ASME
SETTING THE STANDARD

Model-Based Enterprise Standards Committee

Recommendation Report

Model-Based Enterprise Steering Group

American Society of Mechanical Engineers

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Executive Summary

In March 2018, American Society of Mechanical Engineers (ASME) appointed 10 members from industry, government, and academia to a Steering Group (SG) with the purpose of developing expert recommendations on the direction and organizational structure of the Model-Based Enterprise (MBE) Standards Committee (SC) and subcommittees. This recommendation report contains the proposals developed by the SG for the direction, activities, and priorities of the ASME MBE SC. The report also provides a brief background of and motivation for MBE. The intent of the MBE standards activities is presented before the recommended MBE SC structure is proposed. Then, a methodology for developing the MBE standards using a model-based approach is discussed. Finally, a marketing and adoption strategy and a MBE standards roadmap are outlined. The ASME Board on Standardization and Testing (BST), ASME staff, prospective standards developers, technical-assessment personnel, and interested end-users are the intended audience of recommendation report.

Key Findings

After careful analysis, a number of conclusions have been reached:

1. **MBE SC structure.** The MBE SG recommends the following committee structure:
   (a) Model-Based Enteprise Standards Committee
      i. Liaisons
      ii. Terms Subcommittee
      iii. Use Cases, Concepts, and Context Working Group
      iv. Information Connectivity Subcommittee
      v. Product Representation Subcommittee
      vi. Process Representation Subcommittee
      vii. Training and Education Subcommittee
      viii. Assessments and Certification Subcommittee
2. **Model-based standards development (MBSD) methodology.** The MBE SG recommends the MBE standards be developed using model-based methods and that the methodology include guidance for the following elements:
   (a) Standards development policy
   (b) Modeling languages,
   (c) Verification and validation (V&V)
   (d) Configuration management
   (e) Standard delivery
   (f) Normative sources
   (g) Informative documentation
   (h) Supportive resources

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About the Steering Group

In March 2018, American Society of Mechanical Engineers (ASME) appointed 10 members from industry, government, and academia to a steering group with the purpose of developing expert recommendations on the direction and organizational structure of the Model-Based Enterprise (MBE) Standards Committee (SC) and subcommittees. The following are the members of the MBE Steering Group (SG).

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About the American Society of Mechanical Engineers

ASME is a not-for-profit membership organization that enables collaboration, knowledge sharing, career enrichment, and skills development across all engineering disciplines, toward a goal of helping the global engineering community develop solutions to benefit lives and livelihoods. Founded in 1880 by a small group of leading industrialists, ASME has grown through the decades to include more than 130,000 members in 151 countries. Thirty-two thousand of these members are students.

ASME is the leading international developer of codes and standards associated with the art, science, and practice of mechanical engineering. Starting with the first issuance of its legendary Boiler & Pressure Vessel Code in 1914, ASME's codes and standards have grown to nearly 600 offerings currently in print. These offerings cover a breadth of topics, including pressure technology, nuclear plants, elevators / escalators, construction, engineering design, standardization, and performance testing.

The ASME Board on Standardization and Testing (BST) will oversee the MBE Standards Committee. The ASME BST manages and supervises the dimensional, design, application, drafting, performance test codes and miscellaneous standards activities of the Society, as designated by the Council on Codes and Standards. The standards developed by groups managed by the board are intended to be submitted to the American National Standards Institute to become American National Standards.

Disclaimers

Certain commercial systems may be identified in this report. Such identification does not imply recommendation or endorsement by ASME or the affiliated organizations of the authors. Nor does it imply that the products identified are necessarily the best available for the purpose.

1 Introduction

In October 2016, recommendations from several American Society of Mechanical Engineers (ASME) Y14 committee members were brought to ASME staff to pursue a new effort around Model-Based Enterprise (MBE) processes. In April 2017, ASME held an in-person brainstorming session during the MBE Summit hosted by the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. Industry experts agreed there is a high-priority need to establish a new standard committee tasked with developing standards, providing rules, guidance, and examples for the creation and use of model-based datasets, data models, and related topics within MBE.

In March 2018, ASME appointed 10 members from industry, government, and academia to a steering group with the purpose of soliciting expert recommendations on the direction and organizational structure of the eventual MBE Standards Committee (SC) and subcommittees. The MBE Steering Group (SG) began holding teleconferences weekly in June 2018. The effort culminated in consensus on recommendations during a two-day face-to-face meeting in September 2018 hosted by Mitutoyo America at their headquarters in Aurora IL.

The major deliverable from the MBE SG is this report delivered to Mr. Steve Weinman in the care of the ASME Board on Standardization and Testing (BST). The report proposes and recommends an overall MBE SC structure, considerations for a basic governance policy and procedures of the MBE SC, and requirements for a model-based standards development methodology. The report also provides a brief background of and motivation for MBE. The intent of the MBE standards activities is presented before the recommended MBE SC structure is proposed. Then, a methodology for developing the MBE standards using a model-based approach is discussed. Finally, a marketing and adoption strategy and a MBE standards roadmap are outlined. The ASME BST, ASME staff, prospective standards developers, technical-assessment personnel, and interested end-users are the intended audience of recommendation report.

1.1 MBE Standards Stakeholders

The target stakeholders of the MBE standards are individuals and organizations that use digital engineering data to drive downstream applications such as manufacturing, servicing, and technical documentation. Today, most organizations use engineering drawings as their authoritative source for product definition and to drive downstream operations. These activities may transition to using digital data and three-dimensional (3D) data instead of drawings, Thus, people and organizations that currently create and use engineering drawings will become users of these standards.

Also, any organization going through a digital transformation to become a model-based enterprise would benefit from this standard series. Currently, there is very little official documentation or standardization on MBE within industry. The only documents under development in this area are Y14.41, Y14.46„ and Y14.47 and their scope primarily covers generating models for human consumption.

1.2 MBE Standards Scope

The MBE standards must provide rules and structure that facilitate creation and exchange of digital product definition (DPD) and associated data for reuse in downstream datasets, such as, analytical datasets and process-definition datasets. The MBE standards must also facilitate creation and exchange of model-based DPD in upstream and downstream operations. The DPD and associate data defined be the MBE standards are not intended for drawing-only authoritative source definition. The standards must facilitate data exchange, sharing, and reuse between design, analysis, manufacturing, inspection, assembly, and all other lifecycle activities regardless of their originating system. Such exchange and activities will increase productivity of U.S. commercial industry and government activities.

In addition, data-traceability requirements must be normalized, which will provide direct economic benefit to regulated industries through a standardized traceability process. Today, regulated industries have one-to-one agreements with regulatory agencies for controlling DPD datasets. Normalizing the data-traceability process, will enable industries and regulatory agencies to streamline the control of digital data and reduce the economic burden of all stakeholders.

1.3 Verbal Forms

1.3.1 Must

The verbal form "must" indicates requirements to be followed strictly to conform to this document and from which no deviation is permitted. Must is synonymous with "shall."

1.3.2 Should

The verbal form "should" indicates that one possibility among a set of possibilities is recommended as particularly suitable (without excluding other possibilities) or that a certain course of action is preferred but not necessarily required.

1.3.3 May

The verbal form "may" indicates a course of action permissible within the limits of the document.

2 Background

2.1 Industry Problems and Needs

Historically, the communication of technical information about products and processes throughout the enterprise was done through the use of detailed drawings or other two-dimensional (2D) forms of paper-based information. Those detailed drawings often contained information such as depicitions of the product's geometry, manufacturing process information, installation notes, version and configuration information, and much more [1, 2, 3]. As technology has evolved for defining products, from 2D paper drawings to 3D computer-aided design (CAD) software tools, the nature of the information included within those artifacts has evolved, as well. Where drawings routinely contained material, process, and inspection information in the past, a division of information has evolved as CAD systems have become the primary design tool in most organizations [4, 5, 6]. While CAD systems are quite good at capturing geometric and shape definition of a product, the resulting data from 3D CAD systems today is rather sterile in terms of behavioral and contextual references, due in large part to the evolution of software tools that align with the different functional areas of an organization (e.g., manufacturing analysis, materials definition, structural analysis, production planning).

Model-based definition (MBD) and MBE represent a paradigm shift occurring in the way industry communicates and uses technical information today. A DPD dataset is often focused upon on the transition from using 2D drawings to using 3D CAD models as input to modern manufacturing. It includes the shape definition, but must also include the behavioral and contextual definitions as well, similar to legacy 2D drawings. The DPD forms the conduit by which design can communicate with manufacturing, analysis, and inspection more efficiently [6, 7, 8]. A MBE is an organization that uses digital, model-based communication and definition mechanisms as a way to work more efficiently than using 2D drawings. This is a key concept as production capability and capacity are critical components in any product-producing enterprise, but they are often plagued by layers and layers of redundant disconnected data, quality challenges, information discrepancies, and incomplete product definitions. MBD and MBE enable an integrated and comprehensive approach to communicate, define, and represent complex phenomena.

Historically, drawings were used to communicate information. In an engineering setting, they represented the most effective way to communicate a product's requirements based on the design tools available at the time. Over time, drawings became more sophisticated in their information content and their representation of the object being documented. Modern technical drawings often contain more information related to the product definition than actual geometry views of the object [3]. Most engineering drawings use orthographic views of product geometry. Orthographic views are abstract, difficult to understand, and depict the product inadequately for easy understanding of product geometry. Thus, orthographic views do not provide adequate context for understanding product requirements. Other non-geometric data contained on drawings is often defined implicitly, requiring contextual understanding on the part of the reader to make sense of the information. The level of contextual understanding needed is typically dependent upon the drawing reader's tasks in his/her given workflow [1]. This contextual information is not explicitly specified like a dimension or tolerance, rather it is interpreted by the reader of the drawing.

Implicit information is a critical component in engineering drawings; without it, production efforts would be hindered, inspection processes would often be incomplete, and assembly methods would tend to lack needed information to define the proper fit. As drawing creation evolved to meet the communication and validation needs within specific corporate production environments and their supply chains, the result was a variety of ways to apply the body of national and international drawing standards, with each application being unique to individual companies.

This individualized application of drawing standards within a specific company began to cause challenges within the various manufacturing sectors and their supply chains. Since companies often have their own way of executing specific processes and interpreting specific sets of information, the resulting interpretations of information from drawings across industry sectors meant a different interpretation of the same drawing from one company to another. Participants of different workflows would receive the same drawings, but each participant's interpretation of the information presented in the drawings will differ [9]. Even the current DPD standards [10, 11] for using 3D CAD models in place of 2D drawings [12, 13] has not eliminated the need for individualized interpretation.

As the evolution of product definition and documentation has prompted the transition from 2D, paper-based drawings to digital, 3D annotated models, the differences in contextual interpretation of those artifacts remain. A related issue in this discussion of contextual interpretation of artifacts is spatial proximity. In the past, engineering employees often worked in the same location as the production personnel making the product, which allowed for quick, informal communication. This helped prevent the loss of implicit information and promoted behavioral and contextual understanding of the design and production of the product, because if a person was unable to understand an aspect of the drawing, they could easily find the answer. Now, global supply networks, and "design anywhere, make anywhere" business models have made it necessary that the semantic interpretations of digital artifacts (i.e., 3D MBDs) be explicitly defined [14, 15].

The discontinuity among product-data-authoring systems must change for the MBD methodology to succeed in the long term as something more than a simple remaster of a drawing definition by including implicit information. While the method of product definition or interpretation is important, the method for information dissemination is just as critical [16].

2.2 Motivation for MBE

The state of manufacturing today is moving towards leveraging digital data across the enterprise. As such, many commercial and government organizations are looking to leverage 3D data in their digital-transformation roadmaps. Over the years, the term MBE has emerged as the predominant method to describe authoring, reusing, consuming, and collaborating with 3D data throughout an organization.

An example of using 3D data beyond product definition is the concept of the digital twin. The digital twin is a "one to one replica" of the physical object. As described by Glaessgen and Stargel, "A digital twin is an integrated multi-physics, multi-scale, probabilistic simulation of an as-built vehicle or system [or assembly, component (item)] that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding [physical] twin," [17]. Behavioral modeling methods and technologies that network models may need to be further developed for the digital twin to be realized.

The consolidation of product-definition information into a DPD dataset provides numerous benefits across the lifecycle. For every user of 3D CAD models in design, engineering, or manufacturing, there are thirty potential users of data in marketing, product documentation, sales, support, customer service, and beyond [18]. Boeing demonstrated the power of successful MBD implementations. Boeing engaged in a Virtual Product Development technique where the product design, tooling, and manufacturing processes, prior to fabrication were verified virtually. This approach achieved a 62 percent reduction in product development time and 42 percent reduction in the cost of development [5, 19]. Another study showed that transforming from paper-based processes to model-based processes for design, manufacturing, and inspection would reduce part-delivery cycle-time by 75 percent on average [6].

To date, many organizations have shown support for MBD being a more effective method of communication than engineering drawings. As such, 3D CAD model usage throughout the product lifecycle will continue to grow. To maintain the benefits and maximize the utility of the 3D CAD model, MBD may be used differently than drawings are used today. For instance, information unable to be captured in a drawing can be captured in DPD datasets. Industry's understanding of product-definition information today may evolve in the future.

Although models can carry the same explicit information defined in drawings, the next step in model development is the creation of a framework of associative datasets with context that contains all information required for the specific individual who would use the model. A minimum information model could benefit multiple actors within the lifecycle by delivering the information needed in a specific workflow in a specific lifecycle stage [8]. The use of MBD (and by extension, a minimum information model) within manufacturing companies may be an appropriate approach due to the benefits offered by leveraging the 3D model [20].

Various examples of MBE exist today, and more will emerge as technologies, processes, and standards evolve. The ASME MBE standards, guidelines, and recommended practices will serve to support industry's understanding digital transformations across the product lifecycle while also acting as a repository of commonly understood information surrounding MBE.

3 Intent of MBE Standards Activities

3.1 Opportunities Enabled by the MBE Standards Activity

MBE will transform industry by increasing productivity, quality, profitability, and types of products, and by reducing wasted effort, wasted time, non-value-added work, lost information, missed opportunities, and time to market. MBE needs standards for providing digital datasets, frameworks, and workflows that facilitate high productivity and automation using a common set of information throughout a product's lifecycle, from initial idea to product retirement. MBE enhances access to information and communication at previously unattainable levels, as it allows detailed, actionable data (such as: feedback, lessons learned, and process data) to be associated to feature-level product data. This data may come from any part of the lifecycle and must be available to every other part of the lifecycle. To be successful, MBE must be widely adopted by industry and at all levels internally and across supply chains. MBE methods must be based upon internationally recognized standards from a reputable Standards Development Organization (SDO). The ASME MBE standards activity is poised to fulfill this role.

Perhaps the best way to explain MBE today is that it is the business model in which the creation and use of 2D drawings and documents are eliminated, the use of digital data is optimized, and the benefits of these changes are maximized. In MBE, document-based processes and workflows are replaced by data-based processes and workflows. Document-based processes and workflows are inherently inefficient, they drive segmentation of information and siloed business structures, they reinforce and drive creation, retention, and management of redundant disconnected information and the tremendous costs associated with it, and they conflict with what graduates entering the workforce are ready to do, capable of doing, and the manner in which they expect to do it. New hires are faced with staggering levels of inefficiency and archaic methods, and complacency and acceptance of these methods by the existing workforce. The goal of MBE is to optimize how products are developed, defined, optimized, improved, and managed, and how their information is promulgated across the extended enterprise, how information is shared by all activities throughout the product lifecycle, how data is reused rather than recreated, and the resulting increases in productivity, quality, throughput, efficiency, and profitability through automation, artificial intelligence (AI), and machine learning.

NOTE: The benefits in this section are understated and not well understood in industry, as most people have no idea of the magnitude of inefficency in their current business processes and that they are so inefficient.

MBE requires a new approach to doing business. For MBE to succeed, siloed business structures and concepts of "my information" vs. "your information" must be replaced. Current reward systems and metrics for segregated business activities must change. For example, from a design point of view, metrics such as drawings released per week must be replaced by metrics such as level of reusability of engineering data or reduced negative impact tracking (e.g., comparing how easily engineering data is reused vs. the negative impact of current document-based deliverables and workflows). Standardized interfaces must be developed that facilitate bi-directional transfer and ingest of information from other departments, other disciplines, other organizations, the supply chain, from deployed products, and from end users in the field. The MBE standards activity must enable these ideas and make their adoption as easy and risk free as possible.

3.2 Goals for MBE Standards Activities

The following are goals the MBE SC must establish fo the ASME MBE standards activities:

1. Develop standards that provide a structural and logical framework that supports full implementation and optimization of MBE based on representation data and data reuse.
2. Develop standards and related products that provide rules, guidance, and examples for the creation, use and reuse of model-based datasets, data models, and related MBE topics.
3. Develop standards that reduce risk, enable consistency, ensure trustability of data and datasets, interoperability, bidirectional communications and feedback for software developers, solution providers, organizations adopting and implementing MBE, and their supply chains.
4. Provide an environment and platform to envision, enhance, create, and release standards and related products that facilitate understanding of MBE and its successful implementation in industry and government and that helps academic institutions understand MBE and how best to prepare the workforce of tomorrow.
5. Enable development of tools, methods, structures, and environments that facilitate conversion to MBE and full adoption and implementation of MBE throughout industry and support the entire product lifecycle from ideation to retirement.
6. Enable the capture of and bi-directional free flow of knowledge and expertise across the entire product lifecycle such that the best possible decision can be made using the best available information.
7. Create an environment in which the benefits and true goals of MBE are championed and broadcast, ASME is seen as the leader in MBE standardization, and engagement and development of expertise within industry, academia, and government are emphasized.
8. Provide an environment in which people from industry, solution providers, academia, government, and other SDOs can discuss and develop consensus-based forward-thinking solutions and systems that support MBE adoption and implementation.
9. Support and enable the digital transformation of the product lifecycle so industry will understand and achieve the opportunities of MBE using sustainable and effective methods of commerce in realizing products.
10. Ensure that all activity and output follow ASME policies and support open source, neutral approaches, and formats.
11. Develop standards using model-based methods to achieve the benefits model-based methods enable. Clarify the benefits of model-based standards to industry and solutions providers.

12. Ensure MBE standards are coordinated with presentation standards and liaised such that the needs of both activities are achieved.

3.3 Interfacing with Other Activities

The MBE standards activity must build upon, assist, and offer feedback and guidance to other standards development activities. ASME MBE standards must cover new ground where needed, develop methods to transition document-based methods to data-and-model-based methods, request changes needed to document-based standards to remove obstacles to MBE, request new methods be developed in document-based standards to enable MBE, and request changes to the pedigrees of document-based standards to clarify they are document-based or to change their scope to facilitate the clear separation of document-based and model-based workflows. The MBE SC must listen to and work with all related activities. The MBE SC must strive to enable MBE and the future. The MBE SC must avoid competing with existing standards activities, the MBE SC should leverage other's help to realize goals, which coincide with their goals – the expansion and improvement of United States industry.

The MBE SC will be a customer for all other standards-development activities that develop document-based and presentation-based methods for defining product and process requirements. The MBE SG plans on helping other standards-development activities understand how their activities fit within the overall framework of digital standardization and work with the MBE SC accordingly.

4 MBE Standards Committee Structure

The ASME MBE SC is responsible for developing and maintaining governance and policies of its activities. The initial framework for governance and policies is defined here in the MBE SC Recommendation Report and was developed by the MBE SG.

4.1 Governance Policy and Procedures

A governance policy may be considered, "A process of providing strategic leadership [by] setting direction, making policy and strategy decisions, overseeing and monitoring organizational performance, and ensuring overall accountability," [21]. Governance includes the structures, responsibilities, and processes that the MBE SC uses to direct and manage its operations, determine how authority is exercised, how decisions are made and/or taken, how stakeholder needs are addressed, and how decision-makers are held to account. The MBE SC must implement a governance policy and procedures that, at a minimum, dictate the structure and standards development methodology of the MBE SC and its subcommittees.

Further, the MBE SC must ensure that the MBE standards do not define or dictate specific business processes. The MBE SC must define methods and tools that facilitate model-based business processes, standardized interfaces for exchanging model-based data, and model-based interactions between business processes. The MBE SC must leave business-operations decisions to industry.

The MBE SC and its subcommittees must work together toward common goals. The goals of the MBE SC must be defined in its charter, its main governance policy documents, and standards.

The standards developed and released by the MBE SC must focus on the requirements for representation data. The main focus of the MBE SC is data-centric, development of model-based datasets and their reuse and integration across all activities in the product lifecycle. The MBE SC must focus only on representation of the data. Presentation data must remain outside the scope of the MBE SC.

NOTE: Many standards have been developed during the document-based industrial phase to address rules and methods for presentation, such as ASME Y14, American Welding Society (AWS) A2.4, and others.

All MBE standards management must be in accordance with the policies, procedures, and guidelines of ASME accredited by the American National Standards Institute (ANSI) and available at: `https://www.asme.org/about-asme/standards/standards-certification-member-training-resources`.

4.1.1 Comments on Scope and Avoiding Overlap with Existing Standards Activities

For clarification of scope, there is potential of overlap between the ASME MBE and ASME Y14 standards committees.

ASME Y14 standards do several things:

1. Define tools, symbols, and techniques to describe product requirements.
2. Explain the meaning of product-definition tools, symbols, and techniques.
3. Define the methods and rules for *presenting* product-definition information in 2D and 3D presentation environments.
4. Define the rules, formats, and methods for *presenting* product-definition information in a standardized manner.
5. Define rules and methods for *presenting* combinations of product-definition information.

ASME Y14 standards do not define the methods for representing data digitally in a manner that is optimized for data reuse, in a machine-readable structure and format, that facilitates machine-to-machine communication, that facilitates bidirectional feedback and data transfer between all phases of the product lifecycle, that address model-based process definition, that define the business processes in which MBD is used in an MBE, and the automation enabled by these activities. These activities must be in the scope of the MBE SC.

Thus, the scope of the Y14 standards must be limited to items 1.- 5. above.

Some Y14 content, such as portions of Y14.41, Y14.46, and Y14.47, must be moved to or replaced by ASME MBE SC standards. If the material to be moved is not adequately defined for MBE, it must be replaced by new content optimized for MBE. Work must be done to coordinate presentation-focused content in ASME Y14 standards with the representation-focused content in ASME MBE standards.

NOTE: The ASME BST must support this position and assist in the process.

4.1.2 Activities and Roles

1. Roles and duties in the MBE SC and its subcommittees must follow Section 4 of the ASME Codes and Standards Development, Committee Procedures with S&T Supplemental document. The approved list of officers is:
   (a) Chair
   (b) One or more Vice Chair(s)
   (c) Secretary
2. ASME and the MBE SC should define the additional roles and provide a list of duties for each:
   (a) Chair Pro Tempore: An initial person appointed by ASME to get a subcommittee activity started
   (b) Member: A voting member of the MBE SC and/or its subcommittees
   (c) Contributor: A non-voting member of the MBE SC and/or its subcommittees that makes significant contributions to the development of standards content
   (d) Public: An interested person who is not a member of the MBE SC and/or its subcommittees

4.1.3 Members and responsibilities of the MBE Standards Committee

Members of the MBE SC should consist of the following:

1. Chairs of each subcommittee and/or working group
2. Members at large, by recommendation of ASME or its designee

The responsibilities of the MBE SC should constist of at least the following:

1. Ensures alignment between subcommittees and with charter of MBE SC
2. Meets bi-annually face-to-face, monthly by teleconference, and ad-hoc as-needed
3. Subcommittee coordination
4. Acts as a systems integration board
5. Receives, archives, and publishes meeting minutes for each meeting of the MBE SC and its subcommittees
6. Reviews and adjust priorities and scope of the MBE standards activities annually
   (a) This responsibility is especially important in early phases of development and implementation, as the MBE SC will be pursuing a moving target – a target affected by the work and releases of the MBE SC and its subcommittees

4.1.4 Liaisons

The MBE SC must establish and manage liaisons with activities that could provide benefit to the MBE standards activities.

1. Liaisons must provide links to and communication channels with organizations that are external to the MBE SC
2. Linked organizations may be internal or external to ASME
   (a) Internal: e.g. ASME Y14
   (b) External: e.g. AWS, Institute of Electrical and Electronics Engineers (IEEE)
3. Liaisons and liaison activities must follow ASME policies and procedures
4. The MBE SC should define several types of liaisons (e.g., see International Standards Organization (ISO) liaison types)

4.2 Terms Subcommittee

The Terms Subcommittee's focus is to ensure that terms, acronyms and abbreviations used in the MBE Standards are defined and consistently applied. This subcommittee must develop guidance for term selection and definition. If other sources (e.g., ASME, ISO) have established and appropriate definitions for needed terms and acronyms, those must be referenced. The Terms Subcommittee may also identify aliases for similar definitions. This subcommittee must establish a set of rules to resolve conflict between duplicate definitions, and when necessary, create a new definition that fits the MBE context. The Terms Subcommittee must establish, document, and approve terms that must be used in the context of the MBE Standards.

4.2.1 Charter

The Terms Subcommittee's charter must include the following:

1. On behalf of the MBE SC and its subcommittees, collect and moderate all
   (a) Terms and Definitions
   (b) Acronyms
   (c) Abbreviations
2. All MBE-applicable terms, definitions, acronyms, and abbreviations must be documented in a normative online repository. Individual documents, developed by other MBE SC subcommittees, must not document or define normative terms, acronyms, and abbreviations. All normative definitions of terms, acronyms, and abbreviations must reside in only one place.
3. Changes to terms, definitions, acronyms, and abbreviations must be adjudicated by this subcommittee

4.2.2 Responsibilities

The Terms Subcommittee must, at a minimum, be responsible for the following areas:

1. Facilitate consensus for definitions of terms and harmonize with internal and external organizations
2. Build and maintain the online Terms Repository

4.2.3 Initial Focus

The initial focus of the Terms Subcommittee must be as follows:

1. Discover, collect, and compile important terms used in the context of MBE
2. Review and prioritize terms
3. Resolve conflict on terms definitions
4. Create a new definitions that fits the MBE context

4.2.4 Deliverable Types

The following deliverables must be provided by the Terms Subcommittee:

1. Online repository (Normative)
2. Downloadable document (Informative)

4.3 Use Cases, Concepts, and Context Working Group

The Use Cases, Concepts, and Context Working Group's focus is to help the MBE SC and its subcommittees with capturing and modeling use cases and activities identified during MBE standards activities. The working group must develop guidance for modeling use cases and activities. The purpose of a use case is to identify, clarify, and organize requirements. A use case is made up of a set of possible sequences of interactions between systems and users in a particular environment and related to a particular goal. An activity is a task or set of tasks performed by an actor, such as a person, a team, a company, by software. Activities should be captured using an activity diagram, which is a tool that shows the flow or sequence of activities through a system.

In addition to modeling use cases and activities, the working group must support the maintenance of the modeling practices included in the model-based standards development process for the MBE SC.

4.3.1 Charter

The Use Cases, Concepts, and Context Working Group's charter must include the following:

1. Assist subcommittees with defining and modeling use cases that are encompassed by the MBE Standards
2. Assist subcommittees with modeling and decomposing the activities of use cases
3. Support the maintenance of the modeling practices for the MBE SC and its subcommittees

4.3.2 Responsibilities

The Use Cases, Concepts, and Context Working Group must, at a minimum, be responsible for the following items:

1. Facilitate consensus of capturing use cases across all subcommittees of the MBE SC
2. Facilitate abstracting concepts across various data, meta-model, and instance levels

4.3.3 Initial Focus

The initial focus of the Use Cases, Concepts, and Context Working Group must be as follows:

1. Model the activities that encompass the MBE SC's model-based standards development method (See Section 5) MBD use case and its activities

4.3.4 Deliverable Types

The following deliverables must be provided by the Use Cases, Concepts, and Context Working Group:

1. Use Case diagrams (Informative)
2. Activity diagrams (Informative)
3. Reports and white papers (Supportive)
4. Modeling methods (Normative)

4.4 Information Connectivity Subcommittee

Information connectivity consists of bi-directional communication of data from one application to another application or physical asset to address the following concerns:

- Protocol interoperability
- Syntactic interoperability

- Semantic interoperability
- Trustworthiness

The main concern of the Information Connectivity Subcommittee is to address semantic interoperability and sharing of documents using ontological information models that describe the meaning and relationships of information such that they can be used by automated systems. The importance of information connectivity relates to the need for communicating information between disparate systems that may not be provided by a single vendor.

The software industry is moving towards architectures that have distributed and/or federated services providing specialized capabilities. The services are not part of a single monolithic platform, but are composed of a set of interoperable applications that support standardized information models and protocols to provide greater value to the customer.

Information must be at a high enough semantic level, regarding the definition of terms and contextualization, that software can understand the information without additional curation. To this end, languages such as Unified Modeling Language (UML), Systems Modeling Language (SysML), and Ontology Web Language (OWL) as well as other ontological representations allow one to model complex systems using standardized constructs.

These languages provide the ability to provide semantics for any domain, but each domain requires its own specific information model. It is imperative for this group to provide domain models based on an ontological standard so that the abstractions and structure can be understood by software systems.

This meta requirement is necessary since numerous other systems need to interact with the harmonized information that may be outside the scope of the Information Connectivity Subcommittee. They include at a minimum the following areas:

1. Manufacturing Engineering (CAM)
2. Manufacturing Process Planning
3. Manufacturing Process Execution
4. Manufacturing Process Verification
5. Manufacturing Process Assembly
6. Manufacturing Process Analytics
7. Product Quality Planning
8. Product Quality Analytics
9. Product Lifecycle Analysis
10. Product Maintenance and Repair
11. Product Disposal and Reuse

Each domain has or is developing specialized models for their concerns. The challenge will be to create an ecosystem where there is interoperability between these domains that allows them to share data and the initial design requirements are assessed against the outcome resulting in the automation of feedback and reinforcement of automated learning systems.

Trustworthiness of the information is also critical. Trustworthiness subsumes the confidentiality, integrity, security, safety, reliability, and resilience of the product related services. The primary concerns of this group are to define methods to encode the document integrity, provenance, and confidentiality into or around a dataset. Additional trustworthiness concerns are related to the use of the information created, such as ensuring that only intended recipients have access to the data.

Other standards exist that address the secure transmission and storage of information and must be referenced by the MBE standards as meeting the requirements. Mechanisms of creating an immutable chain of trust, such as using a set of certificates, and asserting the correctness of content and authorship are focus areas for the Information Connectivity Subcommittee.

Confidentiality is another area of concern and requiring the representation of information so that systems only provide the necessary portions of the information model. This capability ensures the integrity of the information as well as not providing information that compromises the intellectual property of any parties.

4.4.1 Charter

The Information Connectivity Subcommittee's charter must include the following:

1. Identify use cases required to define the activity and data flows required for MBE
2. Analyze use-case requirements with the goal of creating composable, interoperable services
3. Document protocol, syntactic, and semantic interoperability requirements
4. Document data flows and standards interfaces for each of the services
5. Document process activity from the perspective of inter-process communication
6. Identify trustworthiness concerns and document the requirements for addressing the various areas, with specific attention to provenance, access, and information integrity

4.4.2 Responsibilities

The Information Connectivity Subcommittee must, at a minimum, be responsible for the following areas:

1. Control the sections of the MBE framework that specify the methods of bi-directional data flow and service integration.
2. Generate connectivity and communications standards that meet the requirements for data flow and interactions.
3. Define mechanisms and standards that are required to meet the trustworthiness requirements.
4. Interact with the Process Representation Subcommittee to ensure semantic interoperability.

4.4.3 Initial Focus

The initial focus of the Information Connectivity Subcommittee must be as follows:

1. Analyze all phases of the product lifecycle and harmonization with relevant systems as required
   (a) Identify the primary actors for each use case
   (b) Capture the user stories from each actor's perspective
   (c) Extract the requirements necessary to satisfy the stories
   (d) Decompose the requirements into individual service offerings and identify the nature of the information flows between services
2. Identify requirements that are used to qualify communications and trustworthiness standards for fit-for-purpose

4.4.4 Deliverable Types

The following deliverables must be provided by the Information Connectivity Subcommittee:

1. Documented use cases, actors, and user stories (Informative)
2. Documented the data flows and activity models (Informative)
3. Standards for services and interfaces needed for MBE (Normative)
4. Documented requirements that will be used to qualify communications standards for each information flow (Normative)

4.5 Product Representation Subcommittee

The Product Representation Subcommittee's focus is to develop guidance and standards around defining and communicating product requirements, process constraints, and other product related requirements. The product-focused model-data-representation requirements in the MBE standards must take priority over all other uses of models in any other ASME standards. For example, the MBE SC should have the authority to define model data representation requirements for all ASME Y14.100 Classification Codes (i.e., two, three, four, and five) where models are used. The subcommittee must develop guidance around product-definition datasets and their associated structure. The subcommittee must address all aspects of the product definition to enable reuse in the realization of products (e.g., fabrication, inspection, sustainment). Product-definition datasets should enable bi-directional flow of information and support process representation to ensure that models provide all necessary information for downstream consumption.

4.5.1 Charter

The Product Representation Subcommittee's charter must include the following:

1. Creation of information models for (not limited to):
   (a) Definition of product-model types
   (b) Creation of supporting data dictionaries
   (c) Semantic definitions that support the definition of a product
   (d) Schema definitions that support the definition of a product
2. Digital support for quality- and safety-related product areas:
   (a) Representation and communication of the quality and safety criteria for a product
   (b) Requirements for and representation and communication of the verification methods for a product
   (c) Requirements for and the representation and communication of the validation methods for a product
3. At a minimum, the rules governing:
   (a) Organization of model-based product-definition datasets
   (b) Creation and mapping of product-related data
   (c) Preparation of product-related data for consumption

4.5.2 Responsibilities

The Product Representation Subcommittee must, at a minimum, be responsible for the following areas:

1. Control the content, structure, rules, and recommended practices for DPD datasets. This may be treated as a portion of a MBE framework for representing products in the process of integrating and communicating with a system-of-systems for a product lifecycle, or DPD datasets may be considered as independent entities.
2. Product-model requirements in the MBE Standards must take priority over all other uses of product-related models in any other ASME standards (e.g., MBE has the authority to define model requirements for all Y14.100 Classification Codes where models are used)
3. Interact with the MBE SC and its other subcommittees to ensure alignment of interfaces between each subcommittee's controlled concepts.

4.5.3 Initial Focus

The initial focus of the Product Representation Subcommittee must be as follows:

1. Definition of the various model (e.g., dataset) types within the scope of the Product Representation Subcommittee's charter

2. Creation of an initial data dictionary for common concepts required to represent products
3. Determine how DPD datasets relate to other datasets defined by the MBE SC and its subcommittees; Complete a trades analysis of the DPD dataset being a viewpoint of a larger system model versus the DPD dataset being an independent entity

4.5.4 Deliverable Types

The following deliverables must be provided by the Product Representation Subcommittee:

1. Model-based standards for product representation, including:
   (a) Information models (Normative)
   (b) Associated documentation (informative)
2. Reference documents (Informative)
3. Support material (Supportive)

4.6 Process Representation Subcommittee

The Process Representation Subcommittee's focus is to develop guidance and standards around defining and communicating the requirements that do not define the product. The subcommittee must develop guidance for process-definition datasets and their associated structure, including all non-product-definition data related to processes. The subcommittee must address all aspects of the processes for the direct realization of products. The subcommittee should also address indirect process representations of required processes for the delivery of products – including associated capability representations.

4.6.1 Charter

The Process Representation Subcommittee's charter must include the following:

1. Creation of information models for (not limited to):
   (a) Definition of process-model types
   (b) Creation of supporting data dictionaries
   (c) Semantic definitions that support the definition of processes used to realize a product in any and every stage of its lifecycle
   (d) Schema definitions that support the definition of processes used to realize a product in any and every stage of its lifecycle
2. Definition of digital support for quality-related process areas:
   (a) Representation and communication of the quality criteria for a process
   (b) Requirements for and the representation and communication of the verification methods for a process

   (c) Requirements for and the representation and communication of the validation methods for a process

3. At a minimum, the rules governing:
   (a) Organization of model-based process-definition datasets
   (b) Creation, mapping, and consumption of process-related data

4.6.2 Responsibilities

The Process Representation Subcommittee must, at a minimum, be responsible for the following areas:

1. Control the content, structure, rules, and recommended practices for process-definition datasets. This may be treated as a portion of a MBE framework representing processes governing the integrating and communicating with a system-of-systems for a product lifecycle where appropriate under the scope of the subcommittee
2. Process-model requirements in the MBE standards must take priority over all other uses of process-related models in any other ASME standard
3. Interact with the MBE SC and its other subcommittees to ensure alignment of interfaces between each subcommittee's controlled concepts

4.6.3 Initial Focus

The initial focus of the Process Representation Subcommittee must be as follows:

1. Definition of the various model (e.g., dataset) types within the scope of the Process Representation Subcommittee's charter
2. Creation of an initial data dictionary for common concepts required to represent processes
3. Establish and maintain liaisons with both the MTConnect and Quality Information Framework (QIF) SDOs in, but not limited to, the following areas:
   (a) Both SDOs have data dictionaries of manufacturing and quality assets
   (b) Investigate other SDOs and groups for potential liaison
   (c) Investigate how ISA-95 and process flow concepts fit into MBE process representation

4.6.4 Deliverable Types

The following deliverables must be provided by the Process Representation Subcommittee:

1. Model-based standards for process representation, including:
   (a) Information models (Normative)
   (b) Associated documentation (Informative)
2. Reference documents (Informative)
3. Support material (Supportive)

4.7 Training and Education Subcommittee

The Training and Education Subcommittee must focus on defining and developing content for use within the MBE SC, mainly as a tool for ensuring new members understand the mission of the MBE SC, how to perform duties, how the model-based standards development (MBSD) approach works, and how to use MBSD tools effectively. In addition, the Training and Education Subcommittee may also develop materials for external use to other SDOs and organizations to explain the role of the MBE SC, how to interact with other SDOs, and how MBE standards fit into the hierarchy of standards, and are affected by other standards. The Training and Education Subcommittee must also develop materials for external use to explain what is MBE and what MBE is not. The subcommittee must also provide guidance to new MBE SC members on the structure, scope, and content for education and training activities and materials of the MBE standards.

4.7.1 Charter

The Training and Education Subcommittee's charter must include the following:

1. Definition and development of content for use within the MBE SC to ensure members understand the goals and methods of the MBE SC and why the tools are used
2. Develop materials for internal and external use to help people understand what is MBE (e.g. data-driven) and what MBE is not (e.g. 3D drawings supporting presentation-based workflows)

4.7.2 Responsibilities

The Training and Education Subcommittee must, at a minimum, be responsible for the following areas:

1. Develop and manage educational materials for use within the MBE SC
2. Develop and manage educational materials for use by other SDOs and external organizations to understand the basics of MBE, how the MBE standards relate to and interact with other standards
3. Promotion of using the MBE standards within the formal education community

4.7.3 Initial Focus

The initial focus of the Training and Education Subcommittee must be as follows:

1. Devlop training materials that will be used internally within the MBE SC for the goals, methods, and tools used to develop MBE standards
2. Develop materials for internal use within the MBE SC
3. Develop materials for external use, such as guidance about MBE and the MBE SC for other SDO activities

4.7.4 Deliverable Types

The following deliverables must be provided by the Training and Education Subcommittee:

1. Reports (Supportive)
2. Checklists (Informative)
3. Communications plans (Informative)
4. MBE standards development training materials for internal use (Informative)
5. Explanatory materials for external use (Informative)

4.8 Assessments and Certification Subcommittee

The Assessments and Certification Subcommittee must focus on two related areas. First the certification of MBE professionals. The certification process could be similar to the current geometric dimensioning and tolerancing (GD&T) certification processes offered by ASME. For the assessment portion of this activity, the committee should build a structured process around an updated and improved version of the MBE Capability Index[1] for assessing an organization's MBE capabilities.

4.8.1 Charter

The Assessments and Certification Subcommittee's charter must include the following:

1. Development of material for testing for certification of MBE professionals
2. Definition of MBE software requirements
   (a) Creation of use cases and test cases
   (b) Development of criteria for a MBE testbed
3. Definition of assessment and certification conformance, including, but not limited to:
   (a) Recommended practices
   (b) Capabilities assessments for individuals, software, processes, and organizations
   (c) Rules and criteria for conformance
   (d) Rules for conducting audits
   (e) Test Methods
4. Definition of assessor's and MBE trainer's certification

[1] https://doi.org/10.6028/NIST.AMS.100-1

4.8.2 Responsibilities

The Assessments and Certification Subcommittee must, at a minimum, be responsible for the following areas:

1. Enable a conformance environment to support developers' and industries' adoption and assessment of MBE
2. Develop rules and methods that support automated testing and feedback through model-based assessment
3. Assume responsibility for the MBE Capability Index
4. Update and improve the MBE Capability Index and related recommended practices
5. Control and maintenance of an external MBE testbed

4.8.3 Initial Focus

The initial focus of the Assessments and Certification Subcommittee must be as follows:

1. Develop rules and criteria for assessment based upon the MBE Capability Index
2. Take over the further development and maintenance of the MBE Capabilities Index from U.S. Department of Defense (DoD) and NIST
3. Establish criteria for an external MBE testbed

4.8.4 Deliverable Types

The following deliverables must be provided by the Assessments and Certification Subcommittee:

1. Model-based standards for assessment and certification (Normative)
2. Reference documents (Informative)
3. Support material (Supportive)

5 Model-Based Standards Development Methodology

All but trivial systems involve complexity beyond the ability of the human mind to comprehend a complete viewpoint [22]. Behaviour of systems must be understood before requirements may be derived. Model-Based Enterprise (MBE) and its standards may be considered a system. Document-based engineering standards are complex. For example, the existing ASME Y14 *Engineering Product Definition and Related Documentation Practices* standards suite includes tens of documents, hundreds of pages, and thousands of requirements. Often times, there are conflicting requirements across the documents, which is a challenge that all members of the MBE Steering Group have encountered. How can a user effectively navigate all those documents and ensure compliance with the requirements? The answer is, in practice, the users do not.

Further, MBE requires the use of models in various forms across all phases of the product lifecycle. The models become the primary data source for communication in MBE. Therefore, document-based standards are not sufficient for defining MBE standards. The MBE SC must consider how model-based methods would assist and benefit the MBE standards-development process. For instance, a MBSD methodology predicates the use of modeling to analyze and define key aspects of the MBE standards and their lifecycles. The MBSD methodology will speed the development of standards, make the development process more agile in addressing industry needs, and improve the quality and reliability of the standards.

The MBE SC must include a MBSD methodology as part of an overall MBE SC governance policy and procedures. The purpose of the MBSD methodology is to ensure a uniform application of modeling methods to the development of the MBE standards. The MBSD methodology must include guidance for an overall standards development policy, modeling languages, verification and validation (V&V), configuration management, standards delivery, normative sources, informative documentation, and supportive resources.

5.1 Standards Development Policy

A standards development policy must provide guidance for:

1. Modeling abstraction (e.g., reducing the complexity of the standards, reducing the complexity of concepts)
2. Improving requirement and specification definition and communication
3. Understanding of the models that represent the standards
4. Providing reusable modeling elements (e.g., entities, classes, interfaces)
5. Common naming conventions for elements (e.g., blocks, properties)
6. Explicit procedures for modeling
7. Mapping between models and documentation
8. Using a modular approach to standards development

Further, the standards development policy should provide guidance on the workflow of the standards development process. The MBE SC should adopt the following process order:

1. Gather / identify stakeholder activities, needs, and use cases
2. Derive requirements from needs
3. Develop and/or modify concepts (e.g., use cases, activity diagrams) for verifying, satisfying, and validating requirements
4. Generate normative models to formalize standards
5. Generate informative documents to accompany the models[2]

[2] Consider using Doxygen to automate the document generation process. See `http://www.stack.nl/~dimitri/doxygen/index.html`

5.2 Modeling Language

The MBE SC must investigate how model-based systems engineering (MBSE) methods can help with modeling the MBE standards. The use of standardized modeling languages, such as UML or SysML, is desirable as they are understood across a significant portion of the systems engineering community. However, since it is important to model to the level of the intended audience, it may sometimes be necessary to use an alternative notation.

Further, There are a multitude of modeling techniques and approaches that may be leveraged in the development of MBE standards. The MBE SC at a minimum must consider the following:

1. Structured analysis and design
2. Data flow diagramming
3. State transition diagramming
4. Behavioural modeling
5. Entity relationship modeling
6. Environment visualization
7. Computer-aided design (CAD)
8. Analytic modeling
9. Process modeling

At a minimum, MBE SC should also consider using the following modeling languages and/or methodologies to develop the MBE standards:

1. UML for information and meta-models of classes and information
2. SysML for system engineering models, state, use case, and activity models
3. SysML Use Case and Activity Diagrams to specify the workflow of service activation and capturing concepts
4. SysML State Diagrams when a finite state transition set of activities are required
5. SysML Block Definition Diagrams to capture data-flow models to document the information flow between services

Intra-service interactions should not be required since the construction and implementation of the services are defined in the implementation. Concerns that will help guide implementation should be documented, but the ultimate implementation decisions must be left up to the companies delivering the services.

MBE standards must be concerned with the defintion, communication, and integrations of services and not the implementation of the services. Standards are required when information and knowledge must transfer across vendor and service boundaries.

The listed modeling languages are suggested. The MBE SC must consider its stakeholders and requirements when making the final decisions in selecting modeling languages. Overall, the modeling language must be combined with a modeling methodology to be useful.

5.3 Verification and Validation

ASME MBE SC verification and validation (V&V) activities may take several forms and apply in several areas, including data, datasets, MBE processes, products (e.g., software, platforms), original equipment manufacturers (OEMs), suppliers, and individuals. The ASME MBE SC must develop and maintain V&V standards, policies and recommended practices for use in industry and products such as software and platforms.

Verification and Validation activities address:

Data Content, structure, adherence to format standards, readability, trustability, and lifecycle-stage readiness

Datasets Content, structure, adherence to schema, adherence to format standards, lifecycle stage readiness, trustability, consistency and conformance, arrangement of data and relationships within a dataset

Processes MBE processes and process steps and methodologies and their adherence to MBE standards, recommended practices, and formally-defined procedures for processes

Products The level of MBE support of products (e.g., software), the extent of support, type of support (e.g., authoring, ingest, presentation of represented data, translation of represented data from one type to another type)

OEMs Adherence of OEMs to formally-defined MBE principles; if the OEM has published MBE standards and practices, the completeness of the published MBE standards and practices; the mechanisms by which OEMs validate conformance of their suppliers to their MBE standards and practices, and the OEM's MBE readiness and capability

Suppliers Supplier MBE readiness and capabilities; if the supplier has developed its own MBE standards and practices, adherence to the MBE standards and practices; the supplier's level of compliance with client's (OEM) MBE standards and practices

Individuals Professional MBE readiness and capability, combined with assessment (investigate similarity to GD&T Professional Certification).

The MBE SC must determine how much of internal MBE standards development V&V activity needs to align with the MBE V&V Subcommittee. Also, the MBE SC must determine the possibly of a liason between the MBE SC and the ISO/TC184/SC4/Quality Committee (QC)[3].

The V&V portions of the MBSD methodology must address model quality, standards conformance, and modeling capability.

5.3.1 Quality Procedures and Steps

1. Rules and requirements
   (a) Global
   (b) Specific

[3] `https://www.iso.org/committee/54158.html`

   (c) Instantiated
   (d) Criteria to be evaluated
      i. Criteria may be derivatives of requirements
         E.g., torque value to represent axial joint loading by fasteners
         E.g., resistivity value to represent purity of deionized water

2. Instantiated set of requirements
   (a) For a specific instance
   (b) Possibly subset or superset of criteria

3. Verification and validation to instantiated set of requirements

4. Publication of results
   (a) Publication should be model based, associated to applicable data elements, etc.

Explanation of Quality Procedures and Steps: The MBE SC defines rules and requirements for concepts within the MBE SC's scope. The MBE SC publishes the rules, requirements, and criteria, and determines if these are adhered to in an adequate manner. The MBE SC should enable decision making for a specific business situation, such as a particular project, how the rules and requirements must be implemented (e.g., all the rules and requirements, some of them, are they weighted, additional rules and requirements for special cases). This represents the instantiated set of rules and requirements. V&V is performed and results obtained. Results are published, which in an optimal MBE, should be attached to specific elements in various datasets or linked to the applicable elements in the global dataset such that different viewpoints can see and use applicable results and act on them.

5.4 Configuration Management

Configuration management (CM) is paramount to building trust and reliability into the MBE standards. The MBSD methodology must address CM as follows:

1. A CM plan must be created to govern the MBE standards and their other outputs
   (a) The CM plan must have provisions for traditional documentation, software items, and models created by the MBE SC and its subcommittees
   (b) Provisions must be made for revisioning, versioning, and iterating the MBE standards
   (c) A release and revision process must be defined
   (d) The CM plan and revision to it must be approved by the MBE SC

2. A repository or vault should be created to store the outputs of the MBE standards
   (a) The repository must be software-based and/or data-based, not shared network folders
   (b) The repository must provide dynamic role-based access controls
   (c) The repository must allow remote access by users
   (d) Multiple applications may be used to provide complete CM capabilities

5.5 Standards Delivery

Standards must be delivered to the public in an effective and efficient form that the public can consume. The MBE SC should consider requiring the following forms of standards delivery:

1. Provide a collaborative model-based standards development environment with access controls
2. Provide access to the various normative models for standards users with appropriate rights (e.g., purchased a license to the standard)
3. Provide validated, informative, document-based derivatives of the standards, where appropriate
4. Eventually, enable links between standards from different SDOs using interoperability platforms (e.g., SWISS[4]).

5.6 Normative Sources

Normative sources are the elements of the MBE standards that are prescriptive. Normative sources are to be followed to comply with requirements defined in the standards. All normative elements that are requirements (must) are to be followed in all cases to be in conformance. Elements that are recommended (should) are ones that any organization that wants to be in conformance are encouraged to follow. Finally, elements that grant permission (may) with the option of following if the organization so chooses.

At a minimum, the models should be normative sources of the MBE standards. Normative is synonymous with the ASME terminology of “mandatory.”

5.7 Informative Documentation

Informative documentation are the elements of the MBE standards that are descriptive. Informative documentation are designed to help the standards user understand the concepts presented in the normative sources. Nothing in the informative elements is or can be mandatory. If guidance is mandatory, that is if it includes a must, should, or may statement, it is not informative, it must be normative.

At a minimum, the documentation of the models should be informative documentation of the MBE standards. Informative is synonymous with the ASME terminology of “non-mandatory.”

5.8 Supportive Resources

Supportive resources are the elements of the MBE standards that are exemplar. Supportive resources are designed to help the standards user understand the recommended approaches to using and complying with the standards. Supportive resources could include, but are not limited to, recommended practices, reference implementations, and test cases and/or suites.

[4] `https://swiss.io/`

6 Marketing and Adoption

6.1 Marketing Strategy

The MBE SC must be prepared to assist ASME by providing marketing input for MBE standards and related ASME activities. This input may include, but not limited to, identifying key influences (e.g., individuals and organizations from industry, government, and academia), potential partners, and complementary (non-standards-based) solutions that will help champion the adoption of MBE standards. The intent is to help ASME marketing increase exposure, communicate the importance of MBE to realizing the digital thread, convey return-on-investment and competitive advantages MBE affords, and ultimately drive adoption across key industry verticals and their respective supply chains. ASME must also provide recommendations for socio-technical organizational management to assist in organizational transition to MBE. Last, ASME must develop a strategy for recruiting and maintaining participation in the MBE SC.

6.2 MBE Standards Adoption Aides

The following are suggested aides that would support industry adoption of MBE:

- Reference MBE components: models, templates, and implementations
- Real-world examples and case studies that conform to the MBE standards
- User guides and white papers
- Webinars and seminars
- Collaborations with the MBE SC Training and Education Subcommittee

6.2.1 Technology Outreach

ASME should investigate technology to assist with the MBE standards adoption strategy. The MBE SC must develop recommendations on how to affect social/cultural change around technology adoption. Also, the MBE SC must develop recommendations on how to affect change in technologies.

7 Roadmap

The MBE SG recommends the following order of priority in deploying the proposed ASME MBE SC structure:

1. Governance and Policy
2. Terms Subcommittee
3. Use Cases, Concepts, and Context Working Group
4. Product Representation Subcommittee

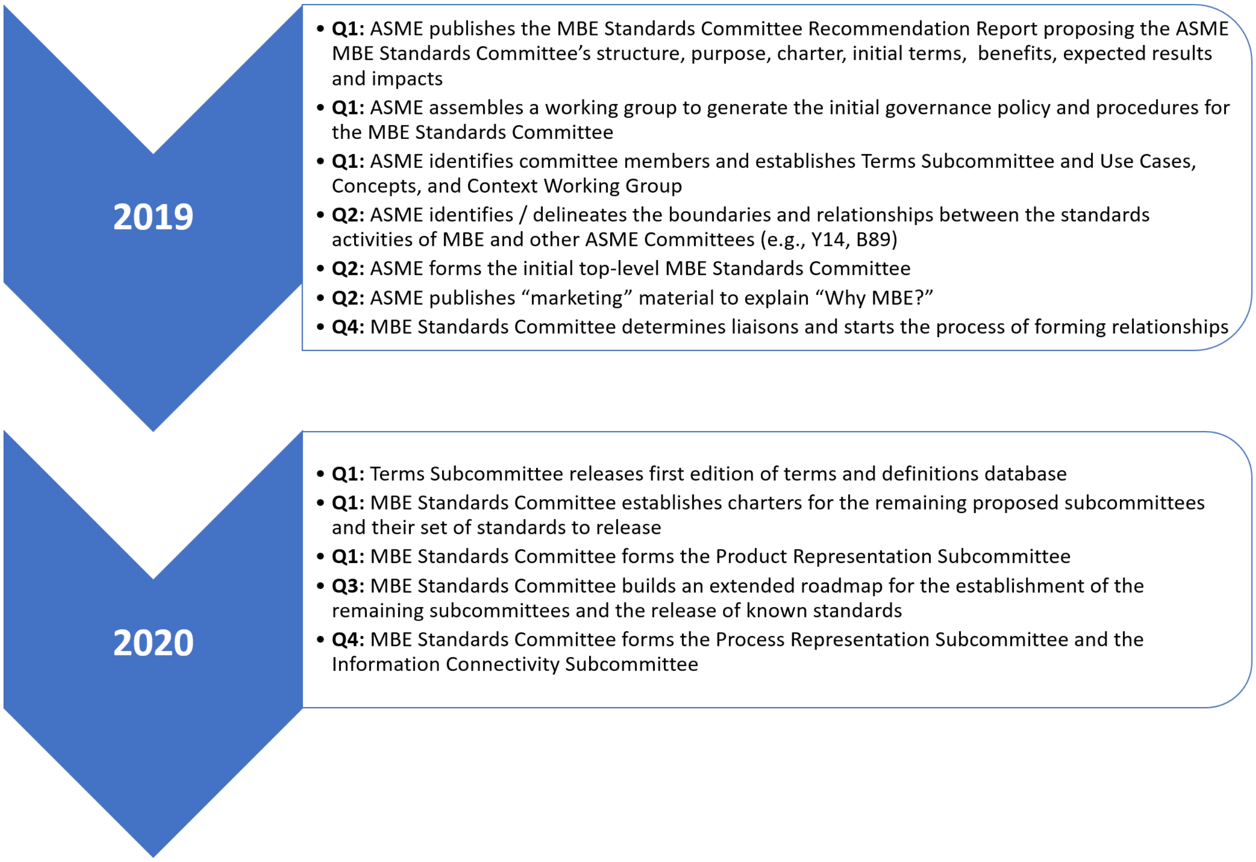

Figure 1: Recommended two-year MBE SC roadmap starting in Calendar Year 2019

5. Information Connectivity Subcommittee
6. Process Representation Subcommittee
7. Training and Education Subcommittee
8. Assessments and Certification Subcommittee

Based on the recommended priority order, the MBE SG proposes the two-year roadmap presented in Figure 1. The two-year roadmap starts in calendar year 2019 and runs through calendar year 2020. The Steering Group recommends that ASME, in collaboration with the eventual MBE SC, should develop at least a five-year rolling roadmap starting with calendar year 2020 or 2021.

8 Summary

This MBE SC Recommendation Report is presented to ASME by the MBE SG. The report is recognized as the starting point for the ASME MBE standards development process. A standards-committee structure is presented in Section 4 and is intended to be the eventual end-state for the MBE SC structure. A long-term roadmap is required for guidance in going from the starting point to the end-state of the standards processes. Further, the MBE SG recognizes that the proposed

MBE SC structure may require changes as lessons are learned and work progresses. MBE is a complex system. The proposed MBE SC structure is a result of trying to abstract out important activities and focal points to provide guidance towards successful deployment of MBE standards.

In addition, while ASME, in collaboration with the MBE SC, ramps up the operations of the MBE standards activities, the MBE SG recommends that the Steering Group remain in place as consultants to ASME and the MBE SC. The roles and responsibilities of the Steering Group would be to advise ASME and the MBE SC during the development of basic governance policies and procedures. The Steering Group could also assist with the starting subcommittee activities until a main MBE SC is established and assumes the role of advise and consent over the MBE standards.

References

[1] Dori, D., and Tombre, K., 1995. “From engineering drawings to 3D CAD models: Are we ready now?”. *Computer-Aided Design,* **27**(4), apr, pp. 243–254. doi: 10.1016/0010-4485(95)91134-7.

[2] Camba, J. D., and Contero, M., 2015. “Assessing the impact of geometric design intent annotations on parametric model alteration activities”. *Computers in Industry,* **71**, aug, pp. 35–45. doi: 10.1016/j.compind.2015.03.006.

[3] French, T. E., Helsel, J. D., Svenson, C. L., and Urbanick, B., 1990. *Mechanical drawing: CAD communications*, 11 ed. Glencoe.

[4] Versprille, K., 2008. Model-Based Definition for the Masses. Tech. Rep. March, Collaborative Product Development Associates.

[5] Quintana, V., Rivest, L., Pellerin, R., Venne, F., and Kheddouci, F., 2010. “Will Model-based Definition replace engineering drawings throughout the product lifecycle? A global perspective from aerospace industry”. *Computers in Industry,* **61**(5), jun, pp. 497–508. doi: 10.1016/j.compind.2010.01.005.

[6] Hedberg, T., Lubell, J., Fischer, L., Maggiano, L., and Barnard Feeney, A., 2016. “Testing the Digital Thread in Support of Model-Based Manufacturing and Inspection”. *Journal of Computing and Information Science in Engineering,* **16**(2), mar, p. 021001. doi: 10.1115/1.4032697.

[7] Ruemler, S. P., Zimmerman, K. E., Hartman, N. W., Hedberg, T., and Barnard Feeny, A., 2016. “Promoting Model-Based Definition to Establish a Complete Product Definition”. *Journal of Manufacturing Science and Engineering,* **139**(5), nov, p. 051008. doi: 10.1115/1.4034625.

[8] Miller, A. M., Hartman, N. W., Hedberg, T., Barnard Feeney, A., and Zahner, J., 2017. “Towards Identifying the Elements of a Minimum Information Model for Use in a Model-Based Definition”. In ASME 2017 12th International Manufacturing Science and Engineering Conference collocated with the JSME/ASME 2017 6th International Conference on Materials and Processing – Volume 3: Manufacturing Equipment and Systems, Vol. 3, ASME, p. V003T04A017. doi: 10.1115/MSEC2017-2979.

[9] Bechky, B. A., 2003. “Object Lessons: Workplace Artifacts as Representations of Occupational Jurisdiction”. *American Journal of Sociology,* **109**(3), nov, pp. 720–752. doi: 10.1086/379527.

[10] American Society of Mechanical Engineers, 2012. Digital Product Definition Data Practices.

[11] International Standards Organization, 2015. Technical product documentation – Digital product definition data practices.

[12] Haight, B., 2003. “New ASME standard for CAD”. *Automotive Industries AI,* **183**(10), p. 42.

[13] Conover, J. S., and Zeid, I., 2006. “Development of a Prototype for Transfer of Drawing Annotations Into the ASME Y14.41 Standard”. In Design Engineering and Computers and Information in Engineering, Parts A and B, Vol. 2006, American Society of Mechanical Engineers, ASME, pp. 1211–1218. doi: 10.1115/IMECE2006-15323.

[14] Morey, B., 2014. "Interpreting the Language of GD&T in Metrology". *Manufacturing Engineering,* **153**(3), pp. 105+.

[15] Louhichi, B., and Rivest, L., 2014. "Maintaining consistency between CAD elements in collaborative design using association management and propagation". *Computers in Industry,* **65**(1), jan, pp. 124–135. doi: 10.1016/j.compind.2013.08.003.

[16] Dong, A., and Agogino, A. M., 1998. "Managing design information in enterprise-wide CAD using 'smart drawing'". *Computer-Aided Design,* **30**(6), pp. 425–435.

[17] Glaessgen, E., and Stargel, D., 2012. "The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles". In 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference
20th AIAA/ASME/AHS Adaptive Structures Conference
14th AIAA, American Institute of Aeronautics and Astronautics, p. 1818. doi: 10.2514/6.2012-1818.

[18] Subrahmanian, E., Rachuri, S., Fenves, S. J., Foufou, S., and Sriram, R. D., 2005. "Product lifecycle management support: a challenge in supporting product design and manufacturing in a networked economy". *International Journal of Product Lifecycle Management,* **1**(1), p. 4. doi: 10.1504/IJPLM.2005.007342.

[19] Price, A., 1998. "Virtual Product Development - Case study of the T-45 horizontal stabilator". In 39th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference and Exhibit, American Institute of Aeronautics and Astronautics, p. 2065. doi: 10.2514/6.1998-2065.

[20] Adamski, W., 2010. "Adjustment and Implementation of CAD/CAM Systems Being Used in Polish Aviation Industry". *Journal of Machine Engineering,* **10**(3), pp. 37–47.

[21] Gill, M., 2005. *Governing for Results: A Director's Guide to Good Governance*. Trafford, Victoria, B.C.

[22] Miller, G. A., 1956. "The magical number seven, plus or minus two: some limits on our capacity for processing information.". *Psychological Review,* **63**(2), pp. 81–97. doi: 10.1037/h0043158.

Appendix A Glossary

Digital Product Definition Digital data representing the product-definition elements required to define a product. Digital product definition includes digital representation of geometry, topology, relationships, tolerances, attributes, and features necessary to define a component part or an assembly of parts for the purpose of design, analysis, manufacture, test, inspection, and sustainment.

Digital Thread An integrated information flow that connects all of the phases of the product lifecycle using an accepted authoritative data source (e.g., technical data package, 3D CAD model)

Digital Twin An integrated model, enabled by the Digital Thread, that combined data from both the cyber-space and physical-space to mirror and predict “things” (e.g., activities, performance, outcomes, events) over the life of the model’s corresponding physical twin.

Informative Elements of standards that are descriptive and designed to help the standards user understand the concepts presented in the normative sources.

Linked Data A method of publishing structured data so that it can be interlinked and become more useful through semantic queries.

Model A representation of the cyber and/or physical structure of a system, and related senses.

Model-Based Definition (MBD) The method or practice of using digital model-data to represent a product and/or process.

Model-Based Enterprise (MBE) An environment and methodology in that models are the data source, rather than documents, for all engineering activities throughout the product lifecycle.

MTConnect An open industry standard for enabling interoperability between controls, devices, and software in manufacturing systems.

Normative Elements of standards that are prescriptive and must be followed to be considered in compliance with requirements outlined in the standards.

Presentation The manner in which information is displayed for use by a human.

Product Lifecycle A high-level set of views that starts with marketing, continues through design and manufacture, to selling, then support, and ends with the decommission and disposal or recycle of the product.

Product Lifecycle Management (PLM) The business activity of managing, in the most effective way, a company’s products all the way across their lifecycles; from the very first idea for a product all the way through until it is retired and disposed of.

Quality Information Framework (QIF) A unified XML framework and ANSI-accredited standard for enabling interoperability between computer-aided quality systems.

Representation The manner in which information is structured, formatted, and stored for interpretation by a machine.

Service A mechanism to enable access to one or more capabilities, where the access is provided using a prescribed interface and is exercised consistently with constraints and policies as specified by a functional description.

Supportive Elements of standards that are exemplar and designed to help the standards user understand the recommended approaches to using and complying with the standards.

Systems Modeling Language (SysML) A general-purpose modeling language, for systems-engineering applications, that supports the specification, analysis, design, verification, and validation of a broad range of systems and systems-of-systems.

Unified Modeling Language (UML) A general-purpose, developmental, modeling language in the field of software engineering, that is intended to provide a standard way to visualize the design of a system.

Appendix B Nomenclature

2D two-dimensional 2, 3, 5, 8

3D three-dimensional 1–5, 8, 32

AI artificial intelligence 5

ANSI American National Standards Institute 8

ASME American Society of Mechanical Engineers i, v, vi, 1, 5–10, 15, 16, 18, 20, 21, 24, 26–29

AWS American Welding Society 8, 10

BST Board on Standardization and Testing i, v, 1, 8

CAD computer-aided design 2–4, 23, 32

CM configuration management 25

DoD U.S. Department of Defense 21

DPD digital product definition 1–4, 16, 17

GD&T geometric dimensioning and tolerancing 20, 24

IEEE Institute of Electrical and Electronics Engineers 10

ISO International Standards Organization 10, 24

MBD model-based definition 3, 4, 8, 12

MBE Model-Based Enterprise i, v, 1–12, 14–29

MBSD model-based standards development i, 19, 22, 24, 25

MBSE model-based systems engineering 23

NIST National Institute of Standards and Technology 1, 21

OEM original equipment manufacturer 24

OWL Ontology Web Language 13

QIF Quality Information Framework 18

SC Standards Committee i, v, 1, 6–12, 15–19, 22–29

SDO Standards Development Organization 5, 6, 18, 19, 26

SG Steering Group i, v, 1, 7, 27–29

SysML Systems Modeling Language 13, 23

UML Unified Modeling Language 13, 23

V&V verification and validation i, 22, 24, 25