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A Next-Generation Model-Based Enterprise Maturity Index

Curtis Brown[*], Sarah Hale[**], and Jeffrey Winter[***]
[*] Kansas City National Security Campus, Kansas City, MO
[**] Sandia National Laboratories, Albuquerque, NM
[***] National Nuclear Security Administration, Washington, DC
cbrown@kcnsc.doe.gov, sshield@sandia.gov, jeffrey.winter@nnsa.doe.gov

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Abstract

For any transition journey, one needs a vision to get started; one needs plans to finish; and one needs a map to define a path for success. This paper introduces the next generation Model-Based Enterprise (MBE) Maturity Index that provides the map for success by defining and normalizing the transition from a document-centric, drawing-based business to a part-centric, digital, model-based enterprise. The aim of this paper is to share NNSA's efforts related to MBE and thus help increase the pace of progress in industry.

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Contents

1 Introduction

The manufacturing industry has been using 3D models for decades; however, attaining trusted product models and managing them for confident reuse in all lifecycle activities throughout the enterprise has remained elusive. Like many other manufacturers, the use of models within the U.S. National Security Enterprise[1] (NSE) is part of our DNA. For over thirty years, the NSE's operational model has been to create 3D models; derive 2D static drawings them; release those 2D drawings as authoritative product definition; and then use those authorized 2D drawings to recreate 3D models for other product lifecycle work (such as to analyze, fabricate, and inspect products). Many organizations have accepted - or more likely we have become numb - to the inherit operating risks, sluggishness, and costs associated with a document-centric, 2D drawing-based business.

1.1 Our Challenge and a Proposition

Now our challenge is to be fast, faster than our competitors.[2] In response to this challenge, we must compress product realization timelines as well as address our changing culture and workforce. Our proposition is for the NSE to become a part-centric, digital product realization enterprise via the model-based enterprise (MBE) paradigm. An MBE promises to enable product realization with greater speed, more responsiveness, and better preparation to use innovative technologies such as additive manufacturing.

A Model-Based Enterprise (MBE) starts with a trusted model-based definition (MBD): a dataset founded on an authoritative, part-defining 3D model that fully defines and effectively communicates complete product definition without a 2D drawing. Subsequently, an MBE is an organization that successfully and efficiently reuses a single-sourced, authorized MBD for its business needs.

1.2 The NSE MBE Maturity Index

The NSE MBE Maturity Index (aka Index) is an analytic rubric: a tool that an organization uses to assess itself as an MBE. The rubric lists the criteria (in the form of assertions) that an organization should exhibit to attain specific capability levels. And, importantly, it serves as a common point of reference for activities and conversations related to MBE.

The material described here acknowledges and extends previous works: 1) the initial U.S. Mantech MBE Capability Index; and 2) the U.S. Army's extension of the index as an MBE Capability Assessment tool, sometimes referred to as the NIST Index, as it was posted at the NIST (National Institute of Standards and Technology) and website for a season.

To help understand, guide, and communicate the NSE's MBE transitional journey, a multi-site team enhanced previous iterations of the NSE MBE Maturity Index, to give it the characteristics that enable more consistent use across a broader set of domains. Working drafts were used to solicit peer reviews from industry, government, consultants, and academic partners. Focus area validation and improvements were incorporated.

1.3 Paper Outline

This paper contains the following sections:

- Section 2, Design Aims describes the structural and operational aspects of the Index in its current incarnation.
- Section 3, Framework of MBE Maturity Index provides a detailed description of the NSE's MBE Maturity Index.
- Section 4, Supporting Material describes information and tools that accompany the Index.
- Section 5, Trust Framework explains the underlying concepts related to trust that the MBE Index weaves into its content.
- Section 6, Planning Context provides ideas about how to incorporate the Index in your broader organizational planning.
- Section 7, Next Steps and Ideas for the Future provides an outlook for the Index.

[1] The NSE consists of Federal programs within the National Nuclear Security Administration (NNSA), an agency within the U.S. Department of Energy (DOE), and its partner Management and Operating (M&O) contractors at national laboratories and plants.
[2] U.S. General John E. Hyten, Commander of U.S. Strategic Command, testimony to Senate Committee on Armed Services, February 26, 2019.

2 Design Aims

The Index is designed to satisfy several aims including the following:

- Be a useable assessment and planning tool.
- Show a clear progression toward being more digital, better integrated, more automated, and more trusted.
- Maintain internal consistency.
- Be generic enough to support any type of product development/realization organization.
- Allow the user to define the scope to which the Index (and its assessment) applies.
- Provide flexibility with respect to target state (date, milestone, event, etc.).
- Provide testable conditions (assertions) that are sufficiently normalized.
- Provide repeatable results.
- Differentiate aspects of the current state.
- Generate results that are easily compared across domains.
- Allow an organization to identify different levels of maturity for different ranges of activities.
- Serve as a basis for an organization's MBE Roadmap.
- Enable near-term and long-range MBE implementation planning.
- Document an MBE lexicon.

3 Framework of MBE Maturity Index

The framework of the Index is that of a scoring rubric, where criteria of product development/realization activities are on rows and levels of maturity are on a scale by columns. Each intersection of maturity level and activity is an assessment point that contains criteria in the form of an assertion.

The intention of the Index, when used as a rubric, is to evaluate an Organization Under Assessment (OUA) as an MBE. The Index provides for scoring a future state (i.e. Target) and the current state (i.e., As-is), which is decomposed into three perspectives: capability, readiness, and adoption. Figure 1 shows a vista of the NSE's MBE Maturity Index.

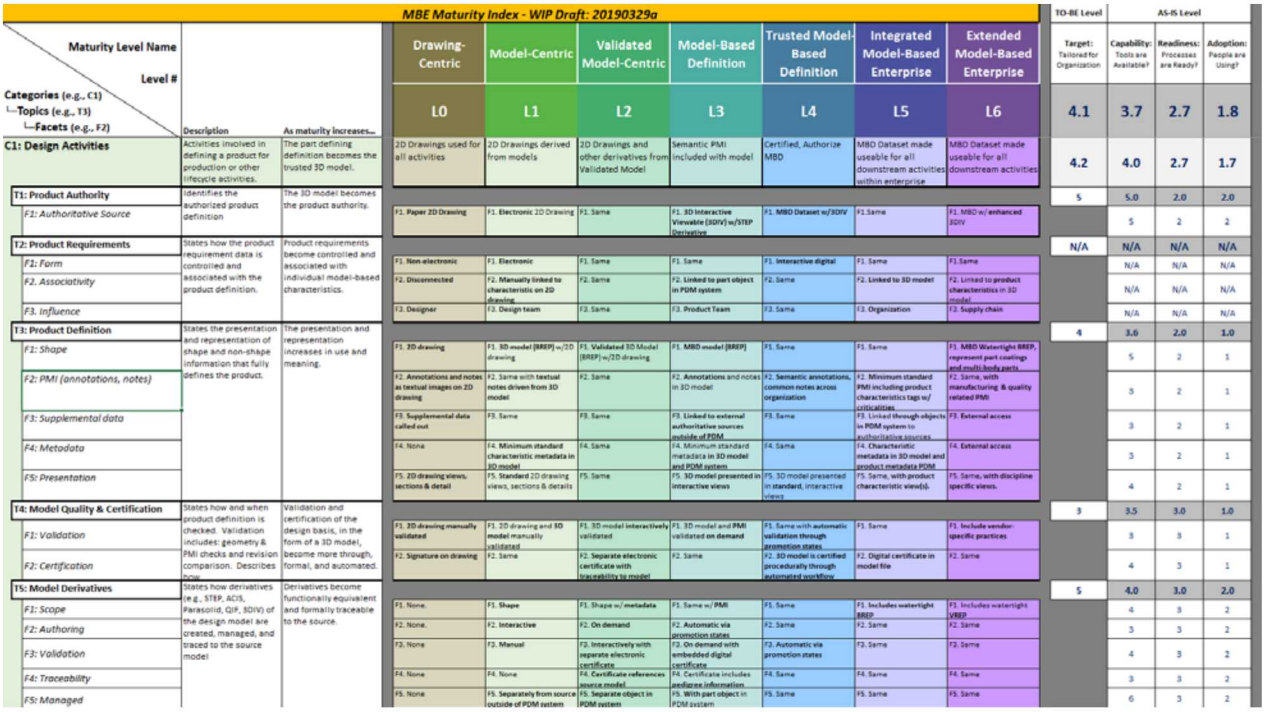

Figure 1: NSE MBE Maturity Index - Sample

3.1 MBE Maturity Levels

The Maturity Levels represent a progression towards becoming more digital, better integrated, more automated, and more trusted. Each level has a name, an identifier, and a theme as described below:

Level	Level Name	Level Themes
L0	Drawing-Centric	2D Drawings Only; Disconnected
L1	Drawing Model-Centric	2D Drawings & STEP Derived from 3D Models; Drawings Managed, Disconnected from Models
L2	Validated Model-Centric	2D Drawings & Equivalent Derivatives from Validated 3D Models; Drawings Managed, Disconnected from Models
L3	Formalized Model-Based Definition	3D Models with Semantic PMI Added; Producing 3D Interactive Viewables, Managed as Part-Centric
L4	Trusted Model-Based Definition	Digital Model-Based Definition (MBD) , Certified & Authorized; Managed & Sourced as Part-Centric
L3	Integrated Model-Based Enterprise	Enterprise Integrated from Trusted Digital Product Definition Dataset; Process Data Managed with Part-Centric
L6	Extended Model-Based Enterprise	Enterprise Extended with Optimized Capabilities and Extended Partners

3.2 MBE Categories

The criteria of activities on rows has the following structure of categories, topics, and facets:

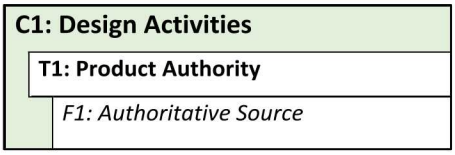

Figure 2: Taxonomy of Activities on Rows

Where:

C# is a broad category of activities (e.g., C1: Design Activities)
T# is a topic (e.g., T1: Product Authority) within a category, and
F# is a facet (e.g., F1: Authoritative Source) of a topic. The facets are where you score the As-is state.

As shown in Figure 3, each Category and Facet has a corresponding description and transition statement ("As maturity increases…").

Categories (e.g., C1) └Topics (e.g., T3)	Description: how the organization . . .	Transition: As maturity increases, the organization's . . .
C1: Design Activities (See category usage note for contexts)	Activities involved in developing a design for product definition or other lifecycle activity.	Product definition becomes the trusted model-based definition dataset.
T1: Product Authority		
F1: Authoritative Source	Identifies the authorized product definition (i.e. legal definition).	MBD Datasets become the product authority.

Figure 3: Facet Description and Transition Statement Example

The Categories in the NSE MBE Maturity Index are as follows:

C1: Design Activities: Activities involved in developing a design for product definition or other lifecycle activity.
C2: Product Data Management Activities: Activities that relate enterprise product lifecycle data to product definition.
C3: Manufacturing Activities: Activities involved in making a product.
C4: Quality Activities: Activities involved in manufacturing verification, part inspection, and product acceptance.
C5: Enterprise Enabling Activities: Activities that enable an enterprise to act as an MBE, but do not directly add value to a product's lifecycle.

Each category contains seven topics, shown in Figure 4. A given topic has one or more facets.

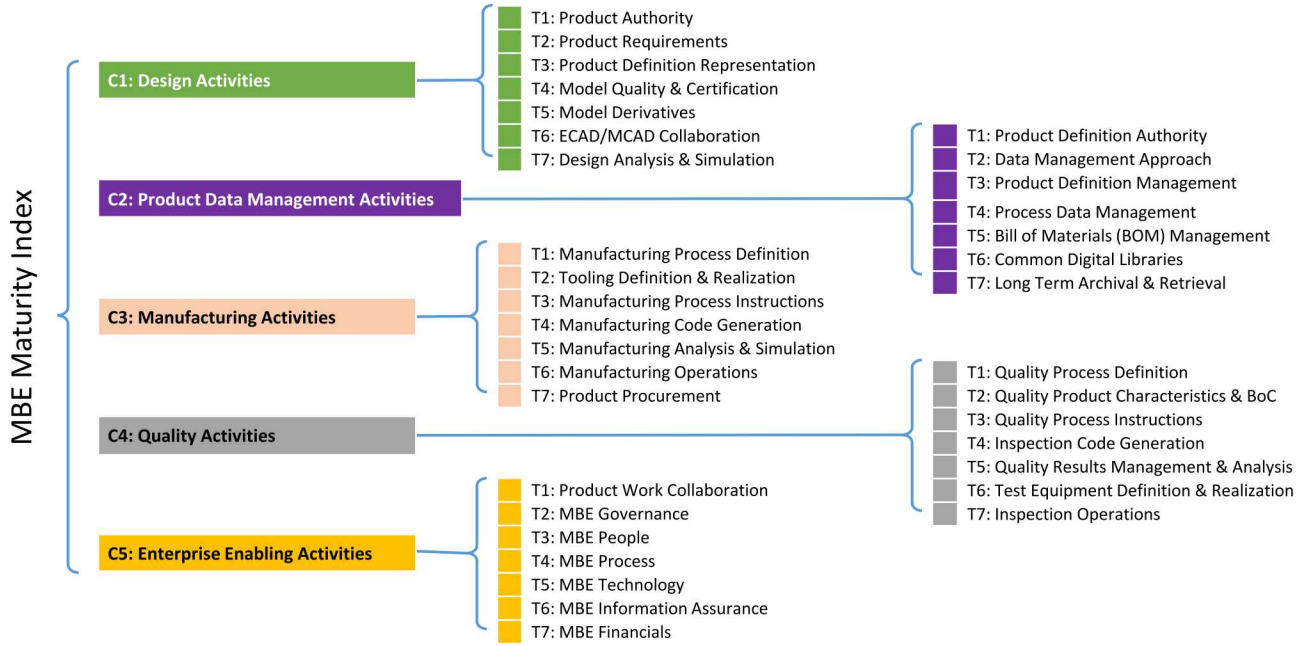

Figure 4: NSE MBE Maturity Index Categories with Topics

3.3 Assessment Ratings & Scoring

The assessment portion of the index allows the user to provide a current state (As-Is) score for each Facet, along with a target score (i.e., future or To-Be) for each Topic. The Index allows As-Is scores from three progressive perspectives: Capability, Readiness, and Adoption. These differentiated ratings enable an organization to more accurately identify its gaps in becoming an MBE, and better tailor its improvement initiative on tools, processes, or people.

- Capability refers to the tools, technologies, and standards that enable MBE within the organization.
- Readiness refers to the collection of processes, policies, and procedures that are ready to employ tools and technology within the organization.
- Adoption refers to the degree to which people in your organization are actually using those tools and processes in an operational environment.

Figure 5 shows an excerpt of the scoring area from the MBE Maturity Index.

AS-IS Level			TO-BE Level
Capability: Tools are Available?	**Readiness:** Processes are Ready?	**Adoption:** People are Using?	**Target:** Tailored for Organization
3.9	2.5	1.3	4.0
3.9	2.5	1.4	4.0
5.0	3.0	2.0	4
5	3	2	

Figure 5: Scoring Area in the MBE Maturity Index

3.4 Assessment Scope

Documenting the scope of an assessment is important and is defined along three orthogonal perspectives:

- Organization under assessment (OUA),
- Target date/event, and
- Selected rows of the Index that the assessment covers.

The OUA should be characterized by as many bounding conditions as necessary to appropriately differentiate the OUA from other potential OUAs. Example bounding conditions include organizational hierarchy, site, product line, functional specialization, product, project, ecosystem, or security level. The target date/event is documented as the To-Be state for the assessment. Further refinement of the assessment scope can be accomplished by selecting which rows of criteria to assess.

4 Supporting Material

The Index is currently packaged as a worksheet within a Microsoft Excel workbook. Other worksheets support the use of the Index as described in the following subsections.

4.1 MBE Maturity Index Header

At the top of the Index sheet is a header area where the user records the bounding conditions of the OUA, target date or event, date of the assessment, and other metadata that is useful for identifying the assessment and understanding its context.

4.2 Overview and Instructions Tab

This sheet provides important information about how to use the Index and the other supporting material.

4.3 MBE Index Summary Tab

Figure 6 summarizes the Index by showing its high-level structure (Categories across Levels) and by adding key information about authoritative source of product definition and model trust. One should acclimate to this summary before delving into the full Index.

NSC MBE Maturity Index

Level Name	Drawing-Centric	Drawing Model-Centric	Validated Model-Centric	Formalized Model-Based Definition	Trusted Model-Based Definition	Integrated Model-Based Enterprise	Extended Model-Based Enterprise
Level Identifier	L0	L1	L2	L3	L4	L5	L6
Level Theme	2D Drawings Only; Disconnected	2D Drawings & STEP Derived from 3D Models; Drawings Managed, Disconnected from Models	2D Drawings & Equivalent Derivatives from Validated 3D Models; Drawings Managed, Disconnected from Models	3D Models with Semantic PMI Added; Producing 3D Interactive Viewables; Managed as Part-Centric	Digital Model-Based Definition (MBD) , Certified & Authorized; Managed & Sourced as Part-Centric	Enterprise Integrated from Trusted Digital Product Definition Dataset; Process Data Managed with Part-Centric	Enterprise Extended with Optimized Capabilities and Extended Partners
Key Differentiators							

Authoritative Product Definition	2D Drawing	2D Drawing	2D Drawing w/ Support 3D Model	Drawing (3DIV preferred) from MBD w/ Support 3D Model	MBD w/ Support 3DIV Drawing	3D MBD Dataset	3D MBD Dataset
Artifact Management	File-Sharing	Document-Centric PDM	Document-Centric PDM	Part-Centric PDM	Part-Centric Lifecycle PDM	Enterprise Part-Centric PDM	Extended Part-Centric PDM
Categories for Assessment							
Design Activities	2D Drawings used for all activities	2D Drawings derived from models	2D Drawings and other derivatives from validated 3D model	Semantic PMI included within 3D model	Certified, Authorized MBD	MBD dataset made useable for all lifecycle activities within enterprise	MBD Dataset made useable for all lifecycle activities
Product Data Management	File-sharing directory	Document-centric PDM; Disconnected models	Document-centric PDM; Connected models	Part-centric PDM; Connected product related disciplines	Authoritative part-centric PDM; Source for product definition; Connected process, & lifecycle related disciplines	Enterprise part-centric PDM; Digitally "One" PDM for enterprise product lifecycle disciplines	Extended digital part-centric PLM exchange with trusted suppliers
Manufacturing Activities	2D Drawings used for all manufacturing related activities	Manufacturing via 2D drawings supported by disconnected derivative or recreated models	Manufacturing via 2D drawings with validated support derivative models	Manufacturing via 3DIV drawings with certified support derivative models	Digital Manufacturing via trusted MBD and support 3DIV drawings	Digital manufacturing via trusted MBD dataset	Digital manufacturing processes automated and extended to trusted partners via enterprise PDM
Quality Activities	2D Drawings used for verification, inspection, testing, & acceptance activities	Verification, inspection & acceptance via 2D drawings with disconnected derivative or recreated models	Verification, inspection & acceptance via 2D drawings with validated support derivative models	Verification, inspection & acceptance via 3DIV drawings with certified support derivative models	Digital verification, inspection & acceptance via trusted MBD and support 3DIV drawings.	Digital metrology via trusted MBD datasets with associated product characteristics	Automated metrology processes, extended to trusted partners via authenticated PLM
Enterprise Enabling Activities	Non-existent MBE	MBE Awareness	Reactive MBE	Repeatable MBE	Digital MBE	Integrated MBE	Optimized MBE

Figure 6: NSE MBE Maturity Index Framework Summary

4.4 Assessment Charts Tab

As you modify and complete your assessment ratings, the tool automatically generates radar charts to reflect the scores provided. A top-level MBE chart (Figure 7) shows the scoring for all the categories. Separate charts break down each category with current ratings for each topic on the Assessment Charts sheet. Use these charts to help evaluate your organization's assessment and determine whether you need to change some of your ratings. This is the beginning of your roadmap to becoming a more capable MBE.

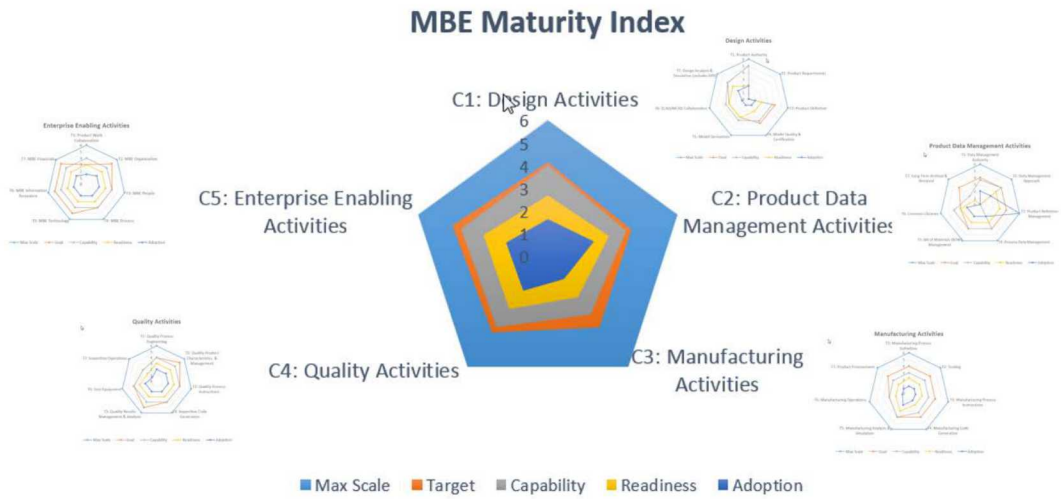

Figure 7: NSE MBE Maturity Index Radar Charts (notional)

4.5 Score Summary Tab

The score summary worksheet shows the results of your assessment in tabular fashion and provides input for the Assessment Charts

4.6 MBE Lexicon Tab

Packaged with the NSE MBE Maturity Index is a lexicon that includes terms (concepts) used in the Index. The Lexicon worksheet (Figure 8) provides terms and definitions that serve as a common context for communication that is no less indispensable than a common language. The definitions are intentionally generic and apply broadly; they are not intended for any specific domain. It also provides two columns intended to help the users (assessors).

- Use the "Specialization" column to refine the definition to your organization's needs.
- Use the "Organization Comments" column to record your thoughts on these terms and to help the community continue to improve the lexicon.

Acronym	Term	Definition *(Normalized)*	Specialization *(Informative) - Optional*	Organization Comment - *Optional*
ToA	Term of Acronym	Basis Definition of Term	Informative Description of Term	Organization's Definition or comment

Figure 8: MBE Lexicon Worksheet

5 Trust Framework

The transition to an MBE requires trust in your models and the associated digital data sets. The aims of digital engineering, digital enterprise, MBE, automation, etc. are unachievable without comprehensive trust in the models.

To that end, the MBE Index emphasizes the notion of trust. Indeed, it weaves concepts related to trust throughout its assertions. Those assertions are founded on the following 'Trust Framework' that applies to a model, dataset, or any other artifact (see Figure 9):

Given:

Trusted: Regarded with confidence, and concurrently being certified, authorized, and authenticated.

Where the artifact intrinsically has these tokens:
Authenticated: Proven to be genuine as issued by its originator.
Authorized: Approved by an authority for use in a lifecycle activity.
Certified: Guaranteed to conform to protocols.

Further, where the minimal conditions must exist for **Certified** are:
Validated: Assured to satisfy intent.
Verified: Assured to satisfy requirements.
Versioned: Successive revisions are stored and sequentially identified.

And further, where the minimal conditions for **Authenticated** are:
Signed: Authenticity of originator cannot be repudiated.
Traceable: The ability to find the authoritative source of a given fact.

Factors that increased confidence in an artifact include the following conditions:
Required: Mandated by some authority.
Specified: Defined to minimally-sufficient detail.
Recorded: Permanently documented for future reference.

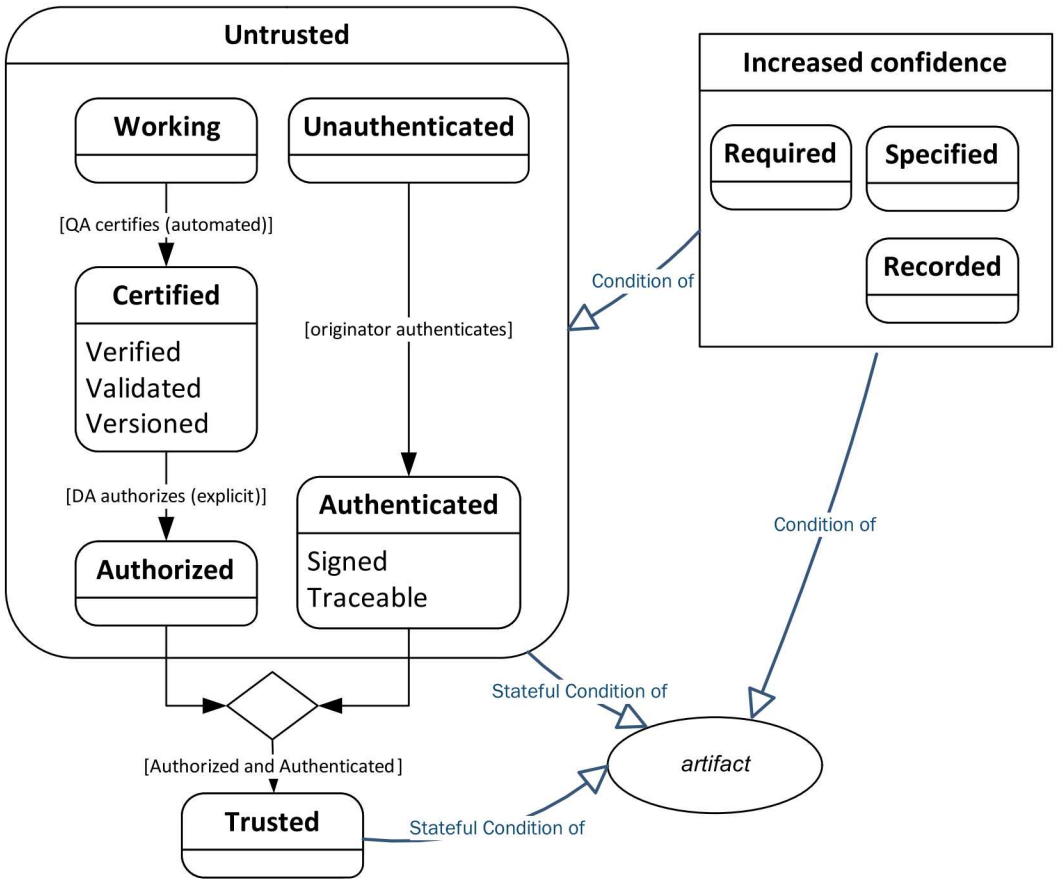

Figure 9: MBE Lexicon – Trusted Key Aspects

Here are a few points of explanation for the above state diagram:

- Trusted, Certified, Authorized, and Authenticated are stateful conditions of an artifact.
- Conditions in the "Increased confidence" box are additional conditions that act on conditions of trust.
- Major states of trust are: Untrusted and Trusted.
- Transition from Untrusted to Trusted requires both Authorized and Authenticated.

- The path to Authorized transitions from Working to Certified to Authorized.
- The path to Authenticated starts as Unauthenticated.

Thus, we can assert that trust, as an expression of confidence, is greatest when an artifact is verified, validated, versioned, authorized, authenticated, signed, traceable, required, and specified.

6 Planning Context

The MBE Maturity Index is most effectively used in a context of broader planning for a product realization organization. A simple approach might be as follows:

- Identify a Strategic Motivation
- Select and Define the Organization
- Identify Candidate Milestones
- Conduct Assessments
- Plot a Course

6.1 Identify a Strategic Motivation

One should have a solid motivation for conducting an assessment using the MBE Maturity Index. Without one, the assessment will likely provide a poor return on the time investment. One's motivation could be to provide structure around a pre-existing MBE vision. It could also be on the other end of the spectrum, where an organization wishes to justify its lack of vision with respect to MBE. Those are just two extremes; every organization will have its own reasons.

6.2 Select and Define the Organization

We've observed that the initial enthusiasm about using the Index often declines markedly when people realize that they can't apply it well to the intended scope of their organization. Large corporations are often far too complex and heterogeneous to apply the Index to the corporation as a whole, at least initially. Other realizations come to mind too: the lack of consistency across product lines, functional areas, security ecosystems, etc. Thus, one should carefully consider feasibility, applicability, and usefulness/impact when defining the OUA.

6.3 Identify Candidate Milestones

With respect to strategic motivation and OUA, try to identify milestones that might be important for plotting your MBE journey. Milestones might relate to product release, production runs, design stage gates, fiscal years, financial conditions, socio-political events, etc. Milestones help you answer the question: "Where do I want to be, by when?" Milestones translate into target dates for assessment.

6.4 Conduct Assessments

Part of conducting the assessment is selecting the rows to assess. While this can be done, in part, up front, it's likely to change during the assessment, possibly depending how the scoring goes or the overall pace of the assessment. The best practice is to complete the As-Is scores once for each OUA, and then fill out a separate assessment for each known milestone in sequence. One can envision a stack of assessments that share the same As-Is scores, but where the respective target dates and target scores differ.

6.5 Plot a Course

The results from an assessment using this Index will allow your organization to tailor an MBE roadmap toward where it wants to be in the future. Then, this roadmap provides focus for developing an MBE implementation plan. The best use is to analyze the scores over a sequence of target dates (corresponding to milestones, for example), and then begin to plot a roadmap of initiatives, projects, acquisitions, etc. that close the tools, process, people gaps over time.

7 Next Steps and Ideas for the Future

Next steps for the Index's continued development include:

- Continue to solicit peer review and to obtain focus area validation and improvements.
- Conduct simulated assessments to confirm the content.
- Prepare training curriculum.
- Publish for NNSA, US Industry, and other government reuses.
- Add C0: System Engineering Activity and C6: Service Activity categories.
- Refine the functional areas of electrical design and production support.
- Continue to update as needed.
- Consider a more useable format for the assessment.

8 References

MBE Capability Index, Not currently available, originally retrieved from Model Based Enterprise: http://model-basedenterprise.org/model-based-enterprise.html.

MBE Capability Index Assessment Tool, originally retrieved from NIST web-site, currently available from https://github.com/usnistgov/DT4SM/tree/master/MBE-Capabilities-Assessment

NSE MBE Maturity Index: Available from the following public web exchange: https://fmt.kcnsc.doe.gov/kcpfm/kcpfm_short.cgi?box=/.Dst9EMRmxucstVHi&path=/&cmd=list

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