Consider the reduced rework errors; improved efficiency from process refinement and optimization; and better product quality. Workforce benefits include improved communication and collaboration using an MBSE governance model, and common use of terms and sharable system models. Engineering teams applying MBSE rigor and discipline to system design and optimization can free up time for innovation. Both indirect and direct benefits deserve attention.

ORGANIZATION

READINESS

Many companies can relate to unsavory reports of a false start. Mistakenly, companies decide to investigate solution providers before MBSE needs are identified. The result can be massive confusion. New tools require a different way of thinking. The common solution – discussed later in this white paper – is to implement a cultural transformation within an organization.

An organization should begin its MBSE journey by looking within before considering external solutions. Companies should assess three major categories: organization, process and technology. The specific sub-categories are beyond the scope of this white paper, but the process is the same. Companies should take a close look at their current "as-is'' engineering environment including (but not limited to) organizational mismatches, process fragmentation and technological shortcomings. Typically, it is helpful to have an outside perspective for the "as-is'' analysis. Resources outside the company offer an objective and realistic perspective (see Figure 1).

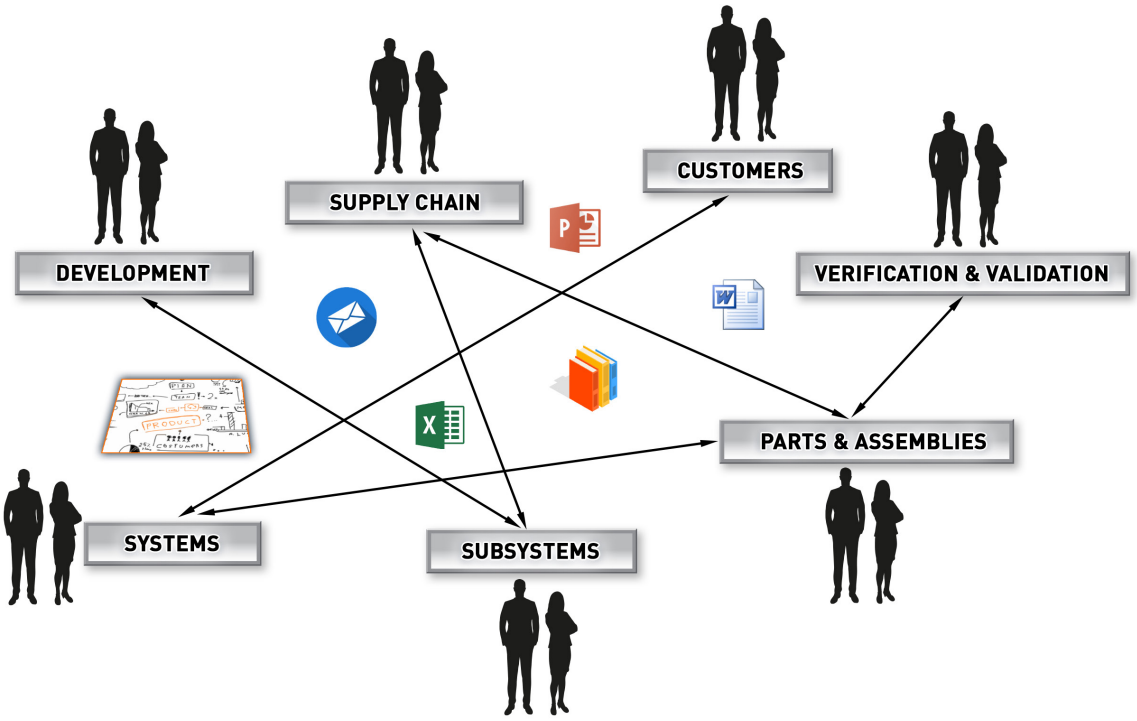

Figure 1: Traditional "as-is'' systems engineering practice

- **Silo-ed** domain models/designs
- **Uncoordinated processes**
- Institutional lifecycle **documents**
- **Informal communications**
  - White Boards
  - Design Team Meetings Presentations
  - Email
  - Chat
  - Napkin

Next, based on corporate plans, companies decide the "to-be'' state and a timeline. Occasionally, this requires substantial research. An outside perspective can also be helpful when defining the potential benefits of an MBSE approach for a high-priority or mission-critical target. MBSE supports a shared "systems model'' where domain specific models are generated and eventually integrated to produce the characteristic overall system behavior (see Figure 2).

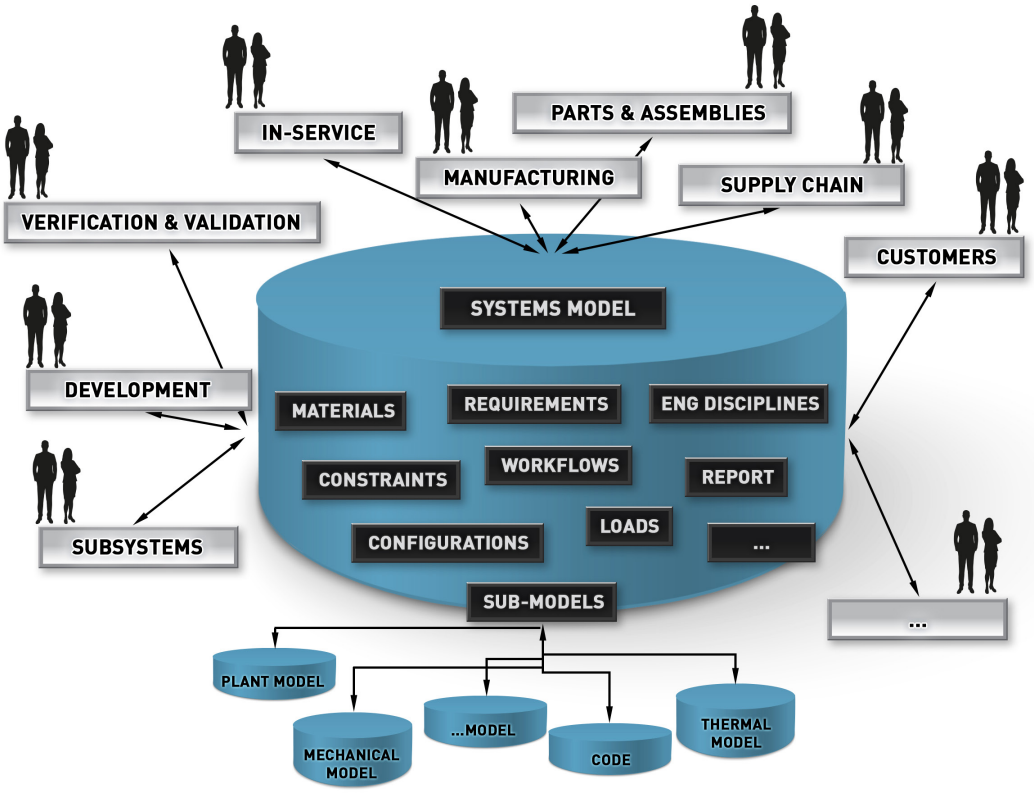

Figure 2: Potential "to-be'' MBSE practice

- **Integrated system model** with multiple views, connected to disipline models
- **Authoritative source** of data & information
- **Closed-loop and collaborative** data and information exchange
- Accessible to **all members** of the project through the model information
- At **every stage** of the **lifecycle**

The equation comes together when a gap analysis identifies the difference between the two initiatives. The tasks required to close the gaps become part of a roadmap. The roadmap becomes a "living document'' as the company executes the defined tasks. Successful roadmaps must be realistic, measurable and hold owners accountable.

When identifying the "to-be'' stage, a company should be open to evaluate if their business model adequately addresses the company's desired position in the marketplace. Specifically, does their business model enable an acceptable level of sustainable innovation? This highly coveted and competitive characteristic is shown using four levels of "S-curves'' (see Figure 3).

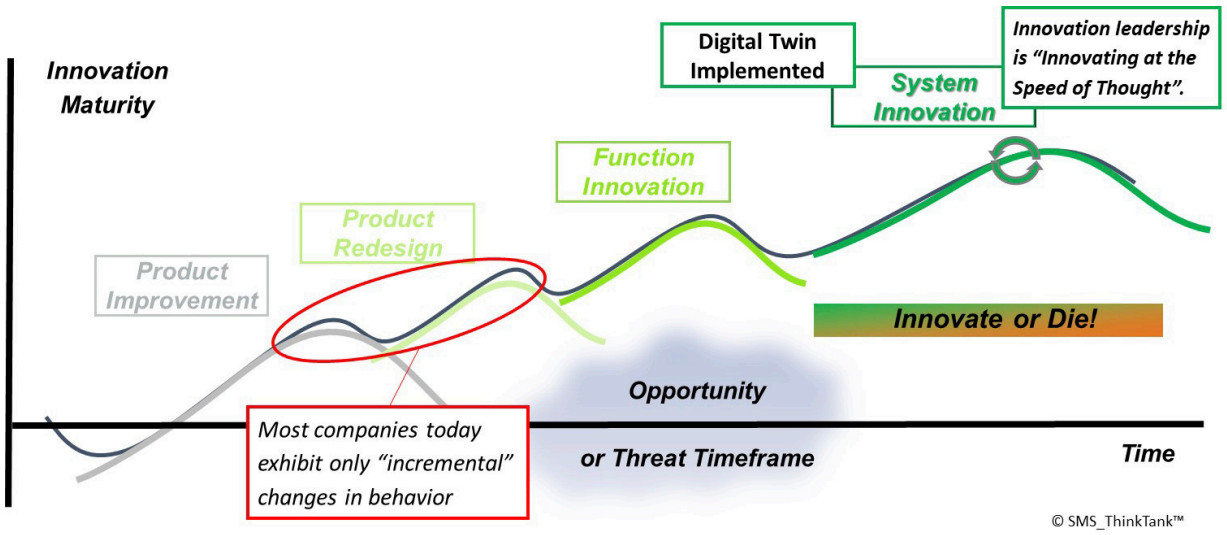

Figure 3: How to achieve sustainable innovation

Notice that effective simulation model storage and management become critical prerequisites (see Figure 2). How data is made accessible and how it is managed determines if a system can really be deemed "integrated''. Models alone do not define the MBSE environment. An MBSE environment requires models to function conjointly. An MBSE model allows information to pass freely across the sub-models to achieve the intended results. Trusted data forms the foundation of MBSE maturity. Companies embrace MBSE to grow market position through increasing performance based on data and analytics. MBSE provides greater insight and helps accelerate innovation (see Figure 4).

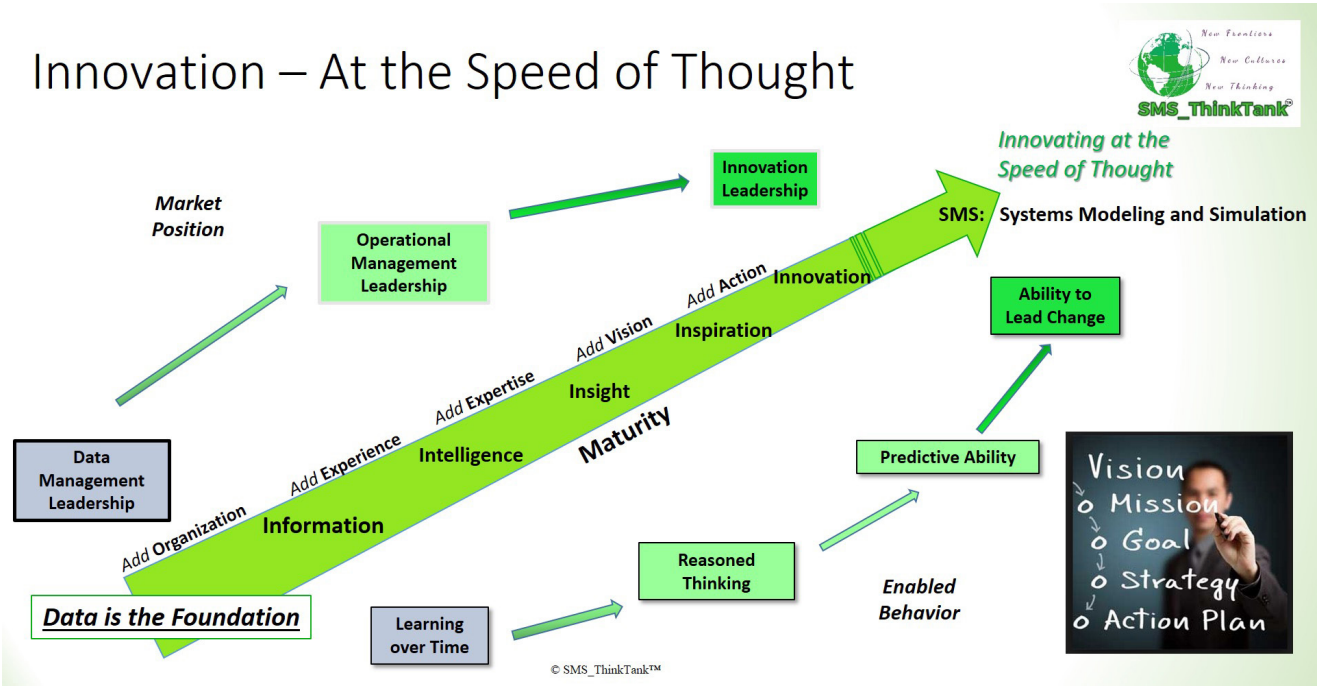

Figure 4: Innovating at the Speed of Thought

The Extremely Large Telescope (ELT) is an astronomical observatory currently under construction in Europe. Figure 5 describes how MBSE best practices could address ELT challenges dealing with information flow and usage. The most important element is that the various parts involved in the system and sub-systems work together seamlessly. Taxonomies and standards, explained later in this white paper, contribute greatly to this interoperability.

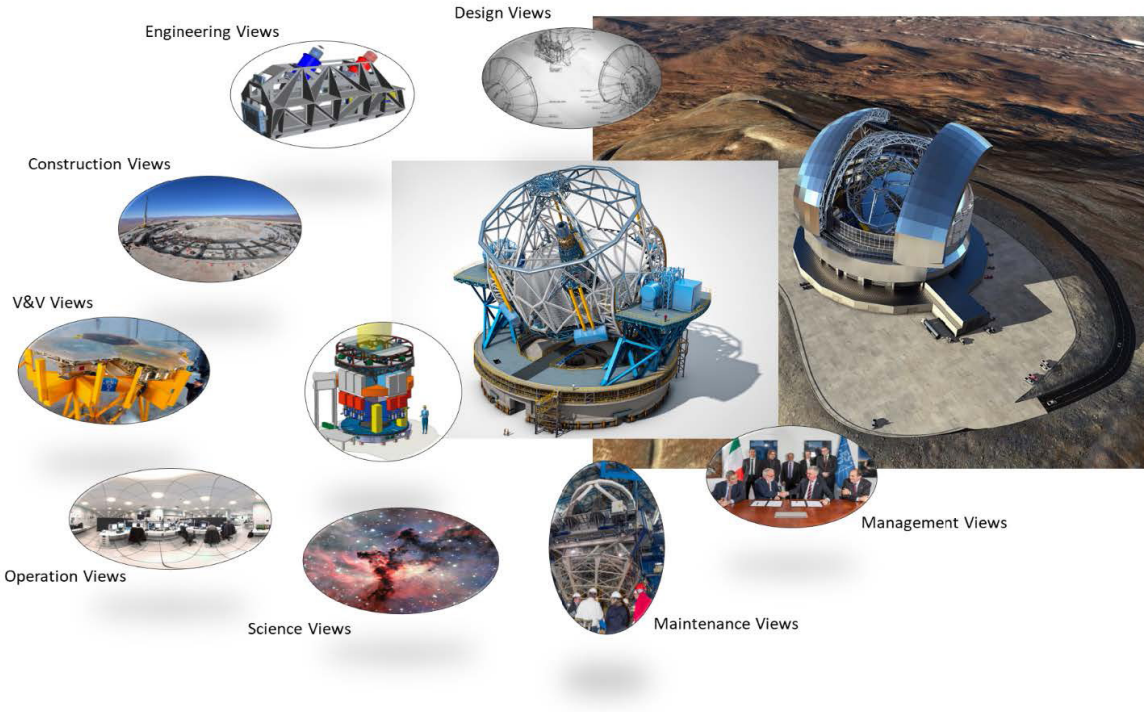

Figure 5: How MBSE addresses the problems of information flow in developing the Extremely Large Telescope project.[2]

Having a consistent, unambiguous and trusted system representation ensures validity and integrity of spawned multi-disciplinary models which:

- Promotes reuse of complex sub-systems models
- Provides traceability and impact analysis for cost analysis and product change
- Ensures communication and collaboration between technological "silos''

An MIT survey asked respondents to select an implementation approach for adopting MBSE software. The results revealed:[3]

- 39% had so many existing models, the effort required to rebuild them in a clean sheet approach was untenable.
- 22% believed that the functionality in clean sheet software would be productive
- 14% have very specific MBSE use cases which would not be addressed in off the shelf tools and would opt to plug their existing models together
- 13% had so many models that tying them together across so many different modeling environments would be impossible, so they would use a clean sheet
- 11% other

The importance of self-examination when embracing MBSE cannot be overemphasized.

INITIATIVE SCALABILITY

Typically, slow and steady wins the race. There are many reasons for early MBSE implementation failures. They might include improper planning, excessive scope, lack of executive commitment, or lack of governance. MBSE adoption also may require the integration of complex processes that involve identifying and following existing and emerging standards. For large organizations, this makes the journey significantly more complex. Although for some simple initiatives, a well-planned approach might include:

- Appropriately scoped objectives and projected outcomes
- Support or sponsorship from upper levels of management
- Commitment of a governance team
- Definition of success, with adjustments as needed as challenges are encountered
- Incorporate lessons learned into tribal knowledge

EDUCATE LEADERSHIP AND THE WORKFORCE

Education and research into the best MBSE solutions and implementation approaches provides the fidelity upon which a company builds its MBSE practice. Some information from sources include: not-for-profit engineering organizations (for example, International Council on Systems Engineering (INCOSE), International Association for the Engineering Modelling, Analysis and Simulation Community (NAFEMS)); industry conferences; on-line university courses; MBSE consortiums; articles and independent consultants.

Formulating the best MBSE implementation approach is a critical decision for your organization and is as unique as a fingerprint. Educating and gaining the buy-in of your company's leaders is critical to developing the MBSE implementation. Keep the message simple. Sharing the benefits linked to high-profile issues is a good way to get the attention of an executive. The request for executive support should include the cost of the technology and the anticipated enhancements to the organization, including its processes and workforce. Many engineering groups are unfamiliar with the V-Model or may have heard of it but do not possess any detailed knowledge. (The V-Model is a graphical representation of a systems development lifecycle.) To make sure everyone has a shared understanding, develop an education roadmap with achievement levels.

GOVERNANCE

Whether aerospace, automotive or other industries, engineering teams act as separate "silos'' of excellence. This can inhibit effective communication and collaboration demanded for a successful MBSE implementation.

Identifying silos is imperative. Integrate all players into your MBSE implementation by establishing a governance committee with participants from each engineering "silo'' and business groups. Establish a sponsor at each level of your organization. Figure 6 shows the main governance levels.

Change management requires executive sponsorship to communicate the importance of an MBSE initiative. This governance committee must visibly provide:

- Engineering leadership
- Well defined structure
- Regular cadences
- Accountability
- Effective reporting
- Authority

Defining a regular cadence for executive committee action, support and communication positively influences cultural transformation within an organization. A governing Systems Modeling and Simulation (SMS) Council carries the weight of your MBSE transformation. Council members align with the Governing Technical Teams and in turn the Business Units. As noted earlier, the group at each level needs a sponsor (see Figure 6).

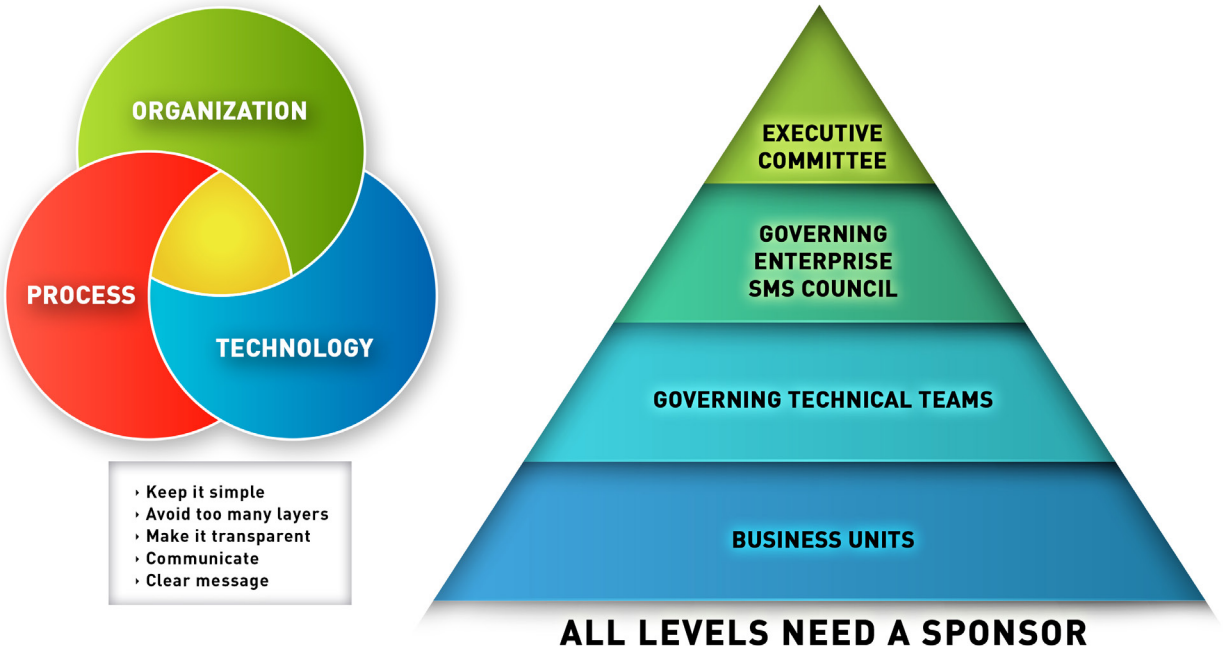

Figure 6: Proper governance is essential

ADOPTION

Industry adoption can be chaotic. By far, automotive companies exhibit the most interest, evident by the industry's investment in pursuing MBSE excellence. The sheer customer demands has brought engineering innovation to the brink of "innovation at the speed of thought'' (see Figure 4). Utility companies, once at the forefront of systems engineering, have lost some ground in capitalizing on MBSE technology advances. However, it is possible to regain ground with dedicated focus and investment. Some suppliers are in a unique position to capitalize on MBSE. Small and medium-sized suppliers benefit from inherent agility without legacy systems. With MBSE, these nimble suppliers can form a more collaborative relationship with their Original Equipment Manufacturer (OEM) customers and smaller suppliers.

EVOLUTION

The MBSE journey includes several milestones (see Figure 7). Companies may be at any level of systems engineering maturity and holistic thinking. MBSE transformations encompass three primary areas: organization, process and technology. Some companies pursue a well-defined, incremental approach. Others companies are more mature having already adopted some basic systems engineering best practices. Ultimately, MBSE requires a well-defined, carefully executed plan over a period of time that takes years not months.

Where do you start? Your "as-is initiative'' drives your starting point. Companies may identify the need to move from a test-driven environment to one that is document-based (See Figure 7). This figure shows a simplified view of the increasing maturity of MBSE stages. A hybrid model may incorporate multiple levels toward MBSE adoption within a company. For this reason, the "as-is'' assessment is a very important component of the early planning process.

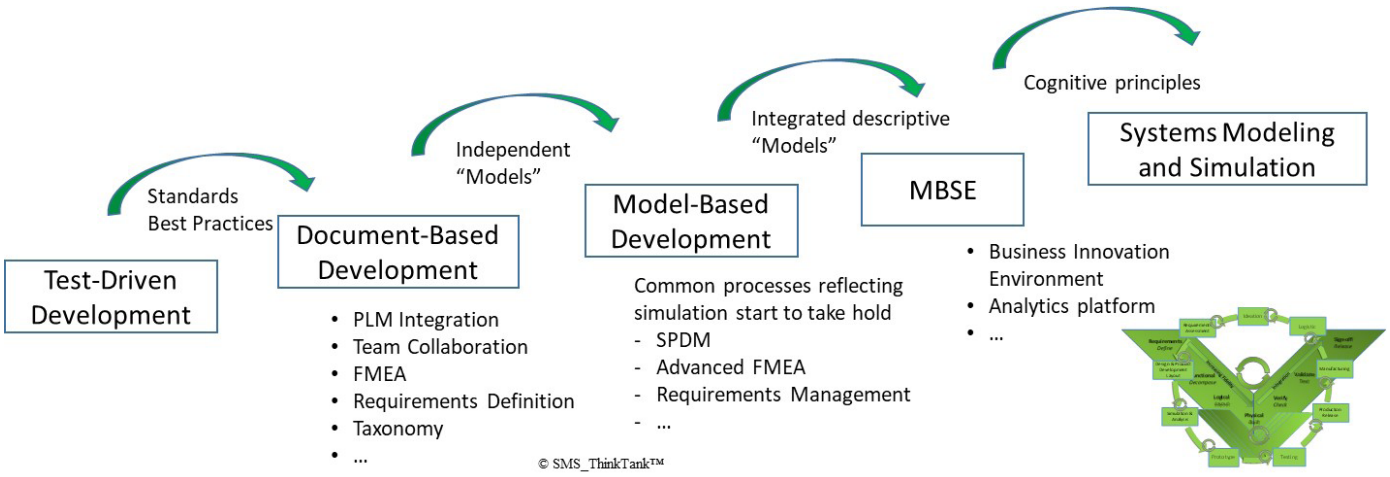

Figure 7: MBSE – maturing towards higher levels in engineering

SURVEYS

Surveys help share MBSE planning information across the enterprise and identify each participant's level of readiness, their needs, the coordination of tasks, identification of obstacles, implementation structure, schedule considerations and much more. Develop simple questions to avoid issues in case groups have different MBSE awareness and provide definitions for terms.

PROCESS

TAXONOMY

One MBSE best practice to consider is the role of taxonomies. Taxonomy, defined as, "a classification into ordered categories,"[4] provides a means to organize large amounts of data. An organized taxonomy reveals similarities and differences in data. MBSE requires taxonomies as a foundation. The different type of taxonomies such as schedule, software risk, failure risk, hazard risk and others are beyond the scope of this white paper. However, consider the use of taxonomies to drive more cognitive behavior. Some questions to consider: Is your corporate, division or department hierarchical structural strategy sufficient? Is it flexible enough to evolve to become part of your MBSE deployment?

TERMS AND DEFINITIONS

In concert with investigating taxonomy, terms and definitions are a critical consideration. Companies frequently experience organizational pain resulting from the unaligned definitions for commonly used terms. Typically, the confusion occurs between various engineering disciplines (hydraulic, electrical, thermal, controls, Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD) and others). When working with OEMs, ask questions like these: What is a model? What is multiphysics? What is multidiscipline? What is scalability? The ensuing discussions between meeting participants is eye-opening and enlightening. The answers to these questions reveal many patterns based upon the engineering disciplines represented. Typically, the discrepancies lead to great confusion and hinder progress leading to frustration. There best way forward is to use a common language. The Systems Modeling and Simulation Working Group (SMSWG)[5] has developed a common set of terms and definitions. This could serve as an assist because some companies already have a list of commonly used terms and definitions. Regardless of the source, cross-discipline engineering teams and suppliers must converge on the meaning of a term.

REQUIREMENTS

Everyone has heard the phrase "garbage-in, garbage-out''. One of the greatest challenges in implementing an MBSE practice is the ability to author, manage and link well-written requirements that can be readily decomposed with test cases. System requirements form the basis of system integration and verification activities. They act as a reference for validation and stakeholder acceptance. Requirements provide a strong link between various technical disciplines throughout the project. They provide the impact of change for a given condition or set of conditions. Requirements ensure compliance with strict regulatory requirements in aerospace, automotive and energy. Government agencies dictate the compliance to critical product and process operations and dependencies before the OEM can bring their products to market. Most requirements include (but are not limited to): functional, performance, usability, interface, cost, schedule, operational, environmental and others

Consider the flowchart in Figure 8, requirements should be clearly stated. Notice the characteristics listed in the top box. Ambiguous characteristics result in confusion for the test cases and can lead to missing the design intent completely.

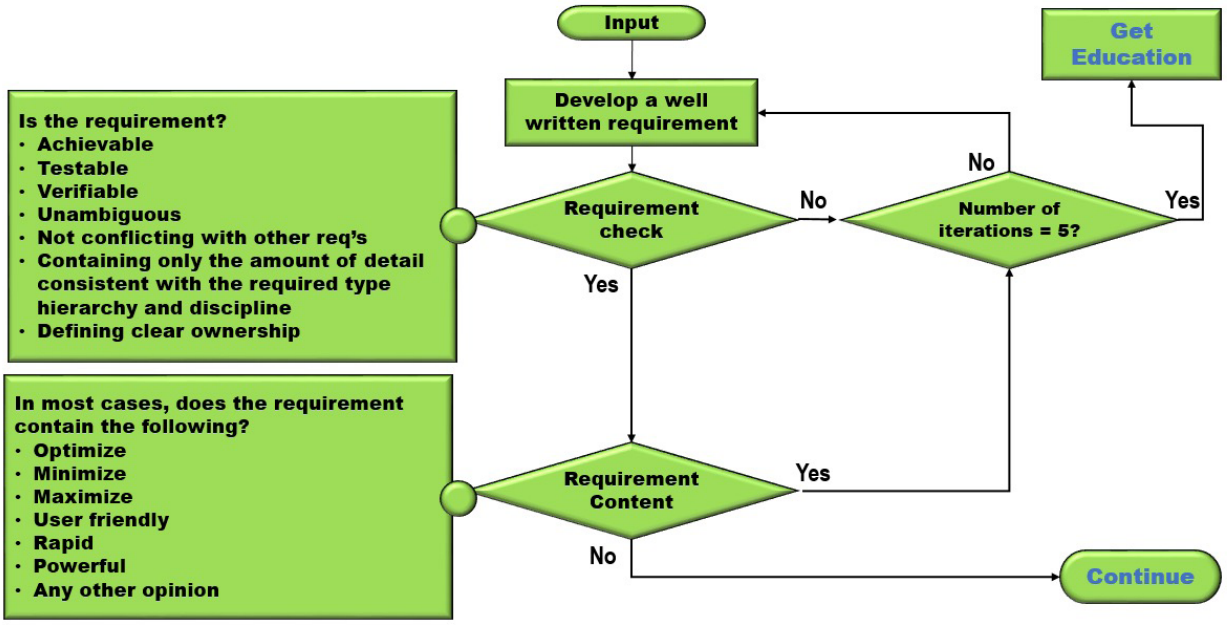

Figure 8: Good requirements flowchart

METHODOLOGY VS. PROCESS

Let us compare the difference between a methodology and a process. A methodology is generally associated with developing an acceptable solution for a project or problem. It typically does not have an associated length of time required to provide a solution. Methodologies formalize processes or sub-processes into phases, stages and procedures. Processes – typically ongoing and repeatable – provide a consistent and efficient way to carry out a given set of tasks.

This comparison helps to prepare the MBSE planner for the tasks associated with reviewing their existing processes and determining the suitability to become part of the MBSE best practices. In many cases, processes are modified in one manner or another to properly fit with the necessary framework. The methodology driving this task must include all consideration for process integration. When looking into

an organization that is contemplating the MBSE journey, requirements are the most critical prerequisite. Without strong requirements, companies may produce products as they have done in the past, which may no longer be sustainable. The sheer complexity of future projects leaves companies with no alternative but to embrace MBSE with all the inherent challenges of late adoption.

TRIBAL KNOWLEDGE

Tribal knowledge is the information that is part of someone's gray matter and found scattered across computer drives in your engineering organization. Capitalizing on tribal knowledge provides a huge advantage in developing MBSE best practices. By capturing this knowledge, components of the MBSE implementation become more "intelligent'' which leads to greater efficiency and promotes more cognitive behaviors. In many cases, for an organization this knowledge answers the questions of "why'' the company is using this strategy or method which leads to great process efficiency, optimization and, in some cases, innovation.

Do not underestimate the value of tribal knowledge. Decades of experience can sometimes get lost over time as employees retire or move on to another job.

STANDARDS

The importance of identifying and linking disparate processes is part of the MBSE central nervous system. To thread together trusted processes, linking or integrating methods must be identified, tested and validated. This ensures the correctness of the data, speeds model data flow, accuracy, completeness, size and manageability among other benefits.

MBSE interoperability reveals that standards interoperability is the greatest gap among MBSE implementations. Too many standards can be worse than too few. To address the complexities of model-based interoperability, be prepared to investigate some existing and emerging standards: Modelica, Functional Mock-up Interface/Functional Mock-up Unit (FMI/FMU), System Structure and Parameterization (SSP), Product Data Exchange Specification/Standard for the Exchange of Product model data (PDES/STEP AP), Long-term Archiving and Retrieval (LOTAR), Modelling and Simulation Information in a Collaborative Systems Engineering Context (MoSSEC), Organization for the Advancement of Structured Information Standards/Open Services for Lifecycle Collaboration (OASIS/OSLC), Resource Description Framework (RDF), Extensible Markup Language/XML Metadata Interchange (XML/XMI), Unified Modeling Language Diagram (UML DI), Object Management Group (OMG), Requirements Functional Logical Physical (RFLP), Requirements Interchange Format (ReqIF), Systems Modeling Language (SysML) v2, Unrestricted Access Framework (UAF), Modeling and Simulation (MODSIM) and other standards.

TECHNOLOGY

ARE WE MAKING MBSE HARDER THAN IT SHOULD BE?

Some industries, especially Aerospace & Defense (A&D), are well versed in systems engineering and embrace the pursuit of formal implementations of MBSE. Very large A&D corporations have the challenge of aligning many partnerships and suppliers each with dependencies. Their overall development is extremely complex allowing only a small margin of error.

Additionally, this journey has been an extreme focus for many years. Could the implementation challenges experienced by A&D companies influence agile small and medium-sized industries attempts? The automotive industry has an entirely different approach in delivering their products to consumers. With high volume, relatively low costs and escalating consumer demands for features, many automotive companies are in a highly reactive state. As a result, the rapid turnaround of new models can be compromised. Other industries are in the same position.

Does the approach have to be "all-in''? Are there points of diminishing returns? Are there solutions that can effectively address targeted areas of the organization that would deliver early successes? This white paper believes the answer is a profound "yes!''. It does not focus on specific software solutions but instead shares best practices.

INFORMATION TECHNOLOGY

Is the proper technology (solutions and infrastructure elements) in place and supported to allow for scalable data sharing, real-time and mobile access to data and information? The capability to enable the analysis of data, typically large sets of business, simulation, test or general process data is the foundation of the MBSE journey. Hardware and software with adequate support must be in place to support enterprise-wide modeling and simulation. Typically, simulation models are stored in a sea of hard drives across the enterprise with little or no ability for one to determine their existence. Effective simulation model storage and management is a critical prerequisite. (For more information, see Figure 1 and Figure 2.)

This is a crucial IT contribution and justification to involve your IT leaders early in the planning stages. Trusted data forms the foundation of MBSE maturity (see Figure 4).

TRUSTED DATA

After defining requirements and model storage, trusted data is one of the greatest challenges. The accuracy of the Computer Aided Engineering (CAE) and data multi-domain models (mechanical, electrical, controls, fluids, thermal, optics, acoustics and others) is frequently not trusted and as a result, considerable time is wasted in reproducing simulations. This has been witnessed within the same department and especially across engineering domains. Creating a common directory of commonly used system models will greatly accelerate the development of a project and help reap the benefits of an MBSE implementation (see Figure 2).

SOLUTIONS

Solutions should have a dedicated white paper and this white paper provides basic guidance. When planning for a set of software solutions for an MBSE implementation, keep in mind that some companies experienced "more is not better''. Look for software solutions that are easily integrated and scalable. Let your gap analysis discussed earlier be your guide. Also learn from those that have deployed or are deploying MBSE in your industry.

IMPLEMENTATION

A company's implementation approach should take the form of a Y and U model or YU model (see Figure 9). Progressive development is a holistic development integrating process, methods and tools.

Once the gaps are clearly defined from the "as-is'' and the "to-be'' states, the recommendations derived from the gap analysis should serve as a roadmap. By carefully prioritizing and scheduling the tasks into short-, medium- and long-term initiatives, the implementation plan is developed.

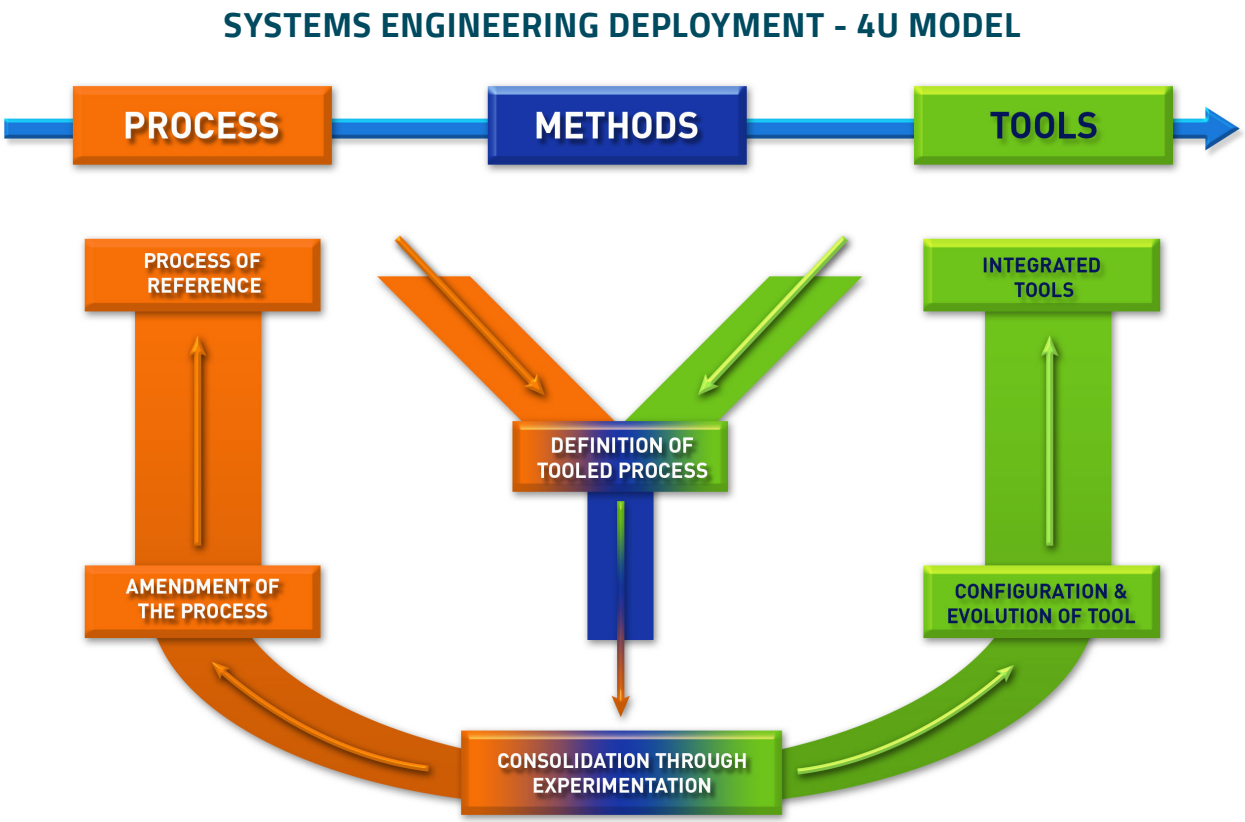

Figure 9: Model-Based Systems Engineering deployment model (used by permission of Dassault Systèmes)

MBSE moves toward a shared system model where domain specific models are generated and integrated with the system model to simulate overall system behavior (see Figure 10). MBSE can be a complex initiative. Do not expect an overnight adoption. MBSE requires taking incremental steps. Collaborate with your software solution partner based upon your plan.

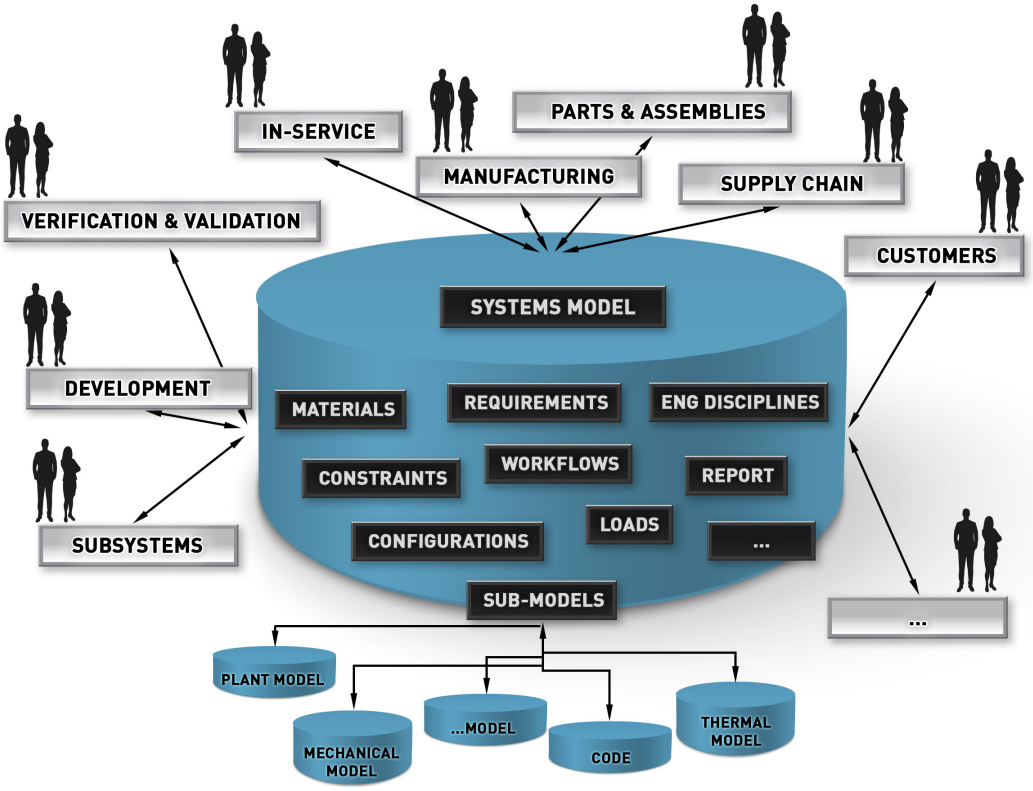

Figure 10: Potential "To-Be" MBSE Practice

- **Integrated system model** with multiple views, connected to disipline models
- **Authoritative source** of data & information
- **Closed-loop and collaborative** data and information exchange
- Accessible to **all members** of the project through the model information
- At **every stage** of the **lifecycle**

CONCLUSION

MBSE moves an organization toward using a shared system model (see Figure 10). With considerable planning, the perceived journey may not be as traumatic as anticipated, especially for small to medium-sized businesses. The successful implementation of MBSE includes transformations in three key areas: organization, process and technology.

Organizational transformations start with gaining commitments from all levels of management and practitioners fused with the drive for success is critical to begin this evolution. Do not perceive this as a cultural change but as cultural growth. Collaboration is the lifeblood of implementation.

Process transformation starts with examining the area(s) to transform. Like fingerprints, no two MBSE implementations will be identical. The establishment and maintenance of a solid data and process management environment is crucial.

Executive sponsorship, corporate education and an outside point of view when needed all contribute to successful MBSE implementations. Governance involving executives, management and practitioners also accelerate and sustain progress. Establish milestones and reward accomplishments. Prioritize tasks and leverage high ROI short-term achievements, while ensuring proper linkage to the medium- and long-term goals.

Avoid "all-in'' scenarios because these typically lead to false starts and confuse the organization. Slow and steady will win the race. Scrutinize existing product requirements for quality and linked test cases. The quality and maturity of engineering requirements (functional, regulatory, performance and others) dictate the rate of your MBSE adoption. This can deliver huge dividends along the journey.

Technology considerations include robust data, where the source is trusted and sound process management environment. Regenerating models across various disciplines helps to improve the accuracy of results. However, this wastes considerable resources. MBSE helps solve this issue when with up-front planning.

The adoption of MBSE will take time and patience. Remember, MBSE is not a tool but a journey.

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ABOUT THE AUTHORS

CEO & Co-founder
+1-704-254-1643
ed.ladzinski@smsthinktank.com

Edward A. Ladzinski is the CEO and Co-Founder of SMS_ThinkTank™. He began his career as a Manufacturing Engineer, NC Programmer and Tool Designer with Burroughs Corp. (now Unisys Corp.). In 1978 he joined IBM in the Kingston, NY laboratory as a Research & Development Engineer. During his 32-year career with IBM, Mr. Ladzinski worked in many different positions within engineering including systems research, systems product design/development and analysis/simulation. Immediately upon his retirement from IBM, Mr. Ladzinski joined Dassault Systèmes as the Systems Engineering leader for North America. In 2014, he left Dassault Systèmes and formed his own company dedicated solely to systems engineering. Mr. Ladzinski serves on the NAFEMS Americas Steering Committee and is the co-founder of the Stochastics Working Group, Simulation Data Management working group and the joint INCOSE/NAFEMS Systems Modeling and Simulation working group. He is also the chairman of the Analysis & Simulation and Systems Engineering tracks at COE (Community of Experts, www.coe.org). He was awarded the distinction of COE Fellow in 2013 and is the winner of the best Engineering and Analysis Division conference paper with presentations on Systems Engineering and Collaboration in both 2012 and 2016. He was elected to the COE Board of Directors in 2016. He is an engineering graduate of RIT (Rochester Institute of Technology) and performed graduate work in Engineering and Business at RIT and UNCC (University of North Carolina Charlotte), respectively. In his spare time, he is a guest lecturer at industry/technology conferences and several university events

Managing Partner & Co-founder
+1-630-423-2497
frank.popielas@smsthinktank.com

Frank W. Popielas is the Managing Partner and Co-founder of SMS_ThinkTank™. He has over 20 years of global experience in engineering and R&D product and materials development, IP management, as well as testing, with a specific focus on the development and application of simulation tools and the establishment of the required supporting infrastructure at Dana Holding Corporation. His expertise includes technology exchange and transfer, business assessments in engineering and manufacturing focusing on the virtual aspect, as well as process development and democratization of its application in this area. Mr. Popielas has been a member of the NAFEMS Americas Steering Committee since 2011. He is the founding chairman of the joint System Modeling and Simulation Working Group (SMSWG) between NAFEMS and INCOSE in 2013 and continues his leading role in the SMSWG as Co-chair since August 2016. He was awarded over 35 granted patents globally on the areas of sealing, shielding and fuel cells with over 30 publications globally covering all the mentioned areas with the focus on the past decade on virtual engineering, its tools and practices. He participates in various and speaking engagements at conferences and various companies, interviews, case studies and teaching engagements. He holds an MSc degree in Engineering, majoring in Theoretical Physics from the Technological University (MIS&A – Institute for Steels and Alloys) in Moscow, Russia and is fluent in English, German and Russian.

ABOUT SMS_THINKTANK

SMS_ThinkTank™ LLC is the global resource and leader in system modeling and simulation, bringing the worlds of systems engineering and computer aided engineering together. SMS_ThinkTank™ is a vendor neutral firm which provides strategic systems engineering and CAE management consulting to help enterprises embrace Model-Based Systems Engineering (MBSE) to achieve sustainable innovation bringing higher quality products to market faster. SMS_ThinkTank™ helps enterprises in developing the methodologies to support these new technologies including emerging systems engineering and CAE standards.

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