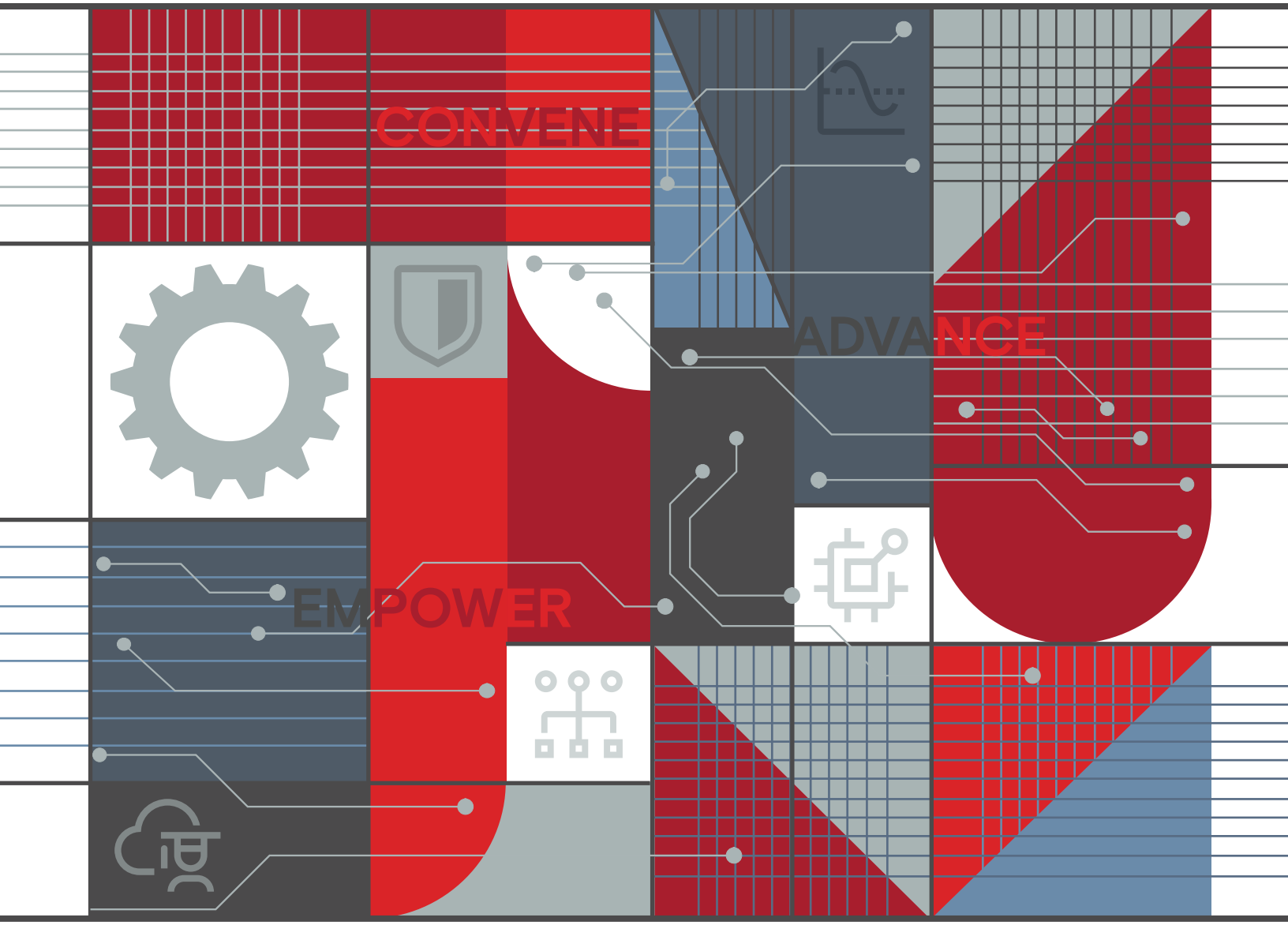
PUBLIC VERSION

RELEASE DATE: 2026

OUTLOOK 2026–2028



The Digital Manufacturing & Cybersecurity Institute

MD

OUTLOOK
2026-2028

RELEASE DATE: Q1 2026

CONTACT: **Clark Dressen**
Chief Technology Officer
clark.dressen@mxdusa.org

Tony Del Sesto
Senior Technical Fellow
tony.delsesto@mxdusa.org

Kristina Young
Senior Associate, Technology Strategy
kristina.young@mxdusa.org

Acknowledgments

The MxD Outlook is developed in collaboration with MxD's member organizations, which include manufacturers, solution providers, academics, nonprofits, and Department of War partners. They represent a cross section of manufacturing that forms a robust public-private partnership committed to an innovative and thriving U.S. manufacturing sector. We are especially grateful for the insights and leadership of the MxD Technical Advisory Committee and Executive Council members.

MxD seeks to engage distinct and sometimes disparate stakeholders in realizing the goal of **advancing economic prosperity and national security through digital adoption in manufacturing**. The MxD Outlook reflects that spirit of collaboration.

Confidentiality

Table of Contents

Table of Figures 6

Message from the CEO 7

Executive Summary 8

Introduction 10

The Current State 10

The Future State 11

MxD's Technology Strategy 13

MxD Mission, Vision, Strategy 13

Priorities 13

Key Challenges 14

Approach: Convene, Advance, & Empower 16

Convene 16

Advance 17

Empower 30

MxD Project Portfolio 33

Abbreviations 36

Table of Figures

Figure 1: MxD strategy to leverage innovation in technology, workforce, and cybersecurity to accelerate digital adoption by the U.S. industrial base 13

Figure 2: Advanced manufacturing areas in which MxD and its members are thought leaders 14

Figure 3: How MxD initiatives will address cross-cutting demands in the next 12 to 36 months 15

Figure 4: The MxD strategic approach of convene, advance, and empower 16

Figure 5: Member events hosted at MxD in 2025 16

Figure 6: Advanced manufacturing technology investments that drive demand for AI readiness 17

Figure 7: The data lifecycle with examples of early and advanced capabilities at each stage 20

Figure 8: The data lifecycle with examples of early, mid, and advanced capabilities at each adoption phase 20

Figure 9: MxD project objectives and metrics 21

Figure 10: Project distribution across the data lifecycle 21

Figure 11: MxD projects active in 2026 22

Figure 12: 2026 Factory Floor layout 27

Figure 13: MxD Learn Lab Recording Studio 29

Figure 14: MxD projects completed in 2025 33

Message from the CEO

Dear MxD community,

U.S. manufacturers pursue multiple achievements at once: They design and make products for customers, but they also contribute to a more prosperous and secure country. At MxD, the nation's Digital Manufacturing and Cybersecurity Institute, we support this mission by helping manufacturers tackle complex challenges and improve productivity as we all work to ensure the strength and resilience of the U.S. industrial base.

In this Outlook 2026-2028 (previously called the Strategic Investment Plan), we assess the current state of manufacturing in the United States and present our goals and plans for driving digital adoption.

Global economic and geopolitical trends make this an exciting but challenging era. Manufacturers must keep pace with rapid technology advances, including artificial intelligence (AI) and machine learning. The reshoring of factories can scale when manufacturers modernize, but too many U.S. companies function with 20th century technology. At the same time, America's rivals are growing increasingly sophisticated.

MxD supports all manufacturing sectors, but our organization is sponsored by the Department of War because national security depends on technological prowess. The advances in AI, cybersecurity, workforce upskilling, and other fields that will keep U.S. manufacturers on the cutting edge are also key to the country's defense. The work we do adds innovation and resilience to the factory economy.

We pursue our work through three core pillars: Convene, Advance, and Empower. Two exciting projects featured in this Outlook exemplify those pillars. They highlight our capacity to bring MxD stakeholders together to collaboratively solve problems by advancing innovation that will empower the manufacturing workforce.

In the first project, Siemens, MK Morse, and Kent Displays teamed up to create an AI-powered inspection system that more accurately identifies defects in the manufacturing process and quickly provides corrective actions — increasing productivity and efficiency on the factory floor.

In a separate project, MxD joined with Northrop Grumman, ScopeAR, and Ohio State University to transform the training of manufacturing workers. Leveraging AI, the project created augmented reality content to simulate the factory floor and incorporate training materials, which resulted in an improved and more efficient workforce training experience.

MxD's secret sauce is our ability, as a neutral 3rd party, to bring together members to spur innovation. MxD's success is never about us. It's about improving the resilience and productivity of manufacturers, the industrial base, and the nation.

If you aren't an MxD member, I invite you to join. If you are a member, thank you, and please consider deepening your organization's relationship with us. I'd also like to thank our sponsor, the Department of War, and the entire MxD team. The work we all do together, as seen in this Outlook, represents the promise of a brighter future for manufacturing in the United States.

Sincerely,

Berardino Baratta, CEO

Executive Summary

The United States is the global leader in technology innovation. By translating our innovation onto the manufacturing floor, we can sustain our economic dominance and ensure our national security. The drive to reshore manufacturing to the United States is greater than ever, and this effort can only succeed by using the latest manufacturing technology advances, building resilient supply chains, and supporting a modern and secure U.S. industrial base.

MxD is proud to support this effort as a thought leader. Our mission as the nation's Digital Manufacturing and Cybersecurity Institute is to strengthen U.S. economic prosperity and national security by driving digital adoption in manufacturing. We do so by convening the industrial base, advancing manufacturing technology innovation and adoption, and empowering the workforce.

Our goals are to:

- Help digitalize, secure, and connect key manufacturers and their supply chains.
- Upskill U.S. manufacturing workers to enable adoption and work process transformation.
- Support the U.S. Department of War's (DOW's) efforts to build a modern and resilient defense industrial base (DIB).

As we progress toward these goals, our efforts will focus on the following priorities:

1. MxD will continue to digitalize and secure the U.S. industrial base by expanding the MxD Supplier Program beyond our key partners of Boeing, DMG Mori, Oshkosh, and Rolls-Royce, which have already successfully implemented this initiative. We will also expand digital manufacturing and cybersecurity content to enable and drive digital transformation in areas including secure domain-specific infrastructure, autonomous devices, data integration, and applications.
2. MxD will continue to modernize the DIB by building on our past successes at organic industrial base (OIB) sites.
3. MxD will continue to upskill the workforce through MxD Learn programs, including the MxD Virtual Training Center (VTC), which currently has over 50,000 enrolled learners. We will emphasize driving new content to enable digital adoption and application for key manufacturing opportunities.

Beyond these priority areas, MxD serves as a resource hub where over 350 members from industry, academia, and the DOW convene to identify key challenges manufacturers face in modernizing and securing their operations and supply chains. MxD and member-hosted events, workshops, and summits bring thought leaders together to share their experience and overcome digital manufacturing challenges. The MxD Factory Floor, which hosts more than 10,000 visitors annually, is a dynamic space showcasing the latest manufacturing technologies. It also serves as a testbed where members collaborate to validate standards and workflows for novel manufacturing technologies to pave the way for wider adoption.

MxD also advances manufacturing and cybersecurity technologies to de-risk adoption across the supply chain. With $435 million in public-private funding invested in 197 completed projects over 11 years, MxD continues to bring the latest advances in manufacturing to the industrial base.

With resources and upskilling curriculum development, MxD empowers the U.S. manufacturing workforce. We have engaged over 350,000 learners through various initiatives, including MxD VTC, MxD Learn Lab Recording Studio, Curriculum and Pathways Integrating Technology and Learning (CAPITAL) training programs, and hiring guides.

We also generate resources and technology to serve the national interest. MxD has engaged with government partners on-site at over 20 Army OIB and Navy facilities to assess, pilot, and scale the integration of digital manufacturing technologies. At the heart of MxD's ethos is the confluence of people, processes, and technology connected by the flow of data. Whether within an enterprise or across an entire supply chain, the integration of carefully curated manufacturing data drives insight, intelligence, speed, and ultimately competitive advantage.

The 2026-2028 MxD Outlook reflects on the current and future state of manufacturing technology and how MxD plays a role in leading the charge. We understand that technologies such as machine learning (ML), artificial intelligence (AI), augmented reality (AR)/virtual reality (VR), cloud and edge computing, additive manufacturing, autonomous vehicles and robotics, and digital twins will enable the agile, intelligent, and integrated supply chains we're striving for. Our initiatives are lowering if not removing the barriers to their widespread integration and adoption.

Introduction

The Current State

Current manufacturing trends show that manufacturers understand the need to accelerate adoption of digital technologies to address key value-driven use cases including quality, reliability, safety, sustainability, and efficiency, but that they are overwhelmed with how to implement them. Traditional manufacturers often depend on legacy equipment and manual processes, resulting in data that is siloed and difficult to access. Inconsistent standards across the industry further complicate data sharing, limiting supply chain visibility, impeding digital design exchange, and reducing responsiveness to disruptions and opportunities.

Accelerating digital adoption is essential to address current manufacturing challenges. However, a significant portion of manufacturing intellectual property is deeply integrated with existing processes, requiring careful consideration to ensure that modernization efforts preserve critical intellectual property while enabling interoperability and scalability. Again, manufacturers understand the need to adopt advanced technologies but struggle to navigate the dynamic landscape to implement them effectively.

Digital adoption begins with data. Establishing a data-first culture is the necessary first step toward realizing the benefits of advanced manufacturing technologies and the power of AI. MxD member EY stresses the importance of culture in an excerpt from one of its success stories: "The journey toward a data-driven culture requires a delicate balance of technology, people and processes, all aligned toward a common goal: unlocking the true potential of data."[1] The latest advancements in manufacturing technology have centered on the integration of data from an enterprise's entire ecosystem of devices and systems, from all aspects of its operations, so that the data can be accessed and analyzed in real time to form a complete and on-demand picture of its operations.

This seamless integration of data within manufacturer systems and across supply chains presents a huge challenge as well as a tremendous opportunity to leverage AI to strengthen the competitiveness and security of the U.S. manufacturing base. The July 2025 release of *America's AI Action Plan*, in accordance with executive order 14179, sounded the call to action in response to these challenges and opportunities.[2] Manufacturers have already been adjusting their investments to this end. Deloitte's manufacturing survey released in May 2025 noted that manufacturers planned to invest in data readiness in the next 24 months as a means to lay the foundation for automation, with 40% of manufacturers investing in data analytics, 29% in cloud computing and AI, and 27% in the industrial Internet of Things (IIoT).[3]

Manufacturers with exceptionally mature digital adoption capabilities have achieved the implementation of "lights out" factories, where a production facility is fully autonomous and operates without human workers present. There is a significant push to establish these types of factories in the United States, as noted by an

1 Singh, Gundeep, Farooque Munshi, and Faisal Alam. 2025. "From legacy to leading edge: real stories of data-driven transformation." www.ey.com. September 3. https://www.ey.com/en_us/insights/industrial-products/industrials-data-and-ai-transformation-success-stories.

2 2025. "AI.gov Action Plan." AI.gov. July. https://www.ai.gov/action-plan.

3 Gaus, Tim, and Michael Schlotterbeck. 2025. "2025 Smart Manufacturing and Operations Survey: Navigating challenges to implementation." www.deloitte.com. May 1. https://www.deloitte.com/us/en/insights/industry/manufacturing-industrial-products/2025-smart-manufacturing-survey.html.

April 2025 article in Robotics & Automation News.[4] This capability represents the establishment of a fully realized digital fabric, manifested as a comprehensive digital twin that virtually replicates every physical aspect and its associated operations within a facility. Every digital workflow in a facility is a digital thread whose data can be interwoven with data from other threads to form a fabric that paints a digital picture of a facility's current state. This allows for remote or even autonomous monitoring and control of facilities, as well as simulation and assessment of possible adjustments to operations before implementation. Such a capability provides the visibility to forecast market and operational conditions, the possibility to adapt to potential risks identified by the forecasts, and the ability to quickly recover from unforeseen circumstances.

Nonetheless, many manufacturers are still in the early stages of digital adoption, although rates of digital adoption and maturity levels are increasing. A Manufacturing Leadership Council survey released in January 2025 showed that only 28% of companies considered their factories to be "somewhat to very smart," and that this percentage was anticipated to reach 76% by 2027.[5] According to a 2024 study by the Interdisciplinary Center for Advanced Manufacturing Systems, high initial investment and finding workers with skillsets in manufacturing, data infrastructure, cybersecurity, and management to implement the workflows remain barriers to adopting advanced digital manufacturing methods.[6] The Manufacturing Leadership Council survey also found that 75% of manufacturers were capable of some cross-functional data sharing, but only 23% were able to do so across all functions.[7] Moreover, there is a lack of frameworks to establish testing, verification, and validation for industry-wide implementation of these existing advanced manufacturing technologies. The absence of data standards and frameworks keeps investment costs high and prevents the scaling of industry-wide supply chain visibility.

The Future State

What does the future state of digital manufacturing look like? Is the United States ready for it? How do we get there? AI is already revolutionizing how society operates, and the limits of its applications have yet to be fully understood. Embedded AI and industrial AI products are becoming widely available, allowing for real-time decision-making and automation to happen both at the edge and in the cloud. Humanoid robots trained to operate autonomously and safely alongside human counterparts represent the pinnacle of AI-augmented robotics. Morgan Stanley estimates that by 2050, there could be over 1 billion humanoids, with 90% in industrial and commercial settings, representing a total market value of $5 trillion or more.[8]

The industrial metaverse and quantum computing are technologies that while not yet viable for mainstream applications are on the horizon. MxD member Siemens is on the forefront of constructing a metaverse of its operations by building a digital twin of its entire enterprise, allowing meetings to take place in the virtual representation of the physical location in question to solve problems. Quantum computing will augment ML models and help solve complex problems faster than classical computing. The optimization of supply chains and complex processes such as materials design and welding will benefit from quantum computing

4 Allinson, Mark. 2025. "Features/Manufacturing: Robotics and Automation News." Robotics and Automation News. April 25. https://roboticsandautomationnews.com/2025/04/25/the-quiet-race-to-build-americas-first-fully-automated-factory/90090/.

5 Puma, Jeff. 2025. "Survey: M4.0 Appears Poised for A Significant Leap." Manufacturing Leadership Council. January 31. https://manufacturingleadershipcouncil.com/survey-manufacturings-digital-leap-37852/?utm_source=731701&utm_medium=email.

6 Harris, Gregory A., Chris Peters, and Ashley Yarbrough. 2024. SMART MANUFACTURING ADOPTION STUDY 2024. Auburn: University of Auburn: Interdisciplinary Center for Advanced Manufacturing Systems. https://eng.auburn.edu/icams/ISE---ICAMS-SMART-Report_2024_V5.pdf.

7 Brown, Penelope. 2025. "Survey: Manufacturers See Data, Lack Strategy." Manufacturingleadershipcouncil.com. September 30. https://manufacturingleadershipcouncil.com/survey-october-39090/?stream=ml-journal.

8 Morgan Stanley. 2025. "Humanoids: A $5 Trillion Market." Morgan Stanley Insights. May 14. https://www.morganstanley.com/insights/articles/humanoid-robot-market-5-trillion-by-2050.

advances. While both the industrial metaverse and quantum computing will remain largely inaccessible to all but the most advanced manufacturers in the short term, identifying areas where tactical deployment of these technologies will yield the most benefit to manufacturers is a priority. Manufacturers will also need a new generation of sensors and hardware to interact with and support these technologies' capabilities. This next-generation ecosystem of equipment will require its own set of standards for testing, verification, and validation of production processes.

MxD is committed to lead in offering manufacturers resources and expertise to streamline adoption of advanced digital manufacturing technologies and integration with operations. The MxD Project Portfolio includes 197 varied projects completed over 11 years. These initiatives include technology pilots and implementations, coursework and hiring guides for the workforce, cybersecurity guidebooks, and testbeds and Factory Floor installations demonstrating the latest advanced manufacturing digital technologies.

Recently completed MxD projects include the establishment of an operational technology (OT) cybersecurity web portal for small and medium manufacturers (SMMs), software to generate cybersecurity playbooks for SMMs, and an AI vision software toolkit to improve worker safety, to name a few. These projects were developed in response to member feedback and industry research. Such projects are essential with manufacturing being the most targeted industry for cybersecurity attacks for 4 years in a row, according to the *IBM X-Force 2025 Threat Intelligence Index.*[9] Also, the 2025 Liberty Mutual Workplace Safety Index found that U.S. manufacturing loses $7.47 billion per year to serious nonfatal workplace injuries.[10] MxD is helping our members and beyond overcome these realities. A comprehensive list of all 47 projects completed in 2025 can be found in the MxD Project Portfolio section (page 37).

9 IBM. 2025. "Security: Be confident in your security with threat intelligence." IBM.com. October 15. https://www.ibm.com/reports/threat-intelligence.

10 Liberty Mutual Insurance. 2025. "Business Insurance: Workplace Safety Index." Libertymutual.com. October 15. https://business.libertymutual.com/workplace-safety-index/.

MxD Technology Strategy

MxD Mission, Vision, and Strategy

Our mission as the nation's Digital Manufacturing and Cybersecurity Institute is to strengthen U.S. economic prosperity and national security by driving digital adoption in manufacturing.

The MxD technology strategy aims to boost U.S. economic prosperity and national security by leveraging our 3 pillars of convene, advance, and empower to generate innovation in manufacturing along 3 lines of effort: technology, workforce, and cybersecurity. These 3 lines of effort must be addressed concurrently to accelerate digital adoption within the U.S. industrial base (**Figure 1**). The vision is to foster a dynamic, resilient, connected, and secure industrial base that ensures U.S. economic and warfighting superiority. This vision manifests itself with a fully integrated, transparent, robust, and adaptive supply chain. Achieving this requires applying strategic technologies to address key manufacturing challenges from design through sustainment to support the following priorities.

Figure 1: MxD strategy to leverage innovation in technology, workforce, and cybersecurity to accelerate digital adoption by the U.S. industrial base

Priorities

1. MxD will continue to digitalize and secure the U.S. industrial base by expanding the MxD Supplier Program beyond our key partners of Boeing, DMG Mori, Oshkosh, and Rolls-Royce, which have already successfully implemented this initiative. We will also expand digital manufacturing and cybersecurity content to enable and drive digital transformation. The expansion required to enable this transformation will include:
   - Secure domain-specific infrastructure, such as private cellular and edge computing and data storage.
   - Data collection and management upgrades from legacy manufacturing environments to secure infrastructure. This will also include integration of existing siloed data across manufacturing domains (design, production, quality, operations, maintenance, and sustainment).
   - Applications and key capabilities include supply chain visibility, real-time decision-making, process optimization, and AI/ML.
2. MxD will continue to modernize the DIB by building on our past successes at OIB sites with a primary focus on the highest priorities, including SkyFoundry for drones. This will include opportunities to improve legacy manufacturing and to introduce capabilities required to deliver on new strategic initiatives.

3. MxD will continue to upskill the workforce through the MxD Learn programs, including our VTC, which currently has over 50,000 enrolled learners. We will emphasize driving new content to enable digital adoption and application for key manufacturing opportunities.

As a dual mandate manufacturing innovation institute (MII), MxD's strategic priorities encompass a wider range of technologies and focus than those of our counterparts. Recognizing this special position, we lean into the spirit of convening and collaboration to advance technology thought leadership across the U.S. manufacturing space (**Figure 2**). Partnering with fellow MIIs, such as the Advanced Robotics for Manufacturing Institute, LIFT, and America Makes, and with our members allows our combined expertise to act as an impact multiplier on uplifting the industrial base.

Figure 2: Advanced manufacturing areas in which MxD and its members are thought leaders

Technology	Cybersecurity	Workforce
• AI • ML • Digital twins • Data interoperability • Process control • Future G communication	• Cybersecurity Maturity Model Certification compliance • Secure information technology/OT environment • Threat awareness and detection • Incident response	• Upskill current workers • Capture legacy knowledge • Streamline training

Key Challenges

MxD and its members leverage their key competencies and thought leadership to help address the many challenges affecting the advancement of digital adoption:

- **Data governance:** Advanced manufacturing processes require reliable data that can be transmitted throughout the product lifecycle and supply chain. In most instances, data is siloed in disparate systems. Integration of these systems will require data to be translated, scrubbed, and annotated with the appropriate context and format for analysis and AI applications.
- **Legacy infrastructure and equipment:** Capital investments in manufacturing assets across the U.S. industrial base have not kept pace with technological advancements. Legacy OT environments are often older and lack the modern connectivity, data acquisition, and cybersecurity needed for advanced data analytics and AI readiness.
- **Supply chain transparency:** The realization of an integrated manufacturing ecosystem starts with a transparent supply chain. Sharing the necessary data among vendors and suppliers allows for the resilience, agility, and scaling required to respond to surges in demand or unforeseen bottlenecks. Supply chain visibility often extends no farther than the 2nd tier, leading to unknown vulnerabilities such as single source suppliers or upstream suppliers of unknown provenance and vetting.
- **Qualification, verification, validation, and standards:** Advanced digital technologies such as additive manufacturing and digital twins are established but still in the process of being adopted, especially by SMMs. There is a need for established datasets associated with various materials and processes to be

used as a baseline for verification and validation. Standards for advanced manufacturing processes are often lacking, leading to system incompatibility between versions or vendors and no consensus on definitions for qualification. Model-based design standards with the capability to carry design and feature data through the manufacturing process and into quality inspection can significantly improve quality and reduce design rework when areas for improvement are identified.

- **Workforce:** Manufacturing workers in the current pipeline lack the skills necessary to fill roles that will be vacated by an ageing workforce. The need to train workers and fill these roles is crucial as the United States accelerates the onshore manufacturing of critical components and equipment for both economic and national security.
- **Lack of business cases for digital adoption:** Investment in information technology (IT) and OT infrastructure and applications required to leverage data capture, analytics, and intelligent automation is significant and complex. A lack of standardized implementation frameworks leads to in-house solutions being developed, which inflates costs and delays the realization of return on investment (ROI). Demonstrating measurable ROI is often difficult because the benefits are realized through the integration of multiple digital systems.

MxD initiatives will address the aforementioned priorities and help to overcome these key challenges with the following roadmap (**Figure 3**).

Figure 3: How MxD initiatives will address cross-cutting demands in the next 12 to 36 months

Business Objective	Current Technology Initiatives	12 Months	24 Months	36 Months
Operational Excellence	• Digital twin use cases and implementations • Worker safety w/ AI • Raise awareness of 5G, Future G, and Wi-Fi use cases • OIB modernization	• IIoT/data strategies for process manufacturing • Data architecture best practices for given use cases • Casting and forging road mapping	• Industrial ML/AI process optimization on-premises edge • Validation framework development for ML models and digital twins • Augmented maintenance and sustainment with AI agents	• Manufacturing systems automation with coordinating AI models
Value Chain Improvements	• Digital Manufacturing Playbook • Factory Floor demonstrations • Retrofitting sensor kits to legacy systems	• AI Readiness Playbook	• Evaluation of commercial off-the-shelf solutions based on manufacturing persona	• Compilation of available solutions for systems integration use cases
Supply Chain Visibility	• Radio frequency/global positioning system asset/inventory tracking • Trust-building initiatives • Automated guided vehicles	• Use Supplier Program to drive digital transformation to SMMs	• Develop supply chain framework based on minimum data requirements	• Demonstrate secure vendor/supplier hubs for a given original equipment manufacturer supply chain
Cybersecurity	• Cybersecurity Buying Guide • Incident command system/OT Cyber Range • CMMC Playbook	• Manufacturing cyber threat detection assessment • Use Supplier Program to streamline SMM CMMC adoption	• Incident recovery playbook • Develop SMM-friendly cybersecurity model trained on large language models	• Open-source IT/OT security suite for SMMs
Workforce	• Virtual Training Center • Learn Lab Recording Studio • Workforce Readiness Guides	• Curriculum development • Course development		

Approach: Convene, Advance, and Empower

Figure 4: The MxD strategic approach of convene, advance, and empower

CONVENE
the Industrial Base

ADVANCE
Technology Innovation & Adoption

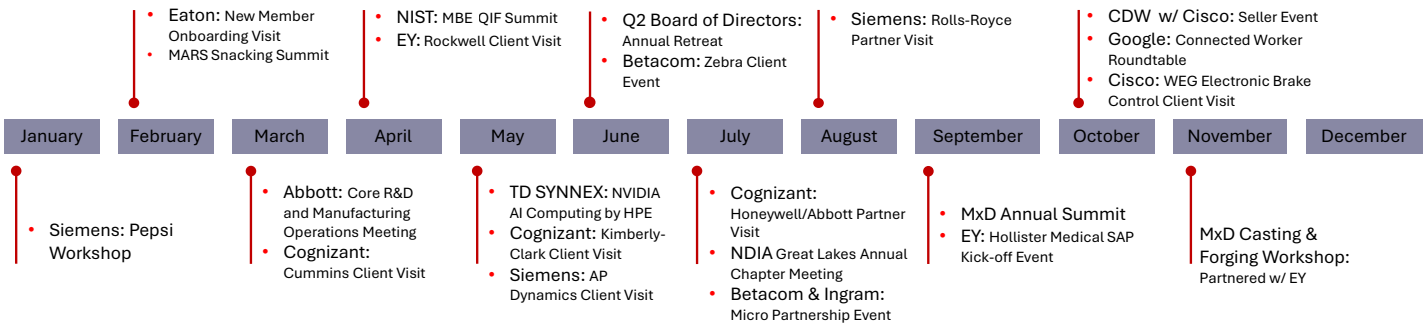
EMPOWER
the Workforce

Technology demands and gaps are identified and assessed by *convening* at program events, workshops, technology advisory committee meetings, technical presentations, working groups, and one-on-one interactions with members. Feedback from these various channels is validated with reviews of recent research articles, government reports, and industry publications. MxD then collaborates with our members to develop projects and MxD Factory Floor installations that *advance* best practices and novel solutions to common challenges in the adoption of digital manufacturing. Outcomes from these projects and demonstrations in turn serve to *empower* the DOW, OIB, and DIB, manufacturers of all sizes, and their workforces with resources such as playbooks, hiring guides, online courses, supplier networks, and program events to accelerate digital adoption.

CONVENE the U.S industrial base to identify key challenges manufacturers face in modernizing and securing their operations.

The depth of knowledge and expertise of the MxD member network enables the innovation required to solve the most pressing digital manufacturing challenges that the U.S. industrial base faces. MxD in turn connects industry, academia, and government to share their perspectives on technology developments and collaborate on creating solutions for current and future needs. MxD hosted events and Factory Floor tours attract over 10,000 visitors annually. Featured events hosted at MxD in 2025 included the MxD Annual Summit; the NIST MBE QIF Summit; Manufacturing with AR/VR: What's Now. What's Tomorrow; and the Abbott Core R&D and Manufacturing Operations Meeting. Workshops hosted at MxD in 2025 included the National Science Foundation-sponsored Manufacturing Systems Data Integration workshop and the Castings and Forgings Industry Workshop series, organized in partnership with EY. Featured member events hosted at MxD in 2025 are shown in **Figure 5**.

Figure 5: Member events hosted at MxD in 2025



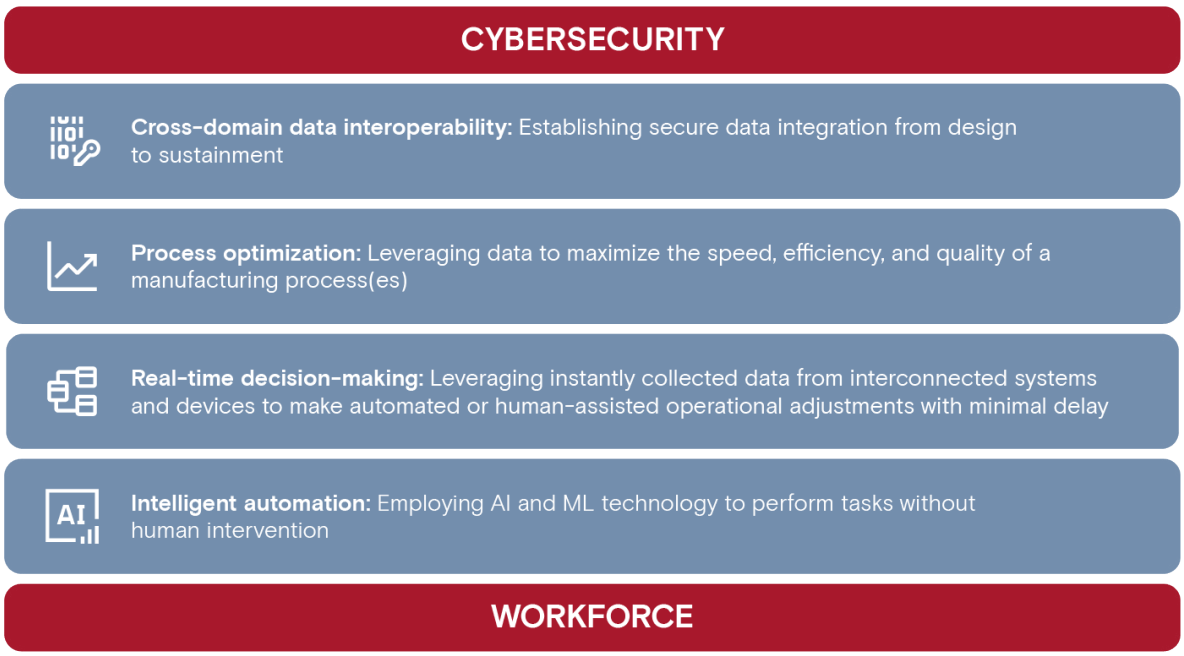
Quarterly Technical Advisory Committee meetings are where MxD Tier 1 and Tier 2 members, SMMs, and solutions provider representatives convene with government partners and academic members to discuss their technology challenges and success stories to help steer our technology roadmaps. Working groups and technical presentations are held monthly to share project progress and discuss relevant technology topics.

The MxD Member xChange is an interactive platform where members can connect with one another and access MxD resources. The platform includes information about upcoming projects and technical calls and access to the full MxD Project Portfolio. Other resources include an area where members can learn about and share upcoming funding opportunities and connect directly with other members to form teams.

ADVANCE technology innovation and secure digital adoption by addressing barriers across the manufacturing supply chain.

In the current manufacturing landscape, the push toward AI-augmented agile factories and supply chains is the primary driver for technology upgrades and investment. Member feedback and industry trends show that manufacturers have focused investment in capabilities that enable AI readiness, such as data interoperability, process optimization, real-time decision-making, and intelligent automation, as shown in Figure 6. These capabilities must be complemented with cybersecurity considerations and workforce training to be fully leveraged.

Figure 6: Advanced manufacturing technology investments that drive demand for AI readiness



Technologies that enable these capabilities include:

- Advanced sensors for IIoT-based data acquisition, including vision, multimodal, and extreme conditions
- Data-agnostic product lifecycle tools, including design, production, qualification, and enterprise resource planning software
- Scalable, standardized information models that link digital twins into a larger system of digital twins
- Robust wireless communication solutions such as 5G that can communicate data securely with the speed and scale required in both factory environments and adverse conditions
- Secure cloud and edge storage and compute
- AI and ML
  - Domain-specific ML algorithms and small language models deployed at the edge and on premise or embedded within an autonomous asset
  - Large and small language models trained for maintenance, repair, and operations; worker training; and cybersecurity applications
  - AI and ML cybersecurity threat assessment and detection technology

Gaps in achieving successful implementation of such technologies are found primarily in the integration of various operational systems and the curation of data produced throughout the product lifecycle for analysis.[11] Feedback from our industry members and government partners is consistent with that gap assessment. In 2025, we began collecting feedback from our SMMs with the Digital Manufacturing Adoption Survey. The survey was developed by the Auburn Interdisciplinary Center for Advanced Manufacturing Systems and adapted for MxD members to better understand where they are on their digital adoption journey.[12] Gaps identified by the survey were prioritized by the Executive Council and Technical Advisory Committee and include:

- **Data quality, interoperability, and standardization:** Data is the lifeblood of digital adoption.
  - The fidelity of the data generated for analysis is critical for accurate and meaningful analysis.
  - Data sources often have inconsistent formats and lack industry-wide standards.
    - Obsolete or proprietary formats must be replaced by those that are open and ready for the future.
  - Data governance, which entails screening, scrubbing, and translation of data into compatible formats, is labor intensive and expensive.
- **Secure transmission and storage of data:** Data security throughout the product lifecycle helps to build and maintain trust and value throughout the product supply chain.
  - Stakeholders are often unwilling or unable to share data between disparate systems within an enterprise and/or supply chain.
  - Stakeholders are often unaware of vulnerabilities in their data infrastructure, namely in their IT/OT environments, or are under resourced in their ability to address them.

11 Awasthi, Amruta, Lenka Krpalkova, and Joseph Walsh. 2025. "Bridging the Maturity Gaps in Industrial Data Science: Navigating Challenges in IoT-Driven Manufacturing." Technologies (MDPI) 13 (1): 22. Accessed September 25, 2025. doi:https://doi.org/10.3390/technologies13010022.

12 The survey is available at https://auburn.qualtrics.com/jfe/form/SV_bdrCSxMtCWyxWAe.

- **Legacy systems and processes:** Assets and workflows that rely on pen and paper to collect data about a manufacturing process and have no connectivity to an OT network are still commonplace.
  - Many obsolete manufacturing systems remain in service beyond their expected lifespans to sustain critical assets and infrastructure. They face additional challenges, such as:
    - Original equipment manufacturer (OEM) vendors to sustain legacy systems are no longer in business.
    - Replacement of legacy systems with modern equipment is cost prohibitive.
    - Ingesting non-digitalized legacy data such as velum designs and schematics is difficult and labor intensive. Technology has yet to mature to provide the accuracy required to automate the process. Vision systems and optical text recognition software continue to improve but still require a human in the loop.
- **Data model and digital twin scalability, maintenance, and sustainment**
  - Minimum data requirements throughout the product lifecycle must be determined at each phase to allow for sufficient data to be transmitted from 3D design models to production, quality inspection, maintenance, and sustainment.
    - Establishing minimum data requirements allows for the validation, verification, and certification of digital twins and other advanced manufacturing and production processes. Additive manufacturing is an area that would benefit from such requirements.
    - Interoperable frameworks allow for digital twin scalability and integration into a system of digital twins.
- **Demonstration of measurable ROI**
  - Investment in IT/OT infrastructure to leverage data capture and analytics is significant and complex.
  - A lack of widely adopted implementation frameworks leads to in-house solutions being developed, which inflates costs and delays the realization of ROI.

These gaps inform which initiatives MxD pursues to have the maximum positive impact on U.S. manufacturing. MxD is partnering with its members to address these technology gaps from a data-first standpoint and to categorize them according to their stage along the data lifecycle. We define the data lifecycle as the stages through which a manufacturer's data flows to unlock a critical capability. **Figure 7** describes the stages in detail.

Note that to achieve a desired capability (e.g., supply chain visibility), it is essential to know what technologies are leveraged at each stage so that they can interact effectively to transmit data from one stage to the next. The goal is to curate high-fidelity data from genesis to analysis by establishing clear data governance policies, standardizing data management processes, investing in training and culture, utilizing advanced technologies, and developing a secure and accessible data architecture. Access to high-quality, high-fidelity data will provide insight into overcoming manufacturing challenges and generate impactful business solutions such as enhanced decision-making, operational efficiency, cost optimization, compliance, and security.

Figure 7: The data lifecycle with examples of early and advanced capabilities at each stage

DATA GOVERNANCE STAGES		Early	Advanced
	GATHER: What are the sources of data?	Random, as needed Limited networking	Defined locality, frequency, and fidelity Hybrid wired/wireless networking
	CONTEXTUALIZE: How do you give data meaning?	Solution dependent	Defined metadata, enterprise > industry
	AGGREGATE: How do you store data?	Local, point storage	Structured, enterprise and cloud
	VALIDATE: How do you verify fidelity and sensitivity of the data?	Open loop, no validation	Closed-loop validation with self-learning
	SECURE: How safe is the data?	Minimal, IT focus	Industry certified, integrated approach
	COMMUNICATE: Who is transmitting the data and how?	Ethernet, dashboards	Enterprise standards > industry standard
	ANALYZE AND APPLY: What can you do with the data? How can the data be applied?	Go/no-go applications Basic point alerts Limits-based analytics In-house focus	Descriptive AI and predictive AI Diagnostic AI and prescriptive AI Real-time digital twins Supply chain and external visibility

Figure 8 illustrates how a data governance strategy involves a progressive process for maturing a desired manufacturing capability. Capability advancement occurs in steps, whereas the quality of data and analysis improves as a manufacturer upgrades the enabling technology. Using this framework, our projects can be mapped to where they contribute to advance technology and how they enable manufacturing capabilities.

Figure 8: The data lifecycle with examples of early, mid, and advanced capabilities at each adoption phase

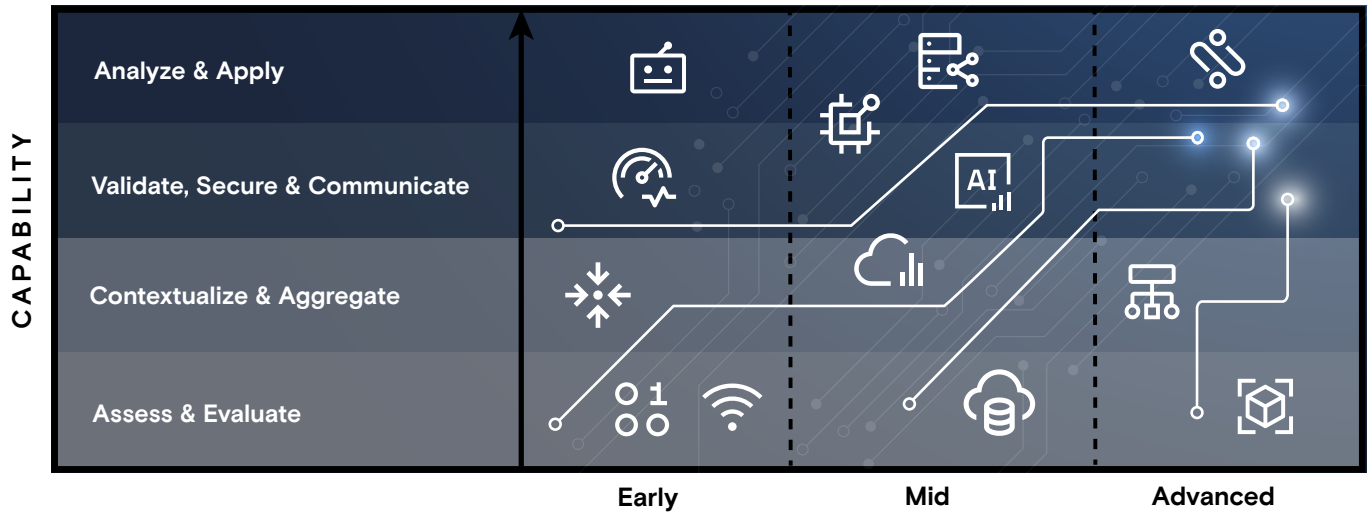
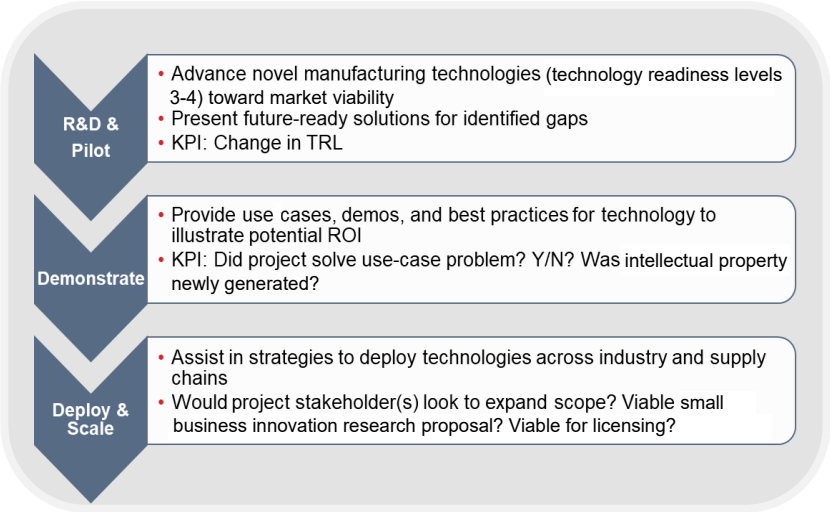


Figure 9: MxD project objectives and metrics



Projects

MxD projects and Factory Floor demonstrations accomplish at least 1 of 3 objectives (**Figure 9**): 1) Advance research and development (R&D) and pilot novel manufacturing technology, 2) demonstrate best practices with testbeds and Factory Floor demonstrations, or 3) deploy and scale validated solutions with case studies, reports, or pipelines for bringing products to market.

Projects showcase member collaboration in the development of novel solutions to digital manufacturing's most pressing challenges. In 2025, 47 projects were completed, representing over $26 million in manufacturing research. A list of the completed projects is available in the MxD Project Portfolio section (page 37). Additional information about these projects and their deliverables can be found on our Member xChange via the MxD website or requested by contacting **projects@mxdusa.org**.

Active Projects 2026 Onward

Ongoing MxD projects reflect the focus on a data-first approach and span the data lifecycle, as shown in **Figure 10**. From exploring novel sensor techniques for process optimization to identifying data standards and minimum data requirements for interoperability, the projects pave the way toward automated processes and decision-making. **Figure 11** lists active projects, and their descriptions follow.

Figure 10: Project distribution across the data lifecycle

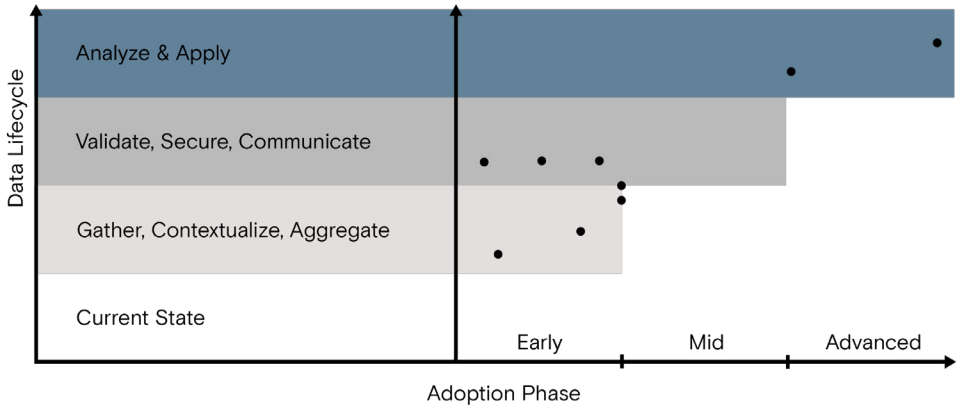


Figure 11: MxD projects active in 2026

		Project
Cybersecurity		24-13-01 | Cyber Appropriations Program Management
		24-13-02 | CREC: ICS/OT Cyber Range
		24-13-03 | CREC: Cyber Incident Response Training Workshop
		24-13-04 | CREC: Cyber Compliance Playbook
		24-13-06 | CREC: Cyber Threat Modeling Training Workshop
		24-13-08 | Cybersecurity Survey
Design		23-08-02 | Model-based Enterprise Readiness Upgrade
		24-04-01 | A Machine-to-X Data Standards Playbook for Manufacturers
		24-04-06 | Data Standards for Model-based Definition Manufacturing
Future Factory		22-23-01 | Closed-Loop Product Defect Identification and Remediation for Semicontinuous Roll-to-Part Manufacturing Systems
		22-23-05 | Defect Identification and Remediation Using AI: Machine Tools and Electronic Devices
		23-12-04 | Scaling Content Development for AR in Manufacturing
		24-12-02 | Picatinny 2D Descriptive Melt-pour Process Digital Twin
		25-01-01 | Castings and Forgings
Supply Chain		24-02-02 | Progressive Trust Building for Supply Chain Transparency
Workforce		23-18 | Michigan Defense Resiliency Consortium Workforce Programming Recommendations and Equity Plan

Data Lifecycle Guide	
	Gather , Contextualize, Aggregate
	Validate, Secure, Communicate
	Analyze & Apply

22-23-01 Closed-Loop Product Defect Identification and Remediation for Semicontinuous Roll-to-Part Manufacturing Systems

Project Team: University of Cincinnati, Kent Displays, Inc., Predictronics

Material thickness and uniformity control is a known challenge in most roll-to-roll manufacturing processes (e.g., steel casting, liquid-crystal film manufacturing). To meet in-line and post-line quality control needs, many optical inspection devices are utilized to inspect the surface quality (e.g., contaminations, cracks, roughness, etc.) of manufactured parts. However, based on a comprehensive literature survey and discussions with manufacturers, the proposal team found that these optical inspection devices are often siloed in production due to several technical barriers. After understanding these technical barriers, this project aims to develop and demonstrate a closed-loop product defect identification and remediation system based on a roll-to-part manufacturing system, where materials from the multistage roll-to-roll production line are directly cut into finished parts. The proposed system will achieve 1) automated optical inspection with AI-assisted data processing, 2) in-line sensing and monitoring for critical components and subsystems, and 3) semiautomated root-cause identification and intelligent clean room temperature control.

The overall closed-loop quality control methodology can be generally applied to any production system. The digital inspection methodology and image-processing algorithm can be broadly applied to many other manufacturing sectors. The developed technology and findings will be disseminated at various technical conferences (e.g., MSEC, AIMST, PHM Society, etc.) and in technical reports and conference articles.

22-23-05 Defect Identification and Remediation Using AI: Machine Tools and Electronic Devices

Project Team: Siemens, MK Morse, Kent Displays

This project is piloting an automated AI-powered vision-based product quality inspection system, enabling more accurate and informed decisions about identified defects and corrective actions in real time. The system is called Smart-DARPQuA and comprises a multi-camera image acquisition subsystem, an image-processing subsystem, and a recommender subsystem with inspection process feedback through a user interface.

It is designed for machine tool and electronic device inspection. It focuses on achieving full transparency into quality issues, reducing variation from manual inspections and corrective actions, and enabling continuous monitoring to detect defects before they reach customers. AI and computer vision technology are used to analyze key product components, inspect their quality and key tolerance metrics, and provide recommendations depending on the defect type or trend toward an out-of-tolerance condition.

23-08-02 Model-Based Enterprise Readiness Upgrade

Project Team: SteelToad

The Model-Based Enterprise (MBE) Maturity Index Assessment used by the National Nuclear Security Agency serves as the base model for this upgrade project. MBE assessments have been characterized as not user-friendly and difficult to follow. As a result, many organizations take the assessment and do not develop a strategic progression plan, resulting in arbitrary implementations that yield minimal discernable benefits to the organization.

This project is refining the MBE assessment based on feedback from industry partners. Key upgrades focus on the challenges of cost, benefits, progression, and instructions, but may also include other elements. The project is developing a guidebook and index using feedback and insight from key industry partners who work alongside the project team in revising the index. The revised guidebook and assessment tool will be designed for a wide variety of manufacturers, organizations, and types of work, allowing for faster and easier adoption across industry. Revisions will focus on improving performance within manufacturing by providing industry-specific guidance and solutions tailored to organizations of varying sizes.

The MBE Maturity Assessment Index is being adjusted to respond to emerging business, technology, and industry trends. The revised assessment tool will increase the quality and consistency of MBE implementation, providing actionable plans based on assessment results.

23-12-04 Scaling Content Development for AR in Manufacturing

Project Team: Northrop Grumman, ScopeAR, Ohio State University

This project aims to reduce the barrier to entry for new manufacturers to adopt augmented reality work instructions (ARWIs) while demonstrating time and cost savings for established ARWI users and stakeholders. This project uses a large language model (LLM) to infer the translation from textual information into ARWIs. The LLM is trained to map context between 2D textual instructions and computer-aided design (CAD) models and will undergo rigorous integration and testing in 2 manufacturing environments. The team is validating the model by analyzing the time saved in creating ARWIs by leveraging the LLM compared with creating them without the LLM. Leveraging the power of LLMs to automate and standardize work instruction conversions can have an immense impact on the ability to rapidly scale and deploy ARWIs across the broader manufacturing industry. This project will reduce time-to-product by at least 70%, increase scalability by enhancing ease of use, and ensure system compatibility for the creation of ARWIs for mass industry adoption.

24-02-02 Progressive Trust Building for Supply Chain Visibility

Project Team: SCRMC, IQBS

Modern manufacturing supply chains are global and distributed, and they include many organizations, from the extraction of raw materials through finished goods. For any large manufacturer or OEM, successfully delivering the end system requires that each link of the chain contributes its portion as expected. However, in practice little visibility into the supply chain exists beyond 1 tier up or DOWn, which results in unforeseen disruptions and inefficiencies. This project is evaluating the types of data shared across the supply chain, ranking them by level of business risk, and developing a model or tool to enable progressive data sharing for establishing and deepening trusted relationships.

24-01-07 Digital Twin Toolbox for Mass Adoption

Project Team: University of Alabama in Huntsville, Auburn University, Innovation Machine, MxD

The possibility of digital twins impacting the manufacturing industry is immense and spans the entire product lifecycle from design to sustainment. However, no two digital twins are exactly alike. To provide value, a given digital twin implementation must match the fidelity and scope of the model to the type of problem being

solved. A manufacturer deciding whether to invest in a digital twin needs an easy-to-use framework and a set of tools to be assured that the digital twin it chooses is the right tool for the job and will be worth the investment.

This project is developing a comprehensive framework, the Digital Twin Toolbox, that aims to offer a strategic roadmap for digital twin adoption and as a means of integrating 3 digitalization efforts: the digital thread, digital twins, and advanced simulation.

This framework addresses the early stages of development, from determining the data elements and capabilities needed to establish the digital thread and create a digital twin, to leveraging the current capabilities of a digital twin that can be trusted to support decision-making. The framework will be tested with CNC machining because it is a prevalent process among U.S. manufacturers that could benefit from a digital twin. This project is also developing a Resource Entity Creator, Resource Entity Library, Resource Entity Translator, Digital Twin Template, and Automated Machining Asset, as well as a step-by-step methodology to ensure quick, easy, and affordable digital twin implementation.

24-04-02 A Machine-to-X Data Standards Playbook for Manufacturers

Project Team: Michigan Technological University, MK Morse Company, Rapta AI

Manufacturers adopting advanced manufacturing technologies face a significant barrier connecting complex heterogeneous systems (machine, software, enterprises, etc.) with varying data formats. Data standards have been developed to address the heterogeneity of manufacturing systems. However, data standards are numerous due to the siloed nature of standards development organizations that release these standards. This siloed approach makes it difficult for manufacturers to adopt data standards for their use case to facilitate semantic interoperability and consistency between systems. This project is developing a Machine-to-X Data Standards Playbook for manufacturers that can recommend data standards for a given use case throughout the product lifecycle. The playbook will alleviate the confusion of data standards and provide broad-based recommendations to the manufacturing community to facilitate the adoption of digitalization. It will also provide preliminary use cases in machine-to-x applications throughout the product lifecycle (design, production planning, manufacturing, distribution, and support).

24-04-06 Data Standards for Model-Based Definition Manufacturing

Project Team: Action Engineering, Rubypoint, Capvidia, Lockheed Martin

The proliferation of overlapping data standards used by the DOW has created inefficiency in data interoperability efforts, causing aerospace and defense manufacturers to rely on familiar but suboptimal methods. This results in inconsistencies and challenges when interoperating with external systems. This challenge is compounded by the critical need for data consistency and semantic interoperability, because incongruities and overlap between numerous existing standards create confusion over which are best for specific applications, hindering effective data interoperability.

The resulting Data Standards Playbook will provide manufacturers with recommended data standards for model-based definition (MBD) manufacturing, a gap analysis of existing standards, and actionable solutions to enhance data interoperability and implement best practices. Specifically, it will examine the current data standards landscape and outline a streamlined implementation pathway tailored for MBD manufacturing workflows relevant to DOW use cases. It will also include value-added workflow demonstration that will

visually showcase cutting-edge real-work applications of data standards while leveraging Quality Information Framework QIF and Standard for the Exchange of Product model data STEP standards.

24-13-02 and 24-13-03 CREC: ICS/OT Cyber Range and Incident Response Training Workshop

Project Team: Immersive Labs, Infinite Ranges, MxD Cyber

The manufacturing industry broadly lacks essential cybersecurity skills and knowledge despite it being one of the most targeted sectors. Specifically, SMMs have the greatest need for more resources. Manufacturers lack the tools to train and hone their cybersecurity skills specific to manufacturing equipment and operational technology. Immersive Labs, supported by Infinite Ranges, is developing a virtual platform, or range, that simulates a manufacturing organization's IT/OT environment and allows participants to practice offensive and defensive skills. The range's capabilities include industrial control system (ICS)/OT devices and software and will be extensible to new 3rd-party software or hardware so that capabilities can be tested in environments that are reasonable approximations of a manufacturer's actual environment.

Project partners are designing and deploying an immersive cyber training range paired with portable ICS and OT training kits. This hands-on training experience will allow SMMs to practice defending realistic manufacturing systems, enhancing workforce readiness and operational resilience.

24-13-04 CREC: Compliance Playbook

Project Team: Ohio State University

Building upon the success of project 22-11-01 Strategies to Address Resiliency and Recovery, this effort is creating compliance playbooks for Cybersecurity Maturity Model Certification (CMMC) and similar cybersecurity compliance standards. The playbook content will be presented in an interactive and dynamic fashion through a web-based software solution and will be accessible to MxD members. Users receive deliverables that focus on specific tasks to be completed for compliance.

24-13-06 CREC: Cyber Threat Modeling Training Workshop

Project Team: Shostack + Associates, MxD Cyber

This effort will develop instructor-led training on how to conduct threat modeling in OT environments. Participants will learn to envision how things can go wrong in their current environments, identify ways to eliminate threats or minimize impacts, and build future systems securely from the start. A train-the-trainer component will be incorporated for MxD Cyber engineers to support their training and lay the groundwork for MxD to conduct future training sessions.

24-13-08 Cybersecurity Survey

Project Team: MxD, QuestionPro

MxD is developing a survey of a representative sample of SMMs to acquire the data necessary to paint an accurate picture of the state of IT/OT in the SMM space, and the knowledge, skills, and abilities of those who support such technology. This baseline knowledge will be used to develop future programs and content tailored to the true state of technology used by SMMs.

25-01-01 Castings and Forgings

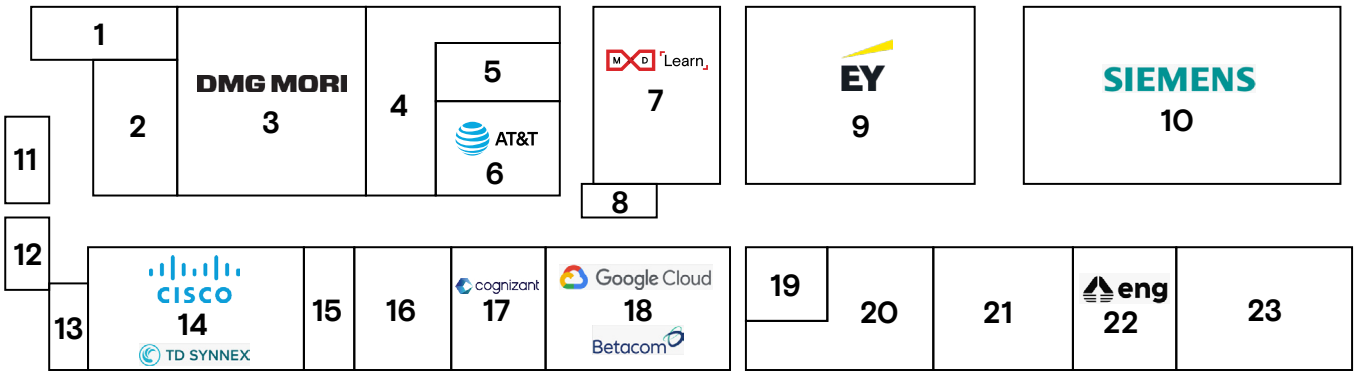
Project Team: MxD, EY

EY is generating a technology roadmap focused on how digital manufacturing technologies can benefit the castings and forgings (C&F) industry. The roadmap examines critical phases in the lifecycle, including design, production, and supply chain. Research and workshops with industry, academia, government, and relevant trade associations have informed the roadmap. MxD will build upon past C&F activities by America Makes, Advanced Robotics for Manufacturing Institute, and OSD-IBAS. The roadmap will provide insights into the challenges that digital solutions can overcome and provide a list of potential projects that can advance commercial adoption of digital technologies in the C&F industry.

Factory Floor Demonstrations

The MxD Factory Floor is a 22,000-square-foot asset with capabilities that include demonstrating technologies, running testbeds, training workforces on new systems and tools, and illustrating the critical need for cybersecurity in manufacturing. The Factory Floor hosts more than 10,000 visitors annually. It is a facility where everyone from a student to a CEO can experience the potential of advanced digital technology. Visitors already familiar with modern factories can further explore how the cyber-physical world of digital manufacturing can transform their facilities to offer the adaptability of high-mix, low-volume capabilities with the scalability of mass production. The Factory Floor also shows visitors how to think strategically about manufacturing data from a holistic point of view and how to leverage digital solutions to solve fundamental manufacturing challenges.

Figure 12: 2026 MxD Factory Floor layout



1. MxD Sensor Kit Testbeds/Proactive Worker Safety
2. Discrete Cell 2.0
3. DMG MORI
4. MxD Sensor-Kit-Enabled Digital Twin
5. Wireless 5G Testbeds
6. AT&T
7. MxD Learn Lab & Recording Studio
8. Track & Trace
9. EY
10. Siemens
11. Automated Wireless Signal Mapping
12. Lungs-in-the-Loop
13. Cybertown
14. Cisco/TD SYNNEX
15. Open Member Space
16. MxD Assembly Line & Cyber Wall Testbeds
17. Cognizant
18. Betacom/Google Cloud
19. MxD Process Platform
20. Integrated Open Process Testbed
21. Open Member Space
22. Engineering Industries eXcellence
23. MxD Fabrication Area

MxD Factory Floor Demonstration Updates

Figure 12 shows the MxD Factory Floor layout as of 2026, with the following MxD members demonstrating new capabilities in their respective spaces (the numbers in Figure 12 correspond to the following numbered demonstrations).

1. Members University of Buffalo, PPC Flexible Packaging, and Arvist partnered in project 22-06-01 Proactive Worker Safety for Industry 4.0 Using AI to develop a platform using AI video analytics technology to give accurate risk assessments of ergonomics by providing real-time performance data to both manufacturers and workers.
2. Discrete Cell 2.0, or Project 20-18-02 Capacity and Mobilization Digital Twin Virtual Commissioning Scenarios, was developed by partners Siemens and Engineering USA to install a small manufacturing cell on MxD's Factory Floor and demonstrate a digital twin capable of virtually simulating emergency scenarios and formulate response plans.
3. The newly installed DMG MORI demonstration space includes the company's latest advanced manufacturing technology with mobile and modular capabilities to meet the demands and conditions experienced by the U.S. military across the globe.
4. The MxD Sensor-Kit-Enabled Digital Twin demonstration is a descriptive mixing batch process digital twin for an air-gapped and on-premises application deployment. This demonstration is a proof of concept for an implementation at Picatinny Arsenal that illustrates the foundation of how a sensor kit can be implemented for the arsenal's melt-pour process operation.
7. The MxD Learn Lab & Recording Studio (**Figure 13**) was completed in spring 2025 and is used for training and workforce development in digital manufacturing and cybersecurity. The recording studio is used for developing virtual training content, producing recordings and podcasts, and creating digital media to support the goal of upskilling the manufacturing workforce for the future.
8. Members Connecticut Center for Advanced Research and Search in Real Life collaborated in project 22-07-02 Track & Trace. This project created a playbook and selection tool for track-and-trace inventory logistics technologies and solutions. It focused on the key factors a typical manufacturer would consider when understanding, developing, designing, and implementing track-and-trace capabilities within their production environment.
11. The Automated Wireless Signal Strength Mapping for Industrial Facilities space was developed in partnership with University of Michigan-Dearborn and OPEX Systems, through project 21-18-09. It demonstrates a solution with the capability to map a facility and correlate wireless radiation signal strength to the facility map in an independent, autonomous manner with minimal input required from the user.
13. Project 22-10-02 Operational Technology (OT) Threat Demonstration, also known as Cybertown, is an MxD-developed interactive testbed representing the major tactics and techniques that SMMs can safely and effectively deploy in OT networks to view the outcomes of cyberattacks and the effects of preventative measures in real time.
16. MxD partnered with Access Living and the College of Lake County to develop the MxD Assembly Line, or Project 22-26 The Manufacturing Workplace Accessibility & Job Training Program. The resulting hands-on demonstration adapts an assembly line station for accessibility. The goal of the initiative is to support manufacturing job opportunities for those with disabilities while increasing workplace accessibility across the manufacturing industry.

20. Project 23-02-01 Integrated Open Process Testbed was a collaboration between members Siemens and ADI. Together they developed and implemented an open architecture testbed for collecting and aggregating all the various sensor data that would be necessary to build a digital twin of a product, process, and auxiliary equipment.

Figure 13: MxD Learn Lab & Recording Studio

Cybersecurity Initiatives

National and sometimes global supply chains are critical for mission success. Large manufacturers can afford to protect themselves against highly skilled adversaries. As a result, adversaries target SMMs, which can undermine the trusted relationships SMMs have with large firms.

To address these issues, the DOW proactively developed the CMMC framework of standards for cybersecurity practices for contractors and other organizations that support the DOW. It is meant to help address manufacturer, and, by extension, supply chain security. CMMC aims to enhance the protection of national security information, including federal contract information and controlled unclassified information, across the supply chain through a standard assessment model and compliance framework. The threat of cybersecurity attacks has become particularly concerning given the rise in geopolitical tensions caused by the war in Ukraine, the ongoing conflicts in the Middle East, and an increase in the use of confrontational tactics in the Pacific Rim.

None of our nation's goals for fighting and winning on the battlefield will come to fruition without a large, robust, and secure industrial base. We cannot hope to secure that industrial base without undertaking challenging and

innovative efforts to apply cybersecurity principles, practices, and technology in a manufacturing context.

Manufacturers operate in a contested space — cyberspace — where threats are ever present and defenses are often inadequate. Progress requires that we create a strategy that is both aligned with the DOW's needs and brings to bear the best possible approaches to moving the needle in ways that matter.

Golden Dome for America, the Cyber Risk Management Construct, the National Strategy for Advanced Manufacturing, and numerous major procurement efforts dealing with defense manufacturing all call for improvement in the ability to make informed decisions to counter threats and mitigate risks, not just for discrete enterprises but for entire supply chains. All these requirements need to be successful at scale and carried out at combat speed. Consequently, MxD's cybersecurity strategy focuses on the following areas:

- **Accelerating SMMs toward CMMC compliance:** We make it faster and easier to create compliant documentation in preparation for assessment.
- **Strengthening supply chain security:** We provide knowledge and tools to help manufacturers identify threats to their supply chains and mitigate risks.
- **Improving security decision-making:** We enable manufacturers to consume and employ actionable intelligence that allows them to make better security decisions.
- **Supporting continuous monitoring and authorization to operate (ATO):** We enable manufacturers to test state-of-the-art cybersecurity solutions for efficacy without disrupting operations.
- **Advancing resilience:** We conduct R&D into methodologies and practices that support manufacturing capabilities under adverse conditions and circumstances.

MxD helps propagate cybersecurity skills and knowledge by leveraging the MxD VTC, a platform offering curated courses to develop manufacturing workers' digital skills, including cybersecurity. Workforce programs focusing on cybersecurity include the CAPITAL and Cybersecurity for Manufacturing Operational Technology (CyMOT) projects. Additional information about these projects can be found below in the Empower section.

MxD Supplier Program

In addition to delivering cybersecurity resources to manufacturers directly, MxD is partnering with Tier 1 and Tier 2 members Boeing, DMG MORI, Oshkosh, and Rolls-Royce to offer their suppliers a turnkey cyber communications program, called the MxD Supplier Program. The program helps large OEMs build more secure and resilient supply chains by raising awareness about cyber compliance, especially for the DIB. The program releases newsletters, webinars, and playbooks and holds hands-on workshops. Reaching thousands of suppliers a month, the MxD Supplier Program is an example of how MxD can drive improvements across company boundaries. MxD will look to extend the current program to additional manufacturers while also using this methodology to pilot and deliver new digital capabilities.

EMPOWER the workforce with resources that support skill development necessary to meet industry's current and future needs.

Empowering the manufacturing workforce is a fundamental component of MxD's mission. Decades of evidence show that a resilient and skilled manufacturing workforce is a prerequisite to a secure OIB and DIB. The OIB and DIB are cornerstones of national security and economic stability, and each faces a significant shortage

of workforce trained to utilize basic digital skills and advanced manufacturing technologies such as AI, data analysis, cybersecurity, and extended reality. This skills gap — especially at SMMs — undermines the OIB's and DIB's ability to meet current demands and adopt productivity-enhancing technologies, threatening their effectiveness and resilience. MxD Learn makes digital manufacturing training and careers accessible to hundreds of thousands of learners and workers in support of U.S. economic prosperity and national defense.

MxD Virtual Training Center

The MxD VTC is an online platform (available at https://vtc.mxdusa.org) for empowering the workforce with the skills needed to strengthen U.S. manufacturing competitiveness. The VTC has a robust library of around 20,000 courses that improve workforce competencies across manufacturing business functions. It includes unique MxD-developed learning content that focuses on the future of work in manufacturing, such as courses on data analytics, cybersecurity, and extended reality.

The VTC fills a gap experienced by SMMs nationwide: the lack of resources to purchase learning management systems widely adopted by large companies. Learning management systems enable a culture of continuous improvement, which is a prerequisite to successful digital transformation. When robust learning resources are available to all employees across business functions — from sales to human resources to production — the entire business's digital capabilities are enhanced.

MxD complements the VTC course library with role-based training programs focused on preparing manufacturers for the future of work. These future-looking training programs include:

- Data Annotator
- Manufacturing Analytics Associate
- Cybersecurity Analyst for SMM
- Supply Chain Cybersecurity Compliance Specialist
- Pre-Metaverse Integration Technologist
- Manufacturing Cybersecurity AI/ML Engineer
- Advanced Cybersecurity Analyst

The asynchronous role-based training programs listed above were developed through the MxD Learn CAPITAL and CyMOT programs.

- **CAPITAL (22-25):** The Curriculum and Pathways Integrating Technology and Learning (CAPITAL) program prepares current and prospective workers for a future in digital and cybersecurity jobs for manufacturing by establishing 5 role-based curricula and training programs in data analytics, cybersecurity, and extended reality. Since inception, at least 27,000 workers have enrolled in the program.
- **CyMOT (22-14):** The Cybersecurity for Manufacturing Operational Technology (CyMOT) program was a partnership between the University of Maryland Baltimore County and MxD to increase the security of U.S. manufacturers against cybersecurity attacks. It did this by providing role-based training to the next generation of cybersecurity workers in manufacturing. Courses developed by this partnership continue to be accessible via the VTC.

MxD Learn, in partnership with MxD Cyber, has developed a live CMMC training. Since the program launched in 2023, more than 300 individuals have been trained to conduct the NIST 800-171 self-assessment to prepare manufacturers to meet CMMC requirements. The training launched out of the RI MADE program (22-28) targeting Rhode Island maritime industrial base suppliers and has since expanded to other states, including Texas.

The VTC enables MxD Learn to scale programs beyond their initial audience and grant-funded performance periods to new regions and learners. It provides valuable insights to the MxD Learn team as it develops new programs, including robust data on learner registrations, enrollments, course progress, and completions.

The VTC unlocks several revenue-generation opportunities, including:

- Selling VTC microsites. A microsite is a custom-branded version of the VTC for organizations interested in hosting training courses on a learning management system that costs far less than other training programs or learning management systems.
- Hosting training programs from channel partners looking to extend their reach within the manufacturing sector, with MxD taking a small portion of channel partners' proceeds.
- Licensing VTC courses developed by MxD to other training partners and libraries.
- Selling access to individual courses.

The VTC has immense potential as a platform for all future MxD courses and resources across business verticals. This effort represents the latest strides in attaining the goal of upskilling 1 million manufacturing workers in the United States.

Workforce Readiness Guides

Building off its original Digital Manufacturing and Cybersecurity Workforce Readiness Guides, published in 2017 and 2020, MxD Learn has published additional guides for electric vehicle (EV) manufacturing and the OIB. With these key additions, the published guides now identify a combined 682 job roles crucial to the future of manufacturing and recommend how to train and upskill workers to perform these jobs. Included in the guides are sample career pathways, candidate success profiles, and recruiting personas. Manufacturers and their human resources departments have used MxD's Workforce Readiness Guides for workforce planning and recruitment. Current and future manufacturing workers have used the guides to plan their career pathways within the sectors. Since 2017, the guides have had thousands of DOWnloads and continue to be a resource for manufacturers.

Recording Studio

The MxD Learn Lab & Recording Studio is designed to support the creation of virtual content for MxD's internal use and for external partners. The recording studio provides access to high-quality equipment, including a 4k camera, full lighting set up, green screen projector, various microphones, a sound-proofed controlled environment, and an expert production team to ensure the recording and editing process runs smoothly. This offering records podcasts, allows members to showcase demonstrations, supports employee onboarding, creates promotional videos for manufacturers, and more. The recording studio assists manufacturers with engaging with customers, employees, learners, and stakeholders in an increasingly virtual world.

MxD Technology Portfolio

2025 Completed Projects

MxD projects showcase member collaboration to develop novel solutions to digital manufacturing's most pressing challenges. In 2025, 47 projects were officially completed, shown in **Figure 14**. Additional information about these projects and their deliverables can be found on our Member xChange via the MxD website or requested by contacting **projects@mxdusa.org**.

Figure 14: MxD projects completed in 2025

	Project
Cybersecurity	● 21-11-04 | Security Solutions for OT
	● 22-10-02 | OT TDLE Cybertown (Reporting)
	● 22-11-01 | Strategies to Address OT Resiliency to Minimize Operational DOWntime
	● 22-12-01 | OT Cybersecurity Web Portal for SMMs
	● 23-09 | DERISC Program Mgmt.
	● 23-11-03 | Cybersecure Enclave Infrastructure as Code
	● 23-13-03 | CMMC Focus Study
	● 24-13-01 | Cyber Approps Program Mgmt.
	● 24-13-03 | Incident Response Workshops
	● 24-13-06 | Threat Modeling Training
	● 24-13-07 | Cybersecurity Buyer's Guide
	● 24-13-02 | ICS/OT Range & Training
Design	● 21-30-01 | Cross-Institute Collaboration (CIC) - Digital Data Management for Transcribing Structural Part Performance Across Additive Manufacturing (AM) Platforms
	● 23-17-24 | Anark OIB Modernization Challenge
	● 24-12-03 | OIB Evaluations
Emerging	● 20-11-01 | ET Follow-on Year A&M/Rutgers: Securing Voice Technology in Manufacturing via Cross-Domain Low-Effort Authentication
	● 20-11-04 | ET Follow-on Year: Physics-Guided Machine Learning (PGML) for CNC Milling
	● 20-11-11 | ET Follow-on Year UNCC: Development of Manufacturing Equipment Digital Twin and Integration with Cyber-Physical Emulation Test Range

	● 20-11-13 | ET Follow on Year PSU: Privacy-preserving Analytics for Smart Manufacturing
	● 21-10-02 | ET Follow-on Year: Machine Learning-based Quality Improvement for Thermal Energy Cutting Processes
	● 21-10-03 | Product Lifecycle Data Analysis
	● 21-10-04 | ET Follow-on Year ISU: Secure Digital Twin Incorporating Physics-Aware Machine Learning for Additive Manufacturing
	● 21-10-06 | ET Y2: Understanding Discrepancy Between Design and Implementation of Inventory Policies
	● 22-04-03 | Using ML to Execute What-If Scenarios
	● 22-08-03 | Building Innovative Blockchain Applications
Factory Floor	● 19-02-01 | Standards for Metrology Aided Robot Technology (SMART)
	● 20-04-01 | Digital Manufacturing Journey
	● 20-17-02 | RSD-MDI: Lungs in the Loop Enhancements
	● 20-18-01 | Capacity and Mobilization Assessment of the Pharmaceutical Industry (CARES Act)
	● 20-18-02 | Virtual Commissioning DT Testbed
	● 21-07-02 | Secure Wireless Testbed
	● 21-07-04 | Secure Wireless Selection Tool
	● 21-14-03 | Predictive Maintenance for Multistage Roll-to-Roll Manufacturing Systems
	21-18 | 5G Manufacturing Testbed (Program)
	21-18-05 | Connectivity & Performance of a 5G Network
	21-18-06 | Process for 5G Client-Side Equipment Testing
	21-18-07 | 5G Cybersecurity Penetration Testing
	21-18-09 | 5G Automated Wireless Spectrum Mapping of Industrial Facilities
	21-18-10 | 5G Hardware Encryption
	21-24-01 | Local Health Alert System
	22-03-02 | MEPs Digital Playbook
	22-06-01 | Proactive Worker Safety Using AI
	22-06-02 | SAFE (Reporting)
	22-07-02 | Track and Trace (Reporting)

	23-02-01 | Integrated OPA Testbed
	24-01-07 | Digital Twin Toolbox for Mass Adoption
	24-06 | SMM100 Sensor Kits (Reporting)
	22-22-01 | OIB Modernization
	23-17-01 | Software AG OIB Modernization Challenge
Supply Chain	21-19-05 | AM Digital Transformation (Paladin)
	21-19-06 | Integrated Digital Operations (Paladin)
	21-26-01 | Rx Product Marketplace Orchestrator
	24-15-01 | NSF Workshop

Abbreviations

AI: Artificial Intelligence

AR: Augmented Reality

ARWI: Augmented Reality Work Instructions

ATO: Authorization to Operate

C&F: Castings and Forgings

CAD: Computer-Aided Design

CAPITAL: Curriculum and Pathways Integrating Technology and Learning

CMMC: Cybersecurity Maturity Model Certification

CREC: Center for Regional Economic Competitiveness

CyMOT: Cybersecurity for Manufacturing Operational Technology

DERISC: Digital Education, Resilience, and Innovation for Supply Chain

DIB: Defense Industrial Base

DOW: Department of War

EV: Electric Vehicle

IBAS: Industrial Base Analysis and Sustainment

ICS: Industrial Control System

IIoT: Industrial Internet of Things

IT: Information Technology

LLM: Large Language Model

MBD: Model-Based Definition

MBE: Model-Based Enterprise

MII: Manufacturing Innovation Institute

ML: Machine Learning

NIST: National Institute of Standards and Technology

OEM: Original Equipment Manufacturer

OIB: Organic Industrial Base

OSD: Office of the Secretary of Defense

OT: Operational Technology

QIF: Quality Information Framework

R&D: Research and Development

ROI: Return on Investment

SAFE: Sensor Augmented Factory Environment

SMMs: Small and Medium Manufacturers

TAC: Technology Advisory Committee

VR: Virtual Reality

VTC: Virtual Training Center