A GUIDE TO DIGITAL TRANSFORMATION

Adoption of Model-Based Definition in the Defense Industrial Base

CONTENTS

FOREWORD

In October 2018, the U. S. Department of Defense (DoD) MIL-STD-31000 was revised to include the use of Model-Based Definition (MBD), with the goal of producing defense-related products faster, better, and cheaper. MBD is the process of using annotated 3D modeling to create a semantic Technical Data Package (TDP), the definitive workflow authority containing all of the necessary information to generate the part so no other files or drawings are needed. MBD is about streamlining the design and manufacturing process.

In August 2020, Connecticut received "Defense Manufacturing Community" (DMC) status - an acknowledgment of the State's long-standing leadership in the aerospace, defense, and shipbuilding industries. As a DMC, Connecticut was awarded a federal grant, overseen by the DoD's Office of Local Defense Community Cooperation (OLDCC), for the purpose of advancing the State's Digital Model Initiative (DMI) - a project that outlines best practices and lessons-learned for small and medium-sized defense suppliers as they adopt Model-Based Definition (MBD).

Unique among defense communities is Connecticut's desire to focus on process innovation, versus product innovation, which has broad applicability both in-state and across the country. Adoption of this technology gives Connecticut a nationally recognized competitive edge and signals DoD that we are aligned with their strategic goals, possess a highly trained workforce, and are eager to undertake DoD's newest Next Generation projects.

PAUL S. LAVOIE

Connecticut Chief Manufacturing Officer

CONNECTICUT DEFENSE SPENDING

The state's high level of defense production is likely to be the case for years to come, as Connecticut continues to build and maintain the world's most sophisticated nuclear submarines, state-of-the-art military jet engines, and a variety of military helicopters used in the United States and worldwide. Simply put, the future for the state's defense economy is very bright.

State of Connecticut
Office of Military Affairs
Annual Report FY 2020-2021
Robert T. Ross,
Executive Director

Connecticut consistently ranks among the top ten States in total defense spending ($23.6 billion), defense contract spending ($22.8 billion), and defense spending as a percentage of the State's GDP (8.2% compared to a national average of 2.8%).

Office of Local Defense Community Cooperation
Defense Spending by State
FY 2020

Connecticut Department of Economic and Community Development

DEFENSE MANUFACTURING Community Consortium Connecticut

INTRODUCTION

THE DIGITAL MODEL INITIATIVE

DoD's Office of Local Defense Community Cooperation (OLDCC) initiated a Defense Manufacturing Community Support Program to strengthen national security by aiding defense manufacturing. Connecticut, with its wealth of defense contractors, is part of that program and has implemented the Digital Model Initiative (DMI), a pilot program to identify and capture lessons learned and best practices for small to medium-sized defense manufacturers. This resource guides manufacturers as they adopt Model-Based Definition (MBD) processes, related technologies, and workforce strategies.

Six suppliers were chosen to participate in this project, two from each of Connecticut's three largest prime contractors to DoD: Electric Boat, Sikorsky, and Pratt & Whitney. These suppliers varied in workforce size, location, production capacity, net sales, product portfolio, and industry sector (e.g., submarine, vertical lift, and propulsion).

Early in the project, each of the six suppliers were assessed and baseline information was gathered using

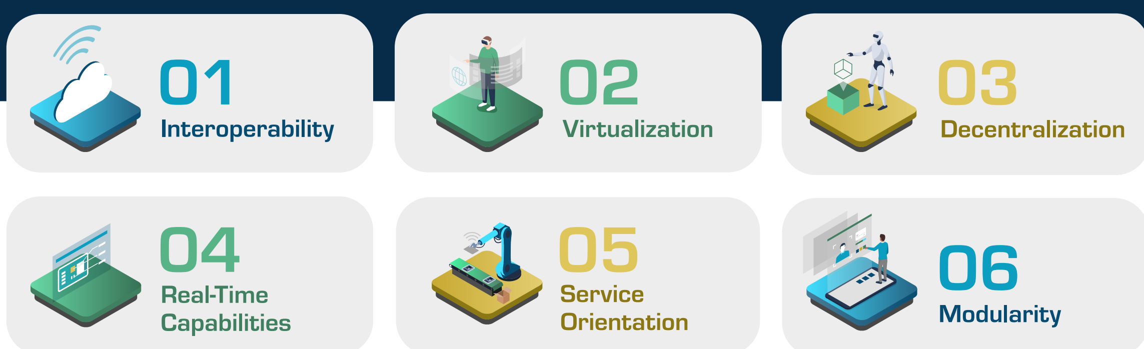
1. the Smart Industry Readiness Index (SIRI), the world's first independent digital maturity assessment for manufacturers,
2. Cybersecurity Assessment, a process used to illustrate company compliance to the NIST SP 800-171 standard,
3. an onsite review of technology, and
4. workforce gap analysis to identify missing roles and skillsets.

This set the stage to develop company-specific next steps to adopt new technologies.

INDUSTRY 4.0 – DEFINITION

Industry 4.0 refers to the fourth industrial revolution, which connects machines, people, and physical assets into an integrated digital ecosystem that seamlessly generates, analyzes and communicates data, and sometimes takes action based on that data without the need for human intervention.[1]

As part of a "digital transformation" towards an Industry 4.0 manufacturing operation, companies strive to leverage the benefits of the 6 enabling principles of Industry 4.0 – including the use of virtual digital models that can be shared between interoperable systems.



U. S. DEPARTMENT OF DEFENSE MANUFACTURING STANDARDS

DoD modernized its design processes, including adopting standards that specify the levels of design detail required. The implementation of MIL-STD-31000 A+B altered how companies design, build, and support defense manufacturing, requiring technical descriptions which are clear, complete, and accurate, and in a form and format adequate for its intended use.

Appendix A and B of MIL-STD-31000 provide details and suggestions about Technical Data Package (TDP) elements, as well as specific steps required for the MBD process (website links to Appendices). Under the new standard, using unannotated and undefined features will no longer be allowed for suppliers that want to participate in DoD next-generation programs.

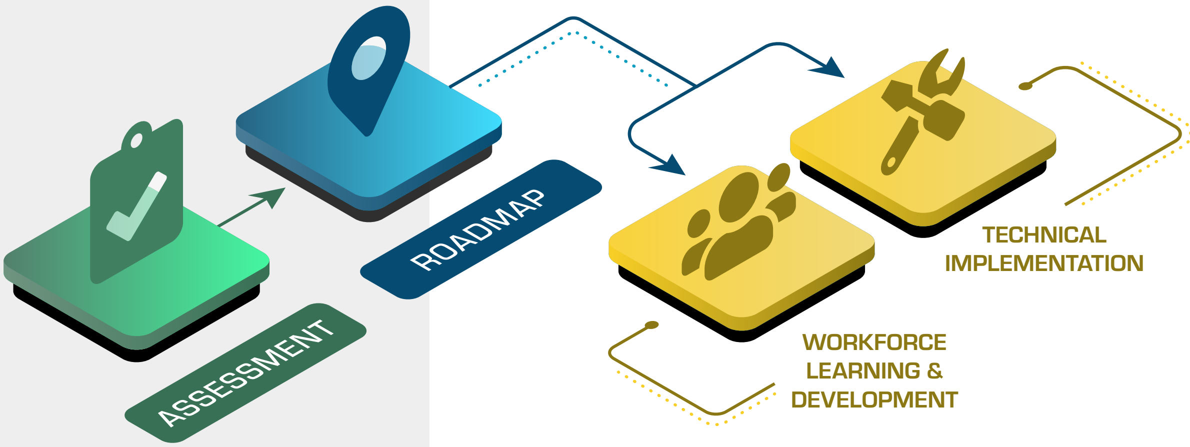
1. Source: PwC's Insights, *Capital efficiency meets Industry 4.0*

HOW TO USE THIS GUIDE

This is a reference for adopting model-based definition tools and creating a digital thread to incorporate 3D models efficiently for manufacturing. The experiences of these defense supply chain manufacturers show basic principles of MBD benefits and best practices to implement solutions, with examples to highlight problems, their solutions, and recommendations on next steps.

Moving to a digital thread implementation follows a general pattern:

- Assessment of the organization's readiness,
- Creation of a roadmap toward implementation, and
- Parallel workstreams for technical implementation and workforce development.



DIGITAL DATA

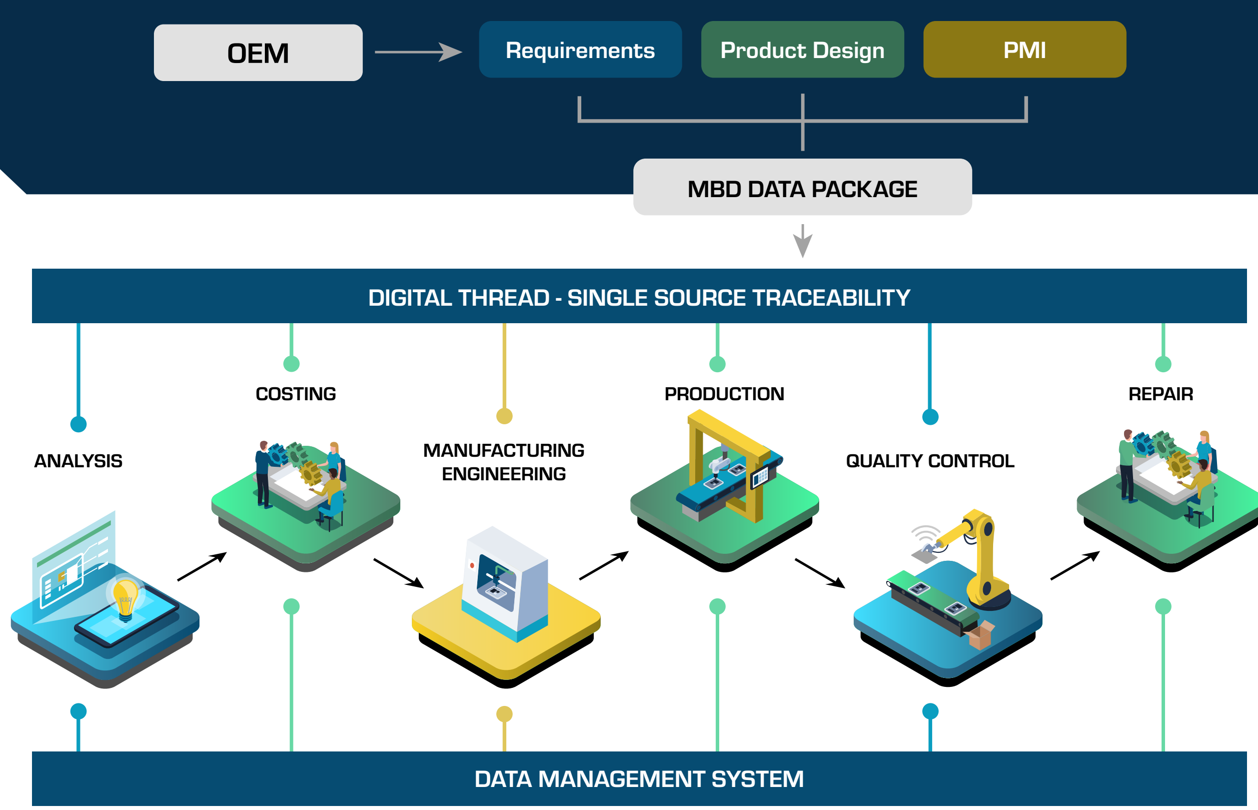
With Industry 4.0, more digital information will be shared across the supply base.

Original equipment manufacturers (OEMs) will share Model-Based Definition (MBD) of parts and assemblies in the form of digital data, which can be used by various technologies. This Guide is meant to help manufacturers transform their operations for MBD.

DIGITAL DATA – DEFINITION

A Model-Based Enterprise (MBE) uses a 3D model format annotated with digital data containing everything needed to design, model, simulate, manufacture, test, and support a product throughout its lifecycle. This digital thread connects every phase of the product and fosters improved communication and understanding between OEMs and their suppliers.

Digital data has other uses, including the simulation, analysis, and field support of end products, but this guide is focused on using digital data to manufacture a product and ensure the required quality. Streamlined access to the data for quoting, scheduling, and inspection ensure a successful exchange and can prevent costly errors and supply chain disruptions.



UNDERSTANDING DIGITAL DATA

MODEL-BASED DEFINITION

Model-based definition is an annotated 3D model which completely documents a part for production with the intention of automating the manufacturing, inspection, and business processes. The annotations of the 3D model are often referred to as Product Manufacturing Information (PMI). PMI and MBD are used interchangeably in this document, though MBD in the context of this document refers to the automation of production processes leveraging PMI. Within MBD the notes and the model are both needed for producing parts and assemblies.

The goal is to implement the digital thread, a seamless data flow which ensures that all the right information is available when and where it is needed. The resulting technical architecture then becomes the foundation of the organization's business process templates for closed-loop manufacturing.

The complete MBD consists of the model, parts list, materials, finishes, processes, notes, analytical data, and test requirements. Just as a drawing contains several views to communicate the design, MBD may have several views with separate annotations for conveying specific information.

Benefits of Model-Based

Why is the DoD pushing for defense manufacturers to implement MBD? Besides simplifying and securing the exchange of data between OEMs and suppliers, there are other business benefits:

Data Reuse – Digital models create a digital thread useful for both manufacturing and quality control as well as business processes. Model-based definition provides needed data directly to electronic work instructions, CNC machining, CMM inspection, and service manuals.

Reduced Effort – Since it is not required to specify every dimension within a design, the effort of documenting is reduced.

Error Reduction – A significant source of errors result from drawings not matching the dimensions in the model.

Clarity – 2D drawings require interpretation. 3D annotations are associative which means the annotations are connected to the 3D geometry on the CAD data.

Validation – The models can be automatically validated for comprehensive and clear definition.

Change Comparison – Versions of the model can readily be compared for both geometry and PMI changes.

TECHNICAL DATA PACKAGE

The digital model definition is often packaged as part of a Technical Data Package (TDP). Often a TDP is packaged in interactive portable formats (3D PDF, JT Plus PDF or HTML5). This allows the consumer of the TDP easy access to the annotated 3D model views and associated notes, parts lists, and attributes. The TDP may contain attachments of additional information or models, such as engineering parts lists, data sheets, native CAD models or derivative models, as shown in Figure 1.

> The greatest benefit of TDP is that all the information is readily accessible in one place.
>
> **Sean Sullivan – CTO, Engineering USA**

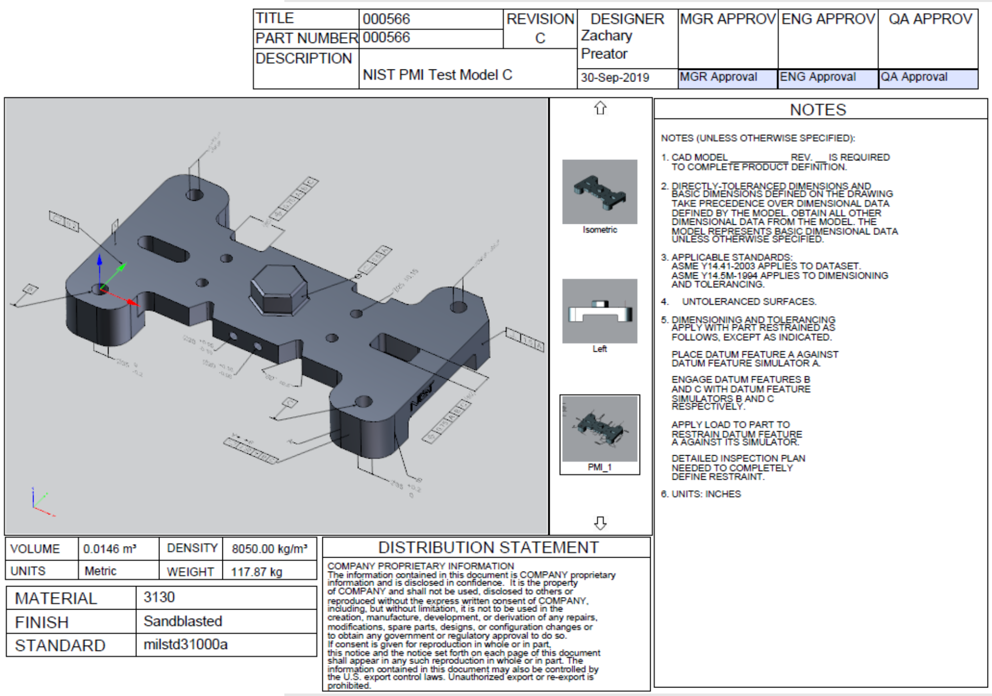


Figure 1

CONSUMPTION OF DIGITAL DATA FROM ORIGINAL EQUIPMENT MANUFACTURERS

Several steps must be taken by suppliers when receiving digital data from OEMs:

> **Validation** of the data,
>
> **Translation** of the customer's data into the supplier's standard format, and
>
> **Change comparison** of the data with a previous version or from the customer's data to the supplier's translated version.

VALIDATION

Is the data correct and complete? Suppliers must check their customers' data against existing standards. Checking immediately upon receipt can save time and effort.

TRANSLATION

Should the data be translated into the existing system or should the system be redesigned to accommodate the digital data? Translation from one format to another can lose some of the data integrity and intelligence. Usually, the associativity between the PMI and the geometry remains, but often the PMI is stripped in the translation and vital information such as tolerances, thread information, and finish requirements are lost. The downstream software cannot process the poorly translated PMI and human intervention to interpret and process the models is now required. Of course, redesigning a company's systems could require a significant investment.

In summary, the translation of PMI as visually correct only, while maintaining associativity, produces satisfactory results. However, translating semantic PMI has been disappointing; the representation after translation was often incorrect. Semantic PMI is necessary to drive downstream processes such as CNC and CMM code automation. The choice of translation or system redesign requires careful analysis and prototyping.

CHANGE COMPARISON

What information has been changed since the last version of the design? There are two use cases for change comparison. When translating customer supplied data, it is important to **verify that it has been translated accurately**. When processing a new revision of customer supplied data, with an earlier revision already processed, **the changes between revisions can be clearly identified** in 3D and documented in a 2D report. The capabilities of some of the software include

1. **Feature Changes** – Have geometry features been added, deleted, or moved?
2. **Component Changes** – Have components been added, deleted, or moved?
3. **PMI Changes** – Has there been PMI added, deleted, or had its parameters changed?

If you have processed a previous revision of a digital model and received a later revision, it does not make sense to reprocess from scratch. Commercial software exists to analyze the models for change comparison purposes.

RETURN ON INVESTMENT FOR MANUFACTURING

In a recent research effort between McKinsey & Company and the Aerospace Industries Association (link here[2]), it was found that increased adoption of digital tools like MBD could lead to a $20 billion increase in EBITDA within the global Aerospace & Defense industries. Of that potential $20 billion value, $12 billion resides in a combination of manufacturing, procurement, and supply chain. This affects not only the OEMs but feeds directly into the supply chain and outsourced manufacturing providers.

This long-term growth opportunity provides some justification to the investment of time and effort into digitization for OEMs and suppliers alike, however there are also near-term benefits to the adoption of MBD and the digital thread within manufacturing operations. As mentioned previously, the digital thread enabled by MBD streamlines processes, reduces errors, and increases overall productivity.

To highlight this with a real-world example, a study was conducted by the Connecticut Center for Advanced Technology (CCAT) in conjunction with a manufacturer of CNC machined parts. Using traditional methods based on 2D drawings, parts were produced by transcribing the critical information into CAM software and inspection probing systems. This process included 2 hours of CAM programming, 1 hour of probing system programming, and an additional hour of rework to bring parts into compliance – for a total time of 4 hours on top of the actual machining time.

Using MBD tools to extract PMI from the models in a form that could be read by the software packages, they were able to reduce the programming times to 20 minutes each for CAM and probing programming. In addition, the automated probing enabled them to include on-machine probing in the part processing step, which prevented the need for costly rework – for a total time of 40 minutes on top of the machining time. This method reduced the non-value-add processing time by more than 80%, which directly improves on-time delivery, lead time, and efficiency on the factory floor.

2. Source: https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/digital-the-next-horizon-for-global-aerospace-and-defense

ASSESSMENTS

Before one begins to evaluate a change, it is best to understand where we are.

Adopting digital tools into the engineering and manufacturing landscape is challenging. The company's readiness should be assessed to decide what actions to take and how to prioritize them.

Readiness applies to more than just the state of technology in an organization, the processes and people also need to be considered. In order for the digital transformation to succeed, the workforce needs to be developed with the skills to leverage the new digital tools and leadership needs to understand how to effectively deploy and manage change initiatives.

DIGITAL TRANSFORMATION READINESS ASSESSMENT

The assessment platforms selected for the DMI project is an independent model that helps companies assess their readiness for digital transformation and incorporates financial and performance data to help them prioritize their next steps and create a roadmap for improvement.

The assessments provided some useful insight into where MBD solutions can significantly impact suppliers' activities. The three core elements are:

PROCESS:

- Identify inefficient and error-prone processes in the exchange of PMI with OEMs
- Highlight opportunities to improve efficiency and quality by incorporating MBD tools into internal operations and supply chain interface

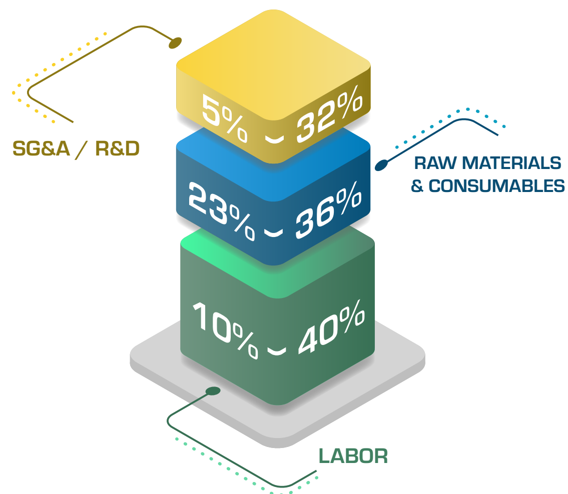
TECHNOLOGY:

- Highlight areas where machine-readable PMI can assist the programming of CNC and metrology systems
- Incorporate 3D models and other data to create augmented reality environments and streamline value-add assembly capabilities

ORGANIZATION:

- Identify skill sets and roles vital to successfully use MBD
- Gauge how to use MBD for increased collaboration and enhanced workforce training and development

The results of the assessments revealed key findings about the driving forces in the six DMI supplier companies (see below). The key performance indicators (KPIs) and cost factors identified by the companies indicate the areas where they need to make significant impacts with advanced technology and MBD practices.



Range of Top 3 Cost Factors (as % of Revenue)

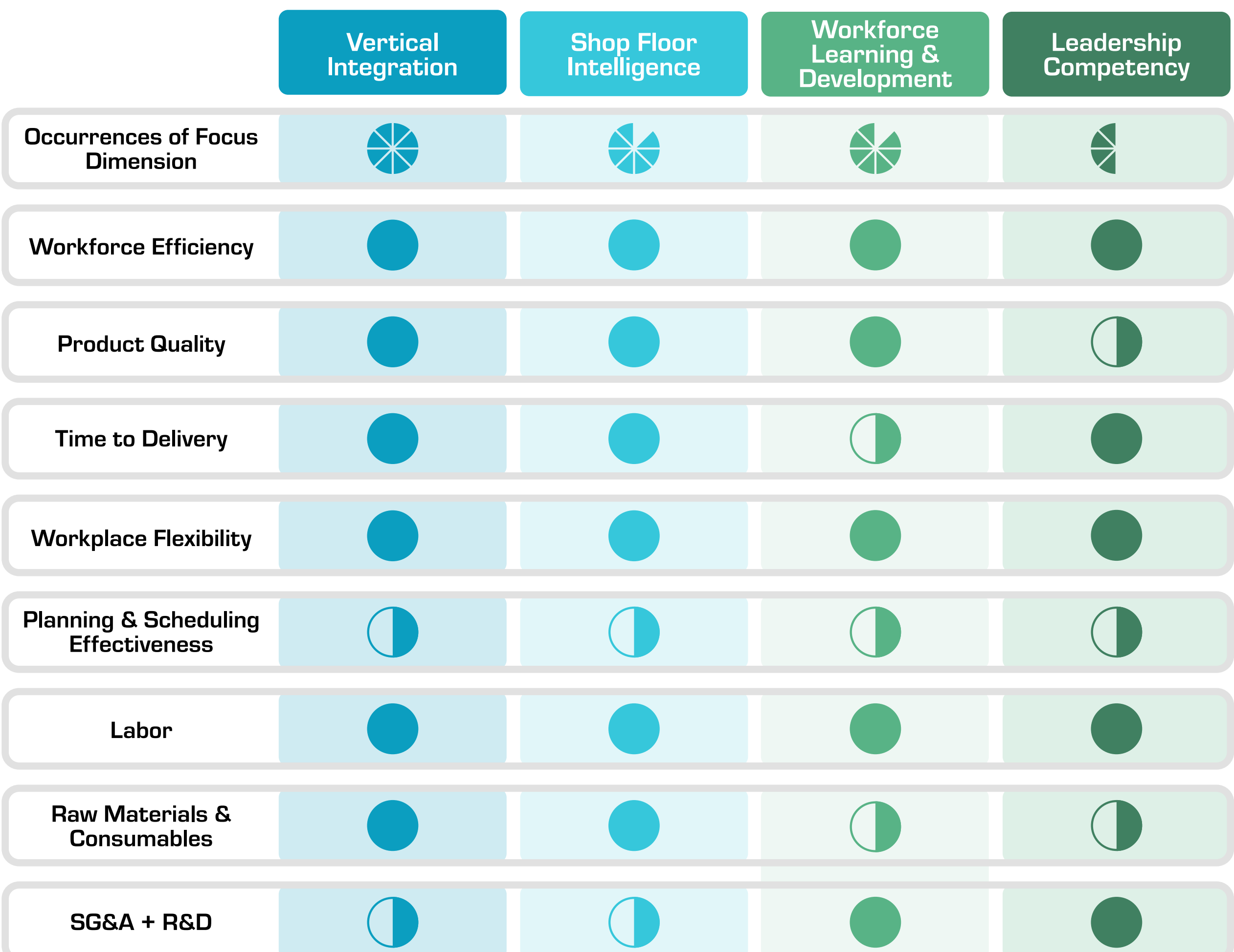
SUPPLIER	A	B	C	D	E	F
Workforce Efficiency	✓	✓	✓	✓	✓	✗
Product Quality	✓	✓	✓	✓	✗	✓
Time to Delivery	✓	✓	✓	✗	✓	✓
Workforce Flexibility	✓	✓	✓	✓	✗	✗
Planning & Scheduling Effectiveness	✓	✗	✗	✓	✓	✓

Top 5 KPIs Selected by DMI Suppliers

When reviewing the recommended areas of focus for each of the suppliers, there were some common themes that emerged. The impact the recommendations can have on the driving factors determines their priority. The following chart illustrates the areas with high impact and moderate impact in each area and the effect on the suppliers.

The assessments provided useful holistic overviews of the Industry 4.0 readiness of the six suppliers involved in the DMI Project. Similar to a traditional value stream mapping exercise, an effective digital transformation assessment captures the current state of the company and provides a roadmap with areas of recommended focus. These recommendations are broad and represent areas for further investigation, root cause analysis, and scouting to identify specific solutions to be implemented. These high-level outputs were augmented by the inclusion of three other steps in the assessment process:

1. Technical experts were included in the assessment workshop to uncover specific information about the use of MBD toolsets and associated capabilities within the company.
2. Experts in employee development were included to further explore workforce learning & development and leadership competency.
3. A separate cybersecurity assessment was conducted according to the NIST SP 800-171 guidelines, and the suppliers were provided with a gap analysis and plan of action to address the findings.



https://siri.incit.org/assessment

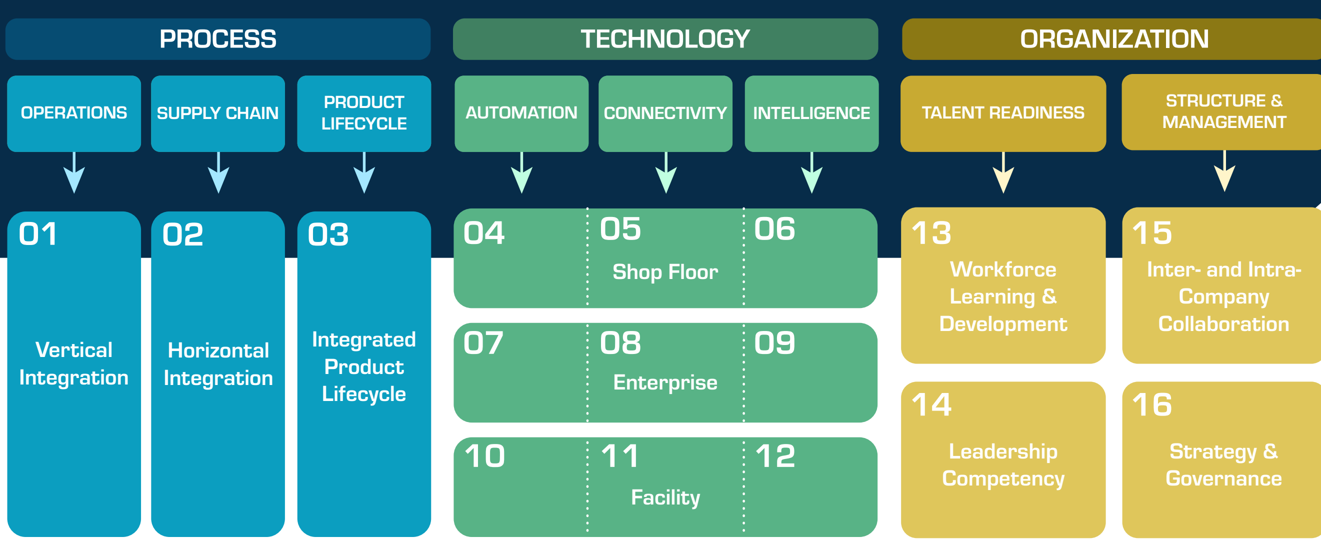
SMART INDUSTRY READINESS INDEX (SIRI)

The assessment platform selected for the Digital Model Initiative (DMI) project was the Smart Industry Readiness Index (SIRI). Developed in 2017 by the Singapore Economic Development Board and endorsed by the World Economic Forum in 2020, SIRI has been used by about 1,000 companies internationally to assess their readiness for Industry 4.0 and digital transformation. One important feature of the SIRI platform is the inclusion of industry-specific benchmarking data, so the six suppliers were able to compare themselves to their aerospace and defense industry averages.

SIRI measures the current state of a manufacturing company across three core elements: their **Processes**, use of **Technology**, and the **Organization** itself. These are divided into sixteen areas of assessment that companies can use to evaluate their current Industry 4.0 readiness. These areas are assessed and prioritized based on their impact on cost, key performance indicators, and the competitiveness of the company within their industry. This prioritization helps create a roadmap for the company and the foundation for continuous improvement and digital transformation.

An important factor to consider in the selection of an assessment platform is the scope of the assessment and depth of detail that will be produced. It is tempting to start with a narrow focus on technology solutions with the hope of quick wins, but this short-sighted approach can miss critical process and organizational opportunities that will pave the way for sustained success.

The intent of the SIRI assessment method is to help companies learn and apply the principles of digital transformation to develop a high-level strategy. While the SIRI platform does not provide granular analysis of technical needs or point to specific technology solutions, it does provide a holistic view of the company and their readiness to undergo a digital transformation.



CYBERSECURITY

Cybersecurity is the practice of protecting computer systems and data from digital attacks. Securing the factory environment is a new challenge for manufacturers.

As companies continue to integrate cyber-physical systems, data security must be considered. It is straightforward to protect access to Information in physical form. As we transition more manufacturing to the digital domain, security becomes more complex.

Within the Defense Industrial Base (DIB), the Department of Defense defined adequate security as implementation of the requirements in the National Institute of Standards and Technology Special Publication 800-171 (NIST SP 800-171). Defense contractors must follow these requirements. For companies which are not required to comply, NIST SP 800-171 is an excellent framework for protecting the confidentiality of data.

All employees need to be involved; good security begins with employee actions.

ORGANIZATIONAL COMPETENCIES

Adopting a model-based definition approach to managing product manufacturing information is more than purchasing a software package, as seen in the last section.

The core operations processes, organizational culture change, and digital transformation can encounter roadblocks in two distinct ways:

1. Leadership and management drive a shift in philosophy and culture in a top-down approach. This can be viewed as unrealistic by employees, who perceive a disconnect between the “real world” of production and the “ivory tower” of leadership.
2. Suggestions originating from initiatives at the employee or “grass roots” level are proposed in a bottom-up approach. This can be perceived by leadership as an unnecessary additional expense, requiring employees to “sell” them on the potential benefits and impacts.

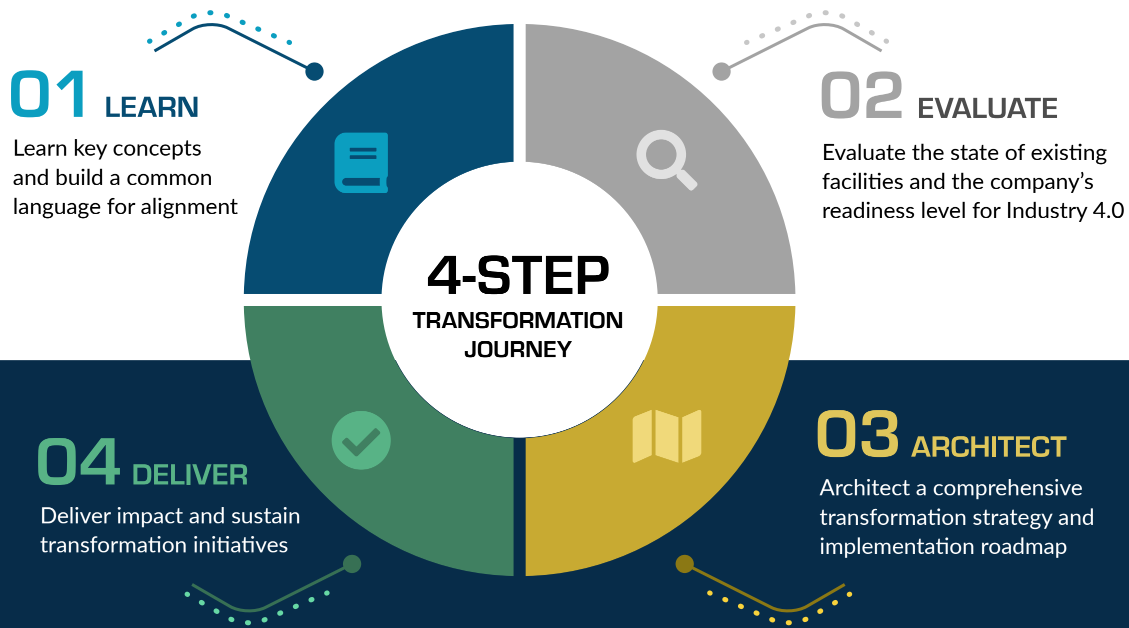
Both scenarios create drains on time and resources to fight the embedded status quo and create the momentum necessary for change. The solution lies in increasing awareness and understanding at both levels.

Leaders and managers must understand the business impact of effective digital transformation: it provides another set of tools to drive efficiency and productivity. With this understanding, they can integrate digital transformation into their company strategy, promote the benefits, and provide the necessary financial support for initiatives. This will create an organization that can quickly develop and deploy initiatives to fuel growth and long-term success.

At the employee level, competency in the relevant technologies requires additional training and upskilling, as will be addressed in the next section. In addition to the technical skills, it is critical for these employees to be able to identify business needs and map them onto digital solutions. Project proposals need to be framed in terms of their impact to cost factors such as labor and raw materials or key performance indicators, like time-to-delivery or workforce efficiency, to justify the investment of time and resources.

As both leadership and employees gain understanding of Industry 4.0, effective communication and collaboration at all levels of the company must be encouraged. A healthy culture, with shared risks and rewards and enabling teams to have decision-making authority, provides the momentum to take this transformation to Industry 4.0 into a sustaining state.

LEAD FRAMEWORK – RECIPE FOR SUCCESS



There are several important steps to ensure the success of any digital transformation. **Step #1** – create a common language for the organization to promote effective discussion. This consists of a learning program that addresses key concepts and technologies, the associated business benefits, and a stepwise approach to reach the ideal future state.

Step #2 – evaluate the current state of the company and its readiness to adopt new technology using that common language. This is most effective when conducted with a team of internal stakeholders and facilitators who look at all aspects of the company from multiple perspectives.

This evaluation becomes the input for **Step #3** – to architect a roadmap with an eye on the overall transformation strategy. A measured approach of incremental improvements in a handful of prioritized areas will create a bridge between the "as-is" state and the "to-be" vision.

Step #4 – deliver on the identified initiatives and reach a point of sustained transformation and ongoing delivery of value. In the early stages of adoption, the use of third-party subject matter experts is required to fill in the gaps of internal technical expertise. As companies mature in this model and develop internal expertise at both the technical and strategic levels, they become more self-sufficient and able to effectively identify and execute initiatives

TECHNICAL IMPLEMENTATION

Digital modeling is not without challenges; drawings have been used as the authoritative source for hundreds of years.

Well-developed processes are in place to consume, interpret and process drawings. Digital modeling requires change. This section provides a guide to processes that can be utilized to achieve optimum results with digital modeling.

DIGITAL IMPLEMENTATION

There are two separate (but connected) digital threads enabled by MBD: manufacturing and quality. Here we will explore two experiences of suppliers with model-based definition. One produces precision machined parts and the second produces fabricated assemblies.

DEMONSTRATION VIDEO LINKS

- **MBD Introduction and Possibilities -** bit.ly/MBD-intro
- **MBD File Handling Tutorial – Creating, importing and validating MBD files in SolidWorks -** bit.ly/MBD-file
- **Creation of CNC Toolpaths Using MBD in SolidWorks CAM -** bit.ly/MBD-toolpath
- **Creation of Structured Light Inspection Program Using MBD in Geomagic Control X -** bit.ly/MBD-inspection
- **Automated First Article Inspection Report (FAIR) Generation Using MBD and Native CAD File Translation to STEP 242 and QIF Neutral -** bit.ly/MBD-capvidia
- **Automated CMM Programming in PC-DMIS Using MBD -** bit.ly/MBD-hexagon
- **Benefits of MBD for CNC Programming in Mastercam -** bit.ly/MBD-mastercam

PRECISION MACHINE PART

RECREATION OF DATA

In the past, precision machining suppliers received drawings and written explanations from their customers, with a 3D derivative model as a supplemental definition. The drawing and the 3D model often did not quite match, so, the supplier manually recreated a new 3D CAD model in their own CAD system to match the 2D drawing provided by the OEM.

The supplier would then:

1. Create in-process models and drawings
2. Design tooling and fixturing
3. Create routings and operation sheets utilizing the in-process drawings just created
4. Create the inspection plan with final and in-process measurements
5. Produce tooling and fixturing

Steps 1 -5 would be followed by these semi-automated steps:

6. Create CNC code for each manufacturing operation
7. Create CMM code for final and in-process measurements
8. Execute the manufacturing operations – machine, measure, and adjust

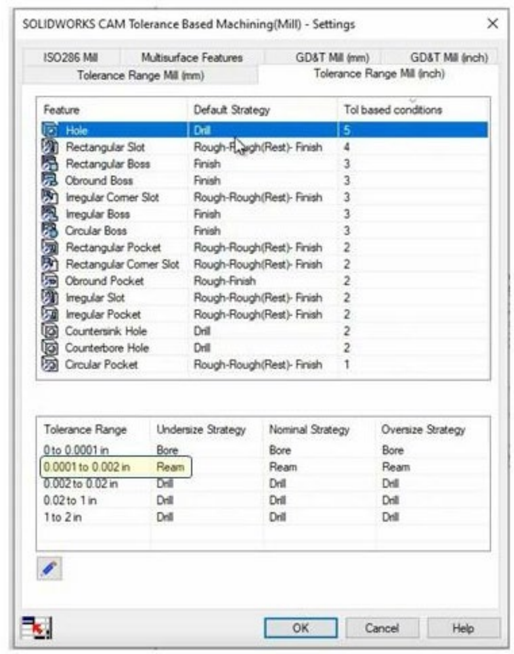


Figure 2: Operational Tolerance Strategy Rules

VALIDATE – DON'T RECREATE

Using model-based definition, the supplier does not need to create a new 3D CAD model, but can simply validate the model supplied by the customer. Software is available to automatically perform the validation. For example, 'Check-Mate' from Siemens NX is used to validate PMI against standards, and Capvidia's 'CompareVidia' compares native CAD data to derivative models.

IN-PROCESS MODELING

The CAD software used for the customer's model contains a mechanism for producing in-process models. It can quickly create the geometry of the manufacturing stages. It can also link the defining PMI from stage to stage and even have the dimensions adapt to the new geometry. This drastically reduces the time to create in-process models.

AUTOMATIC (ALMOST) CNC CODE GENERATION

Several CAM software packages can adjust the operations and toolpaths based on the PMI applied. Once set up, these programs deliver automation to the machine program generation process. The intelligence that can be read and processed into operation changes include size and Geometric Dimensioning and Tolerancing (GD&T) of hole, slots and bosses, asymmetric tolerances, and surface finishes. Figure 2 shows an example of tolerance strategy rules and Figure 3 shows how the tolerance applied to a hole is read and the appropriate operation is applied.

In the case of our supplier, the CAM package was able to recognize and automate the processing of holes and planar surfaces but was unable to process contoured surfaces automatically.

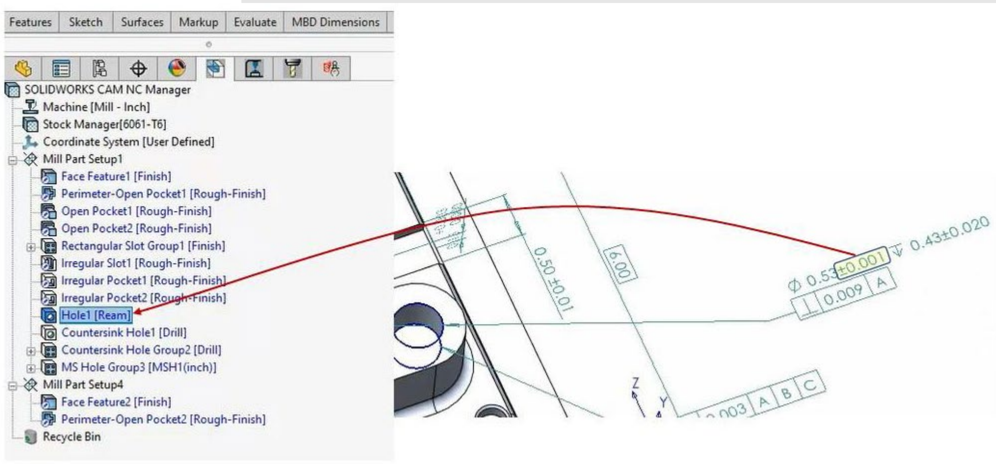
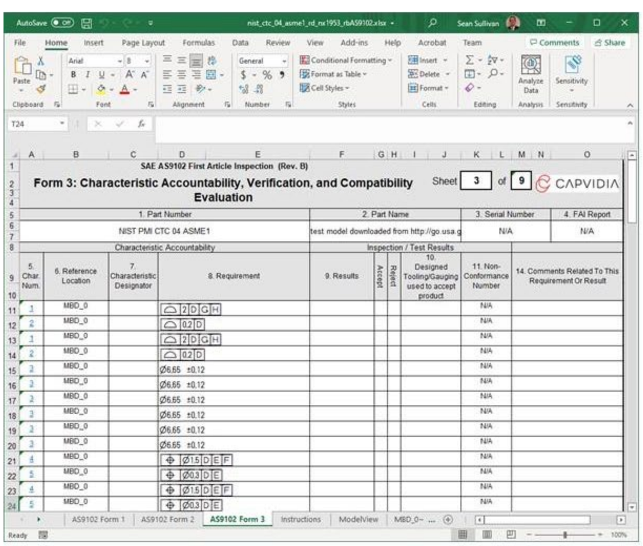


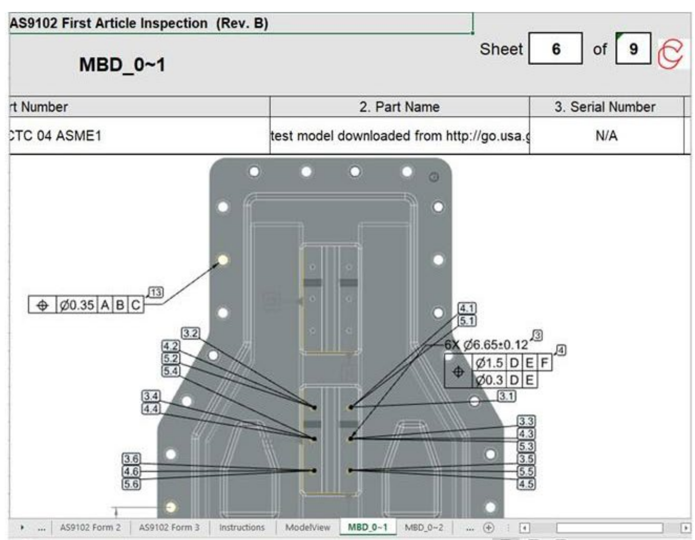
Figure 3: Operation Effect of Tolerance

QUALITY DIGITAL THREAD FOR MACHINING

In the past, the supplier would use software to populate the 2D drawing with characteristic identifiers, which would correspond to measurement rows in a spreadsheet. If the characteristic was to be applied to more than one surface, the user manually entered additional sub-characteristic rows. An inspection plan would be created manually, detailing what measurements to apply at the various manufacturing stages and what instruments to use.

In the case of our supplier, the customer provided a separate quality dataset in QIF format. This comes with the bill of characteristics defined. This dataset was opened in software specifically made to process the quality dataset. From this software a FAIR (First Article Inspection Report) was automatically created, with separate rows for each instance of a characteristic. The characteristics are linked to images within the FAIR that show the exact location on the part where the characteristic is measured. When the customer defines the bill of characteristics digitally, there are no misunderstandings.





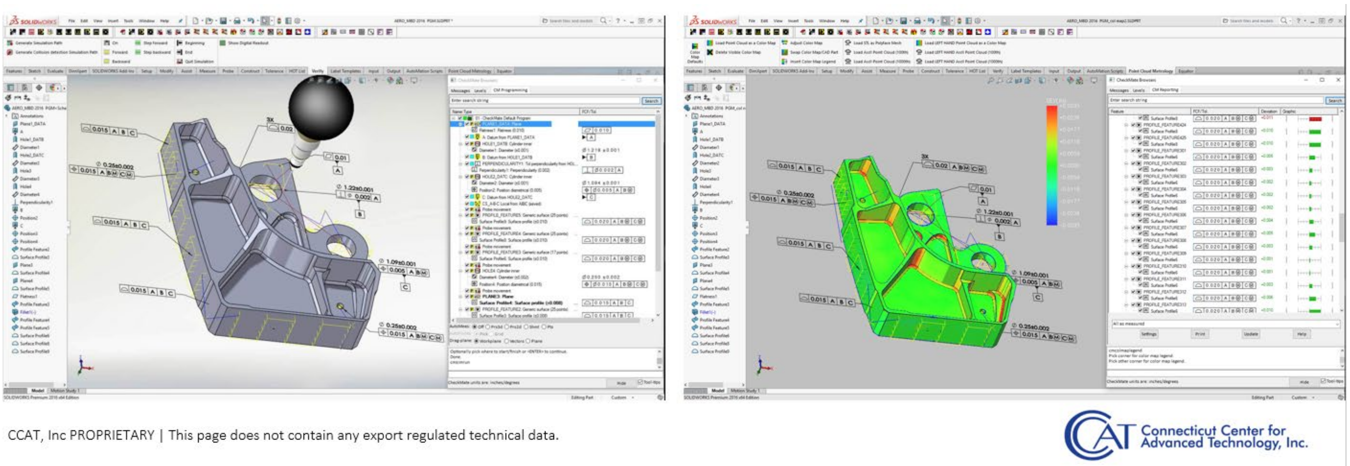


Figure 4: Automated CMM Programming from MBD utilizing, for example, the Origin Checkmate software in Solidworks

CMM PROGRAM

Just as there are several CAM programming packages that can read and automate the programming, there are several CMM programming packages that can do the same for inspection measurements. Some of the programming packages read and interpret native CAD as well as the derivative models (STEP AP242, JT, QIF). Figure 4 shows the results of using MBD to automate inspection such as MBDVidia in the example.

In the past, the supplier would open their recreated CAD model into the CMM software and manually recreate the characteristics to be measured. Now, the supplier can read the native CAD model-based definition provided directly into the CMM software and process it automatically because the software is able to read and apply the semantic PMI (assuming system compatibility).

INSPECTION RESULTS

The results of the inspection have typically been provided in a spreadsheet in a format specified by the customer. It is now possible to review the results in 3D with the points measured along with the numbers achieved and even perform statistical process control on the results, as shown in Figure 5.

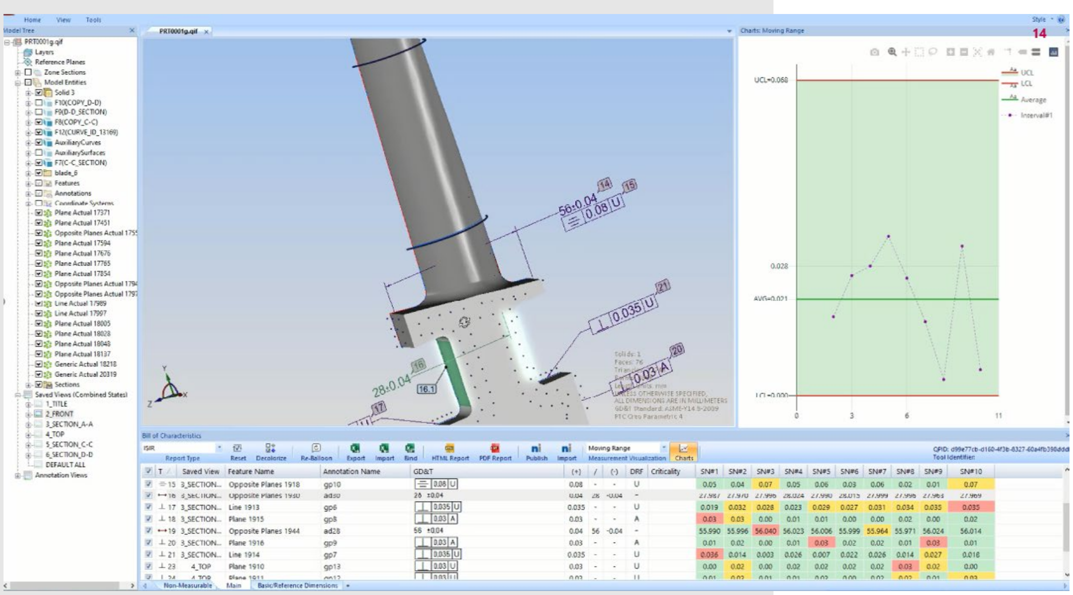


Figure 5: Review of inspection results in Capvidia's MBDVidia software

DIGITAL THREAD FOR ASSEMBLY

Production of an assembly differs from machining in that it often involves the manufacturer sending components out to subcontractors as well as requiring assembly instructions. The method of extending the digital thread to subcontractors is through the creation and communication of TDP of the individual components. The digital thread method of providing 3D work instructions to the shop floor is via Electronic Work Instructions (EWI) and Visual Work Instructions (VWI).

CREATION OF INDIVIDUAL COMPONENT TDP

The process of creating individual component TDP to be sent to a subcontractor is accomplished in a CAD system. If necessary, the 3D definition is extracted from the TDP provided by the customer and opened in the supplier's CAD system. There are several software packages that can operate on the individual CAD models of the components to produce TDP. They utilize templates to automate the population of the TDP fields.

SUPPLIER EXPERIENCE

An example of this is an assembly of several cut and bent plates fabricated into a weldment stiffened with gussets. While the manufacturer specialized in the sophisticated welding required and was proficient at cutting the plates, they were unable to bend the plate. They needed to engage another supplier for that process. The manufacturer had to break out the definitions for the individual bent plates to send to the supplier. The manufacturer received a technical data package from their customer in JT Plus PDF format. Embedded in the PDF was a JT model of the entire assembly. This JT model was processed and imported into CAD, from which individual TDP were made for the components and sent to the supplier.

WORK INSTRUCTIONS

The TDP that came to the manufacturer with all the definitions necessary to produce the fabrication was sent to the shop floor along with a viewer for bringing up the model in 3D. The viewer allowed the planners and mechanics to make measurements on the model for anything that was not specified.

DEMONSTRATION VIDEO LINKS

- **Closed Loop Manufacturing in SolidWorks CAD, CAM and CMM -** bit.ly/SW-closedloop
- **Creation of QIF Dataset and Inspection Spreadsheet in MBDVidia -** bit.ly/QIF-inspection
- **Evaluation of Quality Results in MBDVidia -** bit.ly/MBDVidia-quality
- **TDP Creation in NX -** bit.ly/TDP-creation

EXTENSIONS OF MBD IMPLEMENTATION

VERTICAL INTEGRATION

Instead of having multiple systems within a company that stand alone, enabling smart manufacturing by integrating Product Lifecycle Management (PLM), Manufacturing Execution Systems (MES), and Enterprise Resource Planning (ERP) via bi-directional technical interfaces can support the entire product lifecycle process from start to finish:

> **Product Lifecycle Management (PLM)** brings together all aspects of a product's design, definition, quality control, manufacturing process planning, product configuration, and change management to make a product that is profitable and lasts as long as there is consumer demand.
>
> **Manufacturing Execution Systems (MES)** track and document the transformation of raw materials to finished products, helping to find ways to optimize production.
>
> **Enterprise Resource Planning (ERP)** provides high-level integration of data from many areas of a company, such as sales, supply chain operations, manufacturing, purchasing inventory, and more.

The digital thread is implemented by creating a seamless data flow which ensures that all the right information is available when and where it is needed. The resulting technical architecture achieves the goal of establishing the foundation of the organization's business process templates for closed-loop manufacturing.

MBD can allow data to seamlessly stream from the definition and planning systems to the manufacturing execution systems.

Suppliers of machined components deliver CNC and CMM programs right to the workstations at the exact time they are needed. Suppliers of assemblies bring electronic work instructions right to the workstations at the time they are needed. In a connected shop floor, systems are aware of workflow status and requirements both upstream and downstream.

HORIZONTAL INTEGRATION

Supply Chain Management (SCM) manages the entire production flow of a product, starting from raw components all the way to delivery to the consumer. Model-based definition presents both challenges and opportunities into the SCM process. If the supporting suppliers are prepared for MBD, efficiencies will be gained, if not, accommodation must be made.

While an OEM might have worked with their suppliers and prepared them for MBD consumption, the supplier's vendors might not be prepared to make the investment in software or process required to use MBD. One Tier 1 supplier sends all their sheet metal parts out to small vendors. These vendors processed the sheet metal components, defined as MBD from the OEM, manually, with analog mills, drill presses and breaks. This required the Tier 1 supplier to redefine the sheet metal components with traditional drawing definition. Consideration must be given to processes that are going out to vendors and their capabilities for processing MBD.

SHOP FLOOR CONNECTIVITY

A connected shop floor provides for the exchange of data between cells, workstations and machines. Model-based definition, using digital data, enables the seamless flow of this data.

SHOP FLOOR INTELLIGENCE

PMI in a digital, machine-consumable format allows CAM software to apply the appropriate manufacturing operations to produce a given feature. Inspection software can also take advantage of PMI; the embedded PMI works with automated measuring systems, such as CMM or robot mounted non-contact inspection systems.

These advances in pre- and post-production processes set the conditions within which advanced production monitoring and shop floor intelligence systems can be most effective.

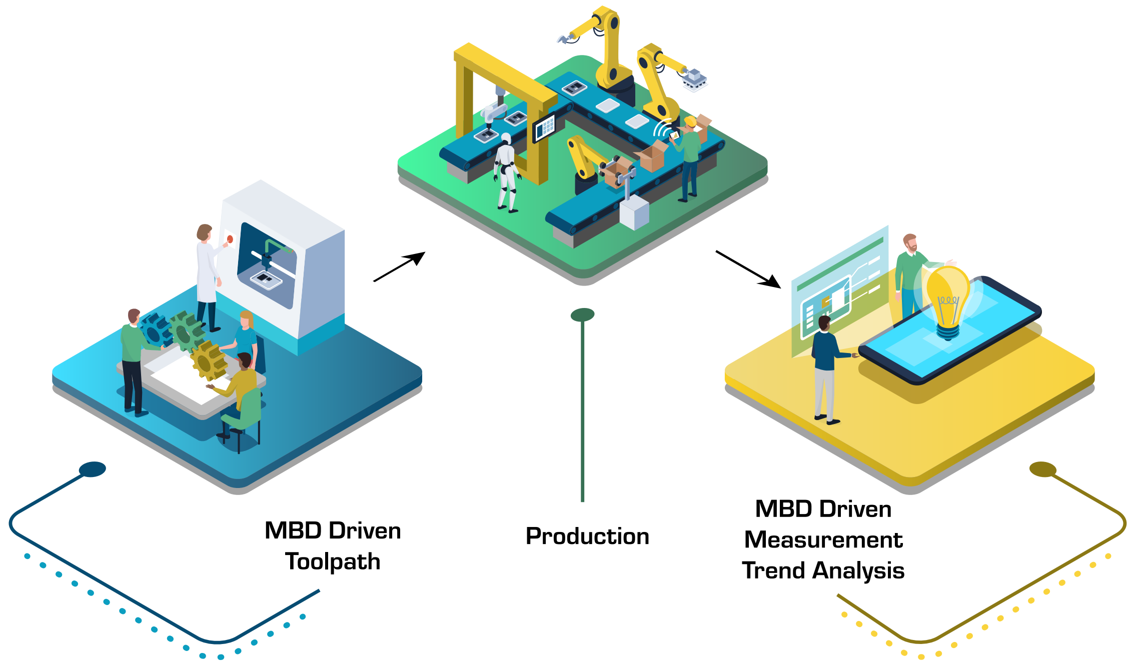


Figure 6: Automation in pre- and post-production processes

Figure 6 shows a toolpath generated, with little interaction from the user, by leveraging MBD along with feature and tolerance-based machining. A measurement program is automatically generated given the CAD geometry and tolerances for each feature. During production, however, there are variations that occur which cause produced parts to occasionally go out of tolerance. This is due to the variations that are inherent in the production process itself. Figure 7 lists examples of the sources of these variations:

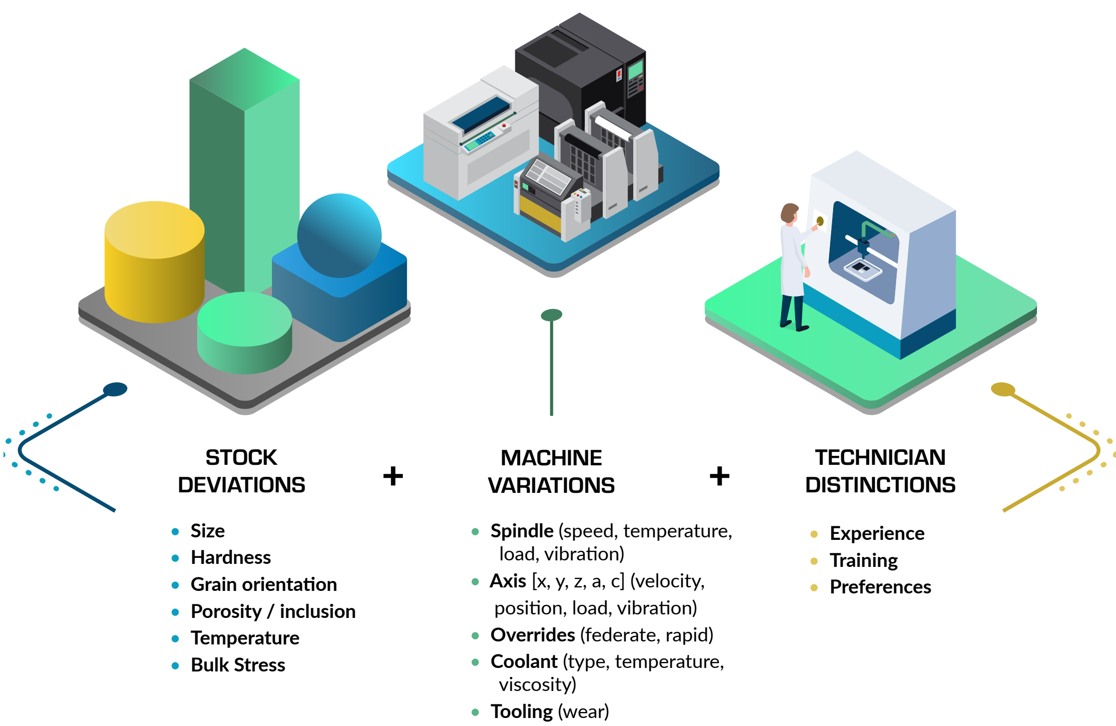


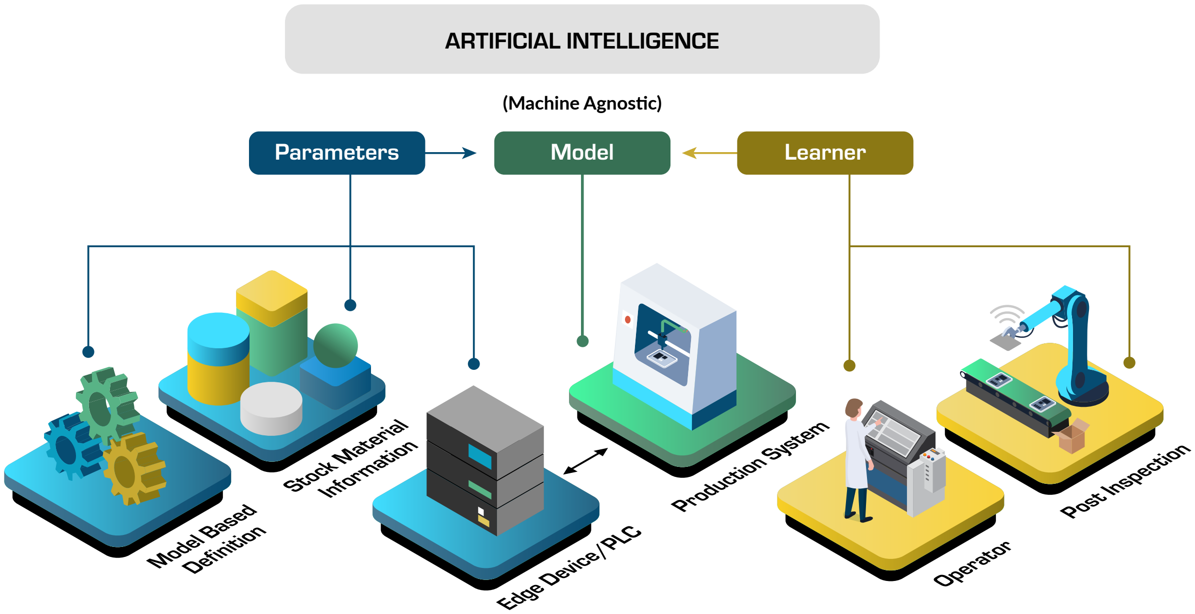
Figure 7: Example sources of production variation

In machining, one of the first sources of variations occurs in the stock material itself. The second most common source of inconsistencies in production are machine variations that occur either during the manufacturing of a part or variations of the machine from one produced part to the next. A third common source is technician experience, training, and preferential distinctions. Ideally, these sources of variations are monitored and corrective action is taken to minimize their impact on the produced part.

Modern advanced machine monitoring systems communicate directly with machines using one of the common protocols. Often, since vast amounts of data are being collected during the manufacturing process, machine learning applications are employed to find trends, detect anomalies, and learn the signature of the signals that create variance out of the acceptable range, particularly when given feedback from post-production inspections. In these setups, when manufacturing signals start to deviate from their learned signatures, the machine itself can take corrective actions to account for changing conditions, or at the very least, stop production and inform the technician of the necessary corrective action needed, commonly related to tool degradation. Figure 8, below, shows the paths of data collection that are needed for the system to first learn and then monitor signal deviations from known acceptable conditions.

Use of Artificial Intelligence - Example

Figure 8: Production process data capture overview



ENTERPRISE INTELLIGENCE

There is another area where digital data can provide significant benefits. As digital data is pulled together from various sources into business tools such as ERP systems, it can be used to drive the performance of administrative and office functions that support the flow of production. For instance, real-time data from different areas of the operation can be incorporated into digital systems for more effective planning and scheduling. Using artificial intelligence technology, trends in performance can be analyzed to allow for more effective response to supply chain disruptions or shifting customer demands.

Two of the suppliers in the project received recommendations from the assessment to improve their enterprise intelligence. The first company has several computerized processes and tools to help manage production scheduling, but the systems require manual data entry and updates. The information is not readily accessible and visible. By creating dashboards with real-time access to customer and supplier data, planning and scheduling can be more agile and effective, leading to an increase in efficiency of engineering and administrative employees. In addition, better visibility of supplier data creates more efficient inventory and raw materials usage and reduces carrying costs.

The second supplier has a more advanced system with visibility of production delays and potential disruptions to customer deliveries. Leading indicators and performance data are available to assist in production planning and to monitor order status. They make use of some digital systems to monitor the current state of key raw materials and consumables that connect to supplier portals to manage replenishment and ordering. The next step to improve the responsiveness of their enterprise systems is to employ diagnostic tools to identify deviations in operating parameters, diagnose potential root causes, and recommend steps to address issues earlier.

FIRST STEPS IN THE MBD JOURNEY

A good first step into becoming a model based enterprise is through inspection. With the maturity of the QIF file format, a number of inspection software that have either CAD translators or QIF import capabilities, and automation workflows that can use the imported PMI, inspection processes can experience significant process time improvements with relatively small investments. Software such as Capvidia's MBDVidia allow CAD translations, automated first article inspection reports generated from Model Based Definition, and integration with the widely used Net Inspect platform to send inspection data back customers. Inspection software such as Hexagon's PC-DMIS, Polyworks Inspector Premium, Origin Checkmate, and Siemens NX CMM programming add-on use imported PMI and user defined strategies to automate and optimize the CMM probing path. Most of these software also handle data from non-contact inspection systems such as 3D laser scanners or structured light 3D scanners. ROIs are typically within the first few months of incorporating and fully utilizing the digital workflows that are available for inspection processes.

> We have found that the success of digital transformation is less dependent on the size of the company than it is on a strategic mindset and culture.
>
> **Erik Fogleman – Sr. Technology Solutions Consultant, CONNSTEP**

WORKFORCE LEARNING AND DEVELOPMENT

WORKFORCE TRANSFORMATION TRAINING

Large OEMs rely on smaller manufacturing and supply companies for precision manufacturing of custom parts. The OEM's success is often predicated on managing a supply chain of smaller suppliers, who must support changing timelines, orders, or OEM priorities. There is increasing demand for this OEM-to-supplier model to be more agile in responding to bid and timing requirements as well as to changes in manufacturing and quality control specifications.

However, the combination of staffing reductions, retirements, and reductions in graduates from feeder programs such as technical high schools and higher education have created challenges for the supplier community.

There is an overall need to increase the management capacity related to Industry 4 0 and MBD adoption within the defense industrial base. Often management lacks the Industry 4.0 skill set and is stuck in an Industry 2.0 or 3.0 mindset. As industry has continued to perform, workforce training has often remained static or even regressed. For a company to successfully move their workforce forward, both technical and leadership training will be needed.

Workforce training for OEMs and their suppliers is necessary for any company to take advantage of the Industry 4.0 model. While specific tool training is often required, this can be provided by a number of specialized providers such as community colleges, technical high schools, and through the equipment manufacturers themselves. Separate from the tool training, there is a shortage of leaders and managers trained to implement the Industry 4.0 model. The leadership team must share a vision, vocabulary, and understanding of Industry 4.0, as well as an appreciation for the complexity of systems and the dependencies of process, people, and technology. Human Resources and executive leaders are the first who should be trained when a company wishes to start large-scale transformation. The advancement of leadership and technician training will allow the entire company to move toward Industry 4.0.

WORKFORCE GAP ANALYSIS

There are workforce challenges across defense manufacturing organizations beyond leadership and frontline management development. Figure 9, below, illustrates three primary categories of critical workforce gaps and opportunities to handle them:

Common Workforce Gaps Across DMI Suppliers

Figure 9

	Learnability (Workforce & Leadership)	Workforce Flexibility & Efficiency	Pathway Development
GAPS	• Awareness of Industry 4.0 and MBD concepts • Generational gaps (Both people and equipment) • Recruitment and turnover challenges • Learning and Development processes that align to critical business needs / Management Buy-In	• Workforce Planning and Scheduling • Workforce Accountability • Shifting business needs/custom projects • Dependence on legacy equipment • Needed process refinements including quality process refinements	• Goal-setting and career development skills matrices not widely implemented for front-line workers • Challenges bridging technical to management/leadership roles • Documentation of learning and training • Workforce Retention
OPPORTUNITIES	• Partnerships with technical schools, colleges, and universities • Mentorships / Internships / Apprenticeships • Improved onboarding processes • Digital training interventions - AR/VR work instructions and training • Clear alignment of Industry 4.0 to business needs	• Increased cross-training • AR/VR work instructions and training • Increased shop-floor and MES intelligence	• Partnerships with technical schools, colleges, and universities • Mentorships / Internships / Apprenticeships • Incentivise continuing education and upskilling

Three primary categories are identified in outlining critical workforce gaps and opportunities:

Learnability concerns the knowledge disparities in embracing Industry 4.0 across supply chains, between existing and new workers, and among organizational leadership. Organizations can respond by building or expanding partnerships with schools, universities, and consultants. Organizations can also expand mentoring through internships and apprenticeships, adopt interactive training approaches with Augmented Reality (AR) and Virtual Reality (VR) technologies, and update business strategies to better incorporate Industry 4.0 and model-based systems.

Workforce Flexibility and Efficiency requires workforce planning and scheduling and better tracking of workforce accountability. Customized projects and orders demand rapid shifts in manufacturing, made more difficult by the widespread dependence upon legacy equipment across the defense supply base. Increased cross-training of workers, using both AR and VR, and MES could help.

Workforce Pathway Development addresses retaining and growing employees, especially front-line workers, through improved training (including in the use of digital records) and defining employment goals and skills required to reach those goals. Building a bridge from technical roles to management and leadership positions would build stronger understanding throughout the organization. These measures respond to the workforce retention challenge experienced by many defense manufacturing suppliers.

ADDRESSING WORKFORCE GAPS

The movement to model-based systems engineering in manufacturing is a key part of the broader digital manufacturing transformation. Digital transformation leads companies into previously uncharted waters, making it difficult to understand what skills and roles are necessary to their long-term success. The MxD Digital Manufacturing Taxonomy provides a framework for workforce planning, training, and assessment as organizations embrace Industry 4.0. Business and HR leaders can use the Taxonomy to identify gaps in their workforce and define the critical roles and responsibilities that will help create training and development paths to fill these gaps.

The original MxD Digital Manufacturing Taxonomy (2017) established model-based systems engineering as a key competency area and identified the Model-Based Systems Engineer as one of the Top 20 critical roles out of dozens vital to Industry 4.0. Additional research into MBD-related skills are reflected in a 2022 update that highlights emerging roles critical for OEMs and manufacturers to effectively implement MBD tools and processes. New leadership and technical roles across manufacturing organizations are evolving in the defense manufacturing supply chain. "Action chains" model how the most critical roles can effectively be deployed in manufacturing settings. For larger organizations, these roles can become a specific job, but for small to medium manufacturers (SMMs) with limited staffing, individual employees may take on the responsibilities of multiple roles.

THE MXD DIGITAL MANUFACTURING TAXONOMY

MxD Digital Manufacturing Jobs Taxonomy and Cybersecurity Hiring Guide: Defining Manufacturing Jobs of the Future

In 2017, MxD and ManpowerGroup released a digital workforce taxonomy, a groundbreaking analysis that identified 165 new data-centric manufacturing jobs with roles like "collaborative robotics technician" and "predictive maintenance systems specialist." The workforce guide includes job descriptions and educational requirements for each role. Universities have begun using the taxonomy in developing curriculum, and Dow Chemical Company used it as a key reference when staffing its new Digital Operations Center.

The Hiring Guide: Cybersecurity in Manufacturing, released in 2020 and also developed in partnership with ManpowerGroup, is a roadmap and must-read for manufacturing executives, HR departments, educators, and policy makers.

With the COVID-19 pandemic and the rise in remote working came new concerns regarding cybersecurity. Manufacturing's growing reliance on automation, advanced control systems, and remote work only expands the attack surface for cyber criminals.

MxD's hiring guide addresses a daunting challenge: America must build a new army to protect manufacturers' intellectual property, factories, and products from cyberattackers that lurk in the shadows and mutate as readily as any virus.

The Hiring Guide is a guide for building that urgently needed workforce. It describes 247 job roles, recommends how to train and upskill workers to handle these jobs, and breaks out detailed descriptions for three specific roles crucial to the future of cybersecurity.

INTRODUCTION TO THE ACTION CHAINS/CAPABILITY NETWORK MAPS

“Action chains” help a manufacturer emphasize the role priorities needed for MBD implementation. Action chain graphics provide a visual process of clustering and associating essential roles, plus these graphics show how these roles interact. These chains, also called Capability Network Maps (CNM), serve to guide training and workforce development efforts.

The first action chain shown highlights ENABLING MBD digital transformation. This focuses on various business, HR, and change roles that can range from the business owner, managers, recruiters, change specialists and more.

All transformations, digital and otherwise, require the organization to be able to meet the challenges of change. Are they aware? Ready? Able? Can they reinforce new ways of doing things once the change occurs? Focusing only on technical skills without the related organizational reinforcement for those skills wastes time and money and increases frustration for both management and operational and technical teams. While grass-roots change can be successful, most manufacturers need a supporting structure to embrace Industry 4.0.

Action Chain 1 is illustrated on the following page.

The second action chain shown focuses on converting and validating digital designs. Our findings revealed a business-technical gap that demonstrated the notion that smaller manufacturers are not focused on designing or building model-based outputs nearly as much as on USING them. Their focus is on bridging MB design and production processes as their interaction with model-based design is in the “build to spec” portion of the overall model-based product lifecycle.

Action Chain 2 outlines an essential workforce cluster for profitable model-based production among SMMs. This is a more technical-focused action chain. From estimators and prototypers to modelers and engineers, these are the technical roles and relationships essential to SMM success with digital model use.

These roles connect with each other as shown in Action Chain 2 on the following page.

ACTION CHAIN 1

A CAPABILITY NETWORK FOR
BUILDING, STAFFING & ENABLING A MODEL-BASED ORGANIZATION

One of the biggest challenges for advancing model-based capabilities is readying the culture, HR processes and the workforce. Who is on the integrated team to sponsor, identify, build, and invest in the people and organizational side of manufacturing 4.0? Here's the chain of key change management roles to ensure model-based manufacturing success.

All Managers (as Digital Manufacturing Sponsors, Strategists, & Evangelists)

From the company owner and the entire senior / C-team to functional, operations and hiring managers, we lead the organization to adopt and accelerate Industry 4.0 and MBM.

Digital Transformation Advisor

My role is to guide the company on business and technical best practices for digital transformation from strategies to roadmaps to technical directives.

Communications Specialist

I create and share messages, information, and documentation that tell the story of how we use, benefit and advance our MBM capabilities.

Culture & Change Management Strategist/Specialist

I assess, design and deliver solutions for making our culture supportive, our people practices innovative and our workplace relations positive.

Recruiting Specialist

I message our openings and source and recruit the best possible candidates to join our company.

Internal Operations and Advisor Team

With other operations leaders, I advise the change team on the everyday MBM skills, tools and uses we need.

Workforce Planner & Resourcer

I model and forecast our MBM and other Industry 4.0 capability and capacity needs and then create build/buy/buddy strategies for our current and future workforce.

PMO Manager

I lead our program and project management efforts across a wide set of initiatives and focus on efficiencies and ways to leverage data, tools and resources.

Workforce Staffing/Contractor Manager

My role is to work with staffing suppliers and our internal teams and recruiters on the best use and sources of outside workers and partners.

Technical & Leadership Trainer

Online, in class and OTJ, I manage, develop and deliver training and coaching solutions to develop and upskill our leaders and team members.

DON'T FORGET:

Workforce, leadership development and culture change are not just HR's job! It's as much the responsibility of business and operational leadership. Look to others – partners, the community and other external resources – to improve capabilities.

Connect with these adjacent readiness and establishment roles:

- Vocational Instructors
- Educators
- Vendors
- Workforce Development Program Providers
- Service Providers

ACTION CHAIN 2

A CAPABILITY NETWORK FOR
BRIDGING MODEL-BASED DESIGN AND PRODUCTION PROCESSES

Whether you are a manufacturer who builds to print or delivers design and spec contracts, you need the roles and related capabilities that bridge design to production. Especially in the more focused activities around bidding, prototyping or start up operational production, the roles below use model-based tools and practices to more efficiently, reliably and profitably deliver standardized quality outputs in less time with less wasted resources, yet with improved performance and compliance.

Estimator

My role is to optimize pricing while aligning customer needs with our proposals, specs, time requirements and cost.

Testing & Validation Engineer

I make sure our equipment, systems and procedures can and do produce orders to spec - safely, efficiently and reliably - while meeting quality and compliance targets.

Prototype Specialist

As part of this team, I perform a variety of technical and production duties: ensuring use of the common models, schematics and specs; coordinating the production and testing of prototypes; and facilitating the decision of whether they should move to mass production.

IT Manager

My role is to ensure our teams, functions and operations have the necessary hardware, software and access to secure Internet 4.0 tools, networks and data.

MBSE

I'm the data and digitally focused, cross-domain engineer who uses and advances model-based design and production to benefit our company and the customer.

OT Integration Engineer

As the engineer of the systems that connect and control our production equipment and systems, I use model-based practices and tools to improve their efficiency, performance and maintenance.

CNC Set-up Operator

My role is to load the program, set up the tools and equipment, test the program, and ensure everything works correctly. I also troubleshoot and maintain these setups.

CNC Programmer

I translate designs, models and specs to production reality. I figure out the tools, feeds and speeds, and write the instructions for CNC machines that connect computers to drive the machines, choreographing how they will dance together.

Manufacturing Process Modeler

I use digital tools to create various visualizations and performance simulations of systems, processes and components. Multiple views and increasing detail are possible.

Manufacturing Process Engineer

Using and creating MBM assets, I focus on the design, control and operations of system and process level inputs, actions and outputs across the manufacturing life cycle.

DON'T FORGET:

Across end-to-end manufacturing processes, there are benefits to adopting model-based practices, standards, and decisions. Stakeholders and resources can come from all stages of the PLC.

Consider other roles involved with MBM like these adjacent roles:

- CAD Drafter
- Product Designer
- Material Specialist
- IoT Security Specialist
- Compliance Auditor

INCREASED IMPORTANCE OF MANUFACTURING TECHNICIAN ROLES

MBD needs both engineering and technical skills. A technician with associated skills supports an engineer because model-based tasks and activities have a longer life cycle and original design engineers may move on. MBD increases automation allowing for less experienced workers on tasks. Also, models can go through revisions that may not require full engineering capabilities and their connection to documentation is often a conventional technician task. As model and digital data use increase, so will the role of technicians.

An organization may not easily be able to find an engineer or may not be mature enough to need an engineer, but an engineering technician may be a sweet spot from a workforce planning and staffing perspective. It also offers budgetary benefits. A technician may meet the need instead of an engineer, and yet when the need for an engineer begins to appear, the technician may be a candidate for further development.

The technician role in manufacturing is a more flexible role both in terms of level of skill and independence, with a set of paraprofessional tasks that are completed with or without a supervising engineer.

The list below shows the recommended emergent technician roles to consider:

DOMAIN	ROLE
Digital Design	Model Based Systems Engineering Technician
	Mechatronics Technician
Digital Manufacturing OT Integration IT Integration	Model Based Production Engineering Technician
	Manufacturing Process Technician
	Predictive Maintenance System Technician
Digital Product	Product Performance Optimization Technician

There is an opportunity for supporting an emerging Model Based Systems Engineering (MBSE) technician role that can fill needs in the technical skills arena for model based and data-centric tasks.

Further MBSE Technician and Model Based Production Engineering role definition and short course training design would be useful. There is strong precedent for the engineering technician to be a flexible role and a career destination.

WHAT IS AN MBSE-TECHNICIAN?

The MBSE Technician provides model-based engineering support primarily via the development, testing and maintenance of digital models.

Top technical knowledge/skills/application requirements:

1. Digital design engineering fundamentals
2. Systems engineering basics
3. MBSE life cycle methodologies
4. Basic programming
5. Basic data management
6. Full life cycle model support tasks
7. Design documentation conversion
8. Modeling - application of MBSE tools
9. Model visualizations for decision support
10. Model integration

Top professional/business skills:

1. Problem solving
2. Teamwork
3. Detail orientation
4. Research and testing
5. Structural analysis
6. Technical documentation, reporting and communications

ACCEPTING THE INDUSTRY 4.0 LEADERSHIP CHALLENGE

Manufacturing leaders are called to understand how the role of management is changed by Industry 4.0, the technology trends and initiatives that enable Industry 4.0 enterprises, and how to create a strategy and plan for their organization to embrace Industry 4.0.

In addition to training and buy-in from senior leadership, there is a shortage of appropriately trained and qualified mid-level managers, limiting the transformation efforts of many companies. While the external market for managers is challenging, HR leaders state there are strong internal workers who appreciate the culture of the company and would be strong candidates for developing into first-time managers. Recognizing that company culture and fit are often the hardest characteristics to hire, a first-time manager training program would make the most of internal upskilling opportunities.

BUILDING FRONTLINE MANUFACTURING LEADERSHIP FOR INDUSTRY 4.0

Core training objectives for developing frontline manufacturing leaders should include continuing education on the key elements of an Industry 4.0 company, the nature of continuous change in an Industry 4.0 company, and how to lead change initiatives within manufacturing operations. In addition, frontline managers should be able to lead problem-solvers relying on data-based analysis to identify root causes and develop corrective action plans for manufacturing problems, lead project teams to upgrade equipment and processes, and become familiar with principles of systems thinking. Supporting human resources development, frontline leaders are called upon to train, coach, and mentor new or inexperienced manufacturing operators to enable them to reach full proficiency in their position. The ability to communicate effectively with stakeholders, both within manufacturing and within the entire organization, is an increasingly critical skill in the transition to resilient model-based manufacturing organizations.

RESOURCE ECOSYSTEM

Resources are available to Small and Medium Manufacturers (SMM) to assist them as they implement new technologies, including model-based design. This support begins with understanding the processes that Industry 4.0 technologies can improve. Connecticut's resource ecosystem offers a range of support including accessing solution providers, supporting implementation, and training employees.

For decision makers, the first step is to clearly articulate the opportunities offered by Industry 4.0 solutions. Resources are available to help a company develop a full problem definition, identify the process and value stream that will be impacted, and understand the business readiness and metrics for the change.

After a clear articulation of the opportunity, companies will look to build an awareness of the potential solutions and providers that can assist the SMM. Studying all the possibilities is a daunting challenge. Resources are available to assist. With the knowledge of possible solutions, the company can then identify, evaluate, and select the solution that works for them.

With the potential solution path in hand, the SMM will need to identify providers of the solution, solicit implementation proposals, select a provider, and create a detailed business case.

Many public and public/private organizations are available to assist manufacturers. Resource information can be found in the Connecticut Department of Economic and Community Developments.

Connecticut
Department of Economic and Community Development

> ct.gov/decd

Manufacturing Innovation Fund (MIF)
Direct loans, grants, and programs to support an array of initiatives (incumbent worker training, equipment purchases, marketing/outreach, etc.)

Chief Manufacturing Officer
Advocates and coordinates state and private-sector efforts – for existing and prospective employers – to promote growth in the state's manufacturing sector

> defense.gov

> oldcc.gov

SBIR STTR opportunities
Funding to develop technology and chart commercialization dodsbirsttr.mil/submissions/login

Connecticut Procurement Technical Assistance Center (PTAC)
Marketing and procurement services ctptac.org/

Mentor Protégé Program (MPP)
Small businesses partner with larger companies to expand defense industrial base business.defense.gov/Programs/Mentor-Protege-Program/

National Security Innovation Network (NSIN)
Programs that promote the development and growth of dual-use ventures nsin.mil/

Connecticut Center for Advanced Technology, Inc.

> ccat.us

Technology Scouting and Validation: ccat.us/atc

Technology Demonstration & Adoption Workshops: ccat.us/events

Additive Manufacturing & 3D Printing Solutions: ccat.us/atc/additive-manufacturing

Advanced Design, Automation & Metrology Solutions: ccat.us/atc/light-scanning-reverse-engineering

Advanced Technical Training: ccat.us/incumbent-worker-training

Workforce Training and Career Readiness: ccat.us/workforce-innovations

CONNSTEP
a CBIA affiliate

> connstep.org

Assess and Plan
Right and Ready Assessment
Smart Industry Readiness Index (SIRI)

Educate and Train
Webinars and Blogs supporting Advanced Manufacturing Technologies

Implement
Technology Scouting
Technology-Driven Market Intelligence
Project Management Support

Sustain
Business Process Improvement and Compliance Support

CENTRAL CONNECTICUT STATE UNIVERSITY

> ccsu.edu

Educate and Train ccsu.edu/ConEd
Packaged incumbent worker training
Employer-driven customized training
Credit-bearing classes and degrees

MxD
The Digital Manufacturing Institute

> mxdusa.org

Research, Development, and Demonstration
Focused on digital thread impacts to the product development lifecycle. Take a virtual tour at MxD's Future Factory in Chicago. virtualtour.mxdusa.org

National Center for Cybersecurity in Manufacturing
MxD Cyber Initiatives have a primary focus on our nation's small and medium manufacturers. mxdusa.org/cyber

Building Digital and Cybersecurity Workforce Initiatives
The Digital Manufacturing and Design Jobs Taxonomy mxdusa.org/taxonomy
The Hiring Guide for Cybersecurity in Manufacturing mxdusa.org/hiringguide

CONNECTICUT DEFENSE MANUFACTURING COMMUNITY CONSORTIUM

The State of Connecticut is focused on supporting and expanding defense technology research, development, and production capabilities within the state. To facilitate this growth, the state has assembled the Connecticut Defense Manufacturing Community Consortium (CDMCC). The CDMCC is responsible for fostering collaboration and accelerating the digital transformation of Connecticut's Defense Manufacturing Community (DMC) members and served at the advisory board for the DoD grant-funded Digital Model Initiative referenced in this guide. The CDMCC, comprised of representatives from key OEMs, industry suppliers, educational institutions, and public/private organizations, is led by Department of Economic and Community Development (DECD) and overseen by the State of Connecticut's Chief Manufacturing Officer.

Government

Connecticut Department of Economic and Community Development

Governor State of Connecticut

Military

Office of Military Affairs Connecticut

Association

Naval & Maritime NMC Consortium

ACM Aerospace Components Manufacturers — Together. A world of expertise.

OEM

General Dynamics Electric Boat

Pratt & Whitney — Dependable Engines

Sikorsky — A Lockheed Martin Company

Collins Aerospace

Technology Adoption

CONNSTEP — a CBIA affiliate

CCAT — Connecticut Center for Advanced Technology, Inc.

MxD — The Digital Manufacturing Institute

Education

Central Connecticut State University 1849

UCONN

CONCLUSION

The Defense Industrial Base is entering a period of adoption of Model-Based Definition. The DoD requires that new programs and contracts use MBD. As a result, companies will need to adapt to the new paradigm creating the Model-Based Enterprise. This transformation will impact all companies that supply defense programs.

The utilization of MBD will allow the creation of digital data that will support the full product lifecycle. This results in products that are designed faster, have better quality, and are less expensive to produce. The greatest benefit is all the necessary information is readily available in one place as the Technical Data Package is the authoritative source of product information. The authoritative information feeds directly into electronic work instructions, CNC machining, CMM inspection, quality reports, and service manuals. The need for processing product information is eliminated and information is delivered directly to manufacturing and inspection systems.

Avoiding the processing of product information increases productivity and reduces errors. With no need to translate design data into 2D drawings the potential for human errors is drastically reduced. As the authoritative source of part information, the digital design eliminates confusion between the OEM and supplier as well as removes the need for interpretation of design data.

Using MBD, validation of product definition and manufacturability is done by automated tools. When products change, detailed summaries of the changes can also be automatically generated. The opportunity for human error is eliminated when authoritative information is sent from the OEM to the supplier.

As with any transformation, companies will need to prepare for the change. An assessment of the company that allows the company to build a roadmap of change based on their business model and strategic objectives is an excellent place to start. Every company's journey will be specific to their future, but will include technical implementation and workforce learning. The company's leadership will need to build a roadmap and create activities to change process, technology, and organizational structure within the company. The leaders must communicate the vision, provide a sense of urgency, and navigate the company through the transformation.

Companies that quickly adopt Model-Based Definition will be the leaders in DoD supply chain manufacturing in Connecticut and the country. To ensure that Connecticut maintains our leadership role in supporting the defense of our country, there are resources to support companies implementing their digital transformation. The State of Connecticut will successfully lead our stakeholders in the implementation of MBD across the defense supply chain to ensure the sustainability of our very important defense sector. Failure is not an option.

Paul Lavoie – Connecticut's Chief Manufacturing Officer

GUIDEBOOK APPENDIX

> mbdguidebook.connstep.org/appendix/

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