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**14. ABSTRACT**
The objective of this agreement is to establish a Digital Manufacturing and Design Innovation (DMDI) Institute that will significantly advance manufacturing within the United States.
The Government has led several independent initiatives addressing technologies both on and above the factory floor with the goal of maximizing the use of digital data across the life cycle of products. This "digital thread" captures information generated from concept development and design to analysis, planning, manufacturing, assembly, maintainability, and through to disposal. The complexity of what can be designed, built, and maintained to meeting product needs in both military and commercial markets is constantly increasing while the lead time available to develop and move these products from design to the customer is decreasing. Early consideration of manufacturability, during both the development of the science and technology and the design and acquisition phases, is essential to dealing with this complexity. Government and industry both have recognized the need to integrate physics-based characteristics into models that enable the simultaneous consideration of the physical configuration, computational

**15. SUBJECT TERMS**
Digital Manufacturing and Design Innovation, DMDII, MXD USA, UI LABS, supply chain, machining toolkit, augmented reality, assembly line, factory floor, cyber wall, cyber process skid, National Center for Cybersecurity in Manufacturing (NCCM), workforce development

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FINAL REPORT

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# CONTENTS

## I. INSTITUTE HIGHLIGHTS

In February 2014, then-President Barack Obama announced the launch of MxD, known originally as the Digital Manufacturing and Design Innovation Institute (DMDII), in an event at the White House. At the time, the institute had about 75 organizations in its member base and a broad mandate to accelerate manufacturing innovation by harnessing the "digital thread."

Over the course of the Cooperative Agreement (CA), MxD, which stands for "Manufacturing times Digital," has amassed hundreds of partners across industry and academia, built a state-of-the-art Future Factory for testing and demonstration, funded and facilitated dozens of complex R&D projects, defined and fortified the workforce pipeline from middle/high school through current practitioners, become a leading voice on cybersecurity for manufacturing operational technology, and contributed its expertise to the international conversation on the fourth industrial revolution.

As a public-private partnership, one of MxD's greatest assets is its network of partners from large technology and manufacturing companies, small and medium manufacturers (SMMs), universities and research institutions, and non-profits and community organizations. Each member has a unique set of offerings and benefits gleaned from the arrangement, with the symbiosis on full display in project teams that pull from a cross section of partner types. MxD meets each partner where it stands in its digital journey and provides ample opportunities for matchmaking and collaboration.

Another major MxD accomplishment that continues to pay dividends to partners and stakeholders is the construction of a world-class innovation center in Chicago, outfitted with a manufacturing demonstration floor like none other in the country and, in many respects, the world. With $16.5 million in funding from the City of Chicago and State of Illinois, MxD transformed a vacant windows and doors factory into a modern office for permanent and visiting teams, a factory floor equipped with millions of dollars in hardware and software, and an event space that has easily transformed from a field trip destination to the background of a cabinet secretary's official portrait.

The development of the innovation center, which has become an integral part of the fabric of MxD, is the result of an incredibly ambitious plan that addressed pain points in the community and leveraged the many benefits of its location. The building has an unusual combination of traditional office workspace, the ability to accommodate industrial scale equipment (an important distinction from more commonly found maker spaces and laboratories) on a factory floor, classroom-style rooms for trainings of up to 75 people, and large multi-purpose areas for conferences and workshops with hundreds of attendees who can move seamlessly from lectures to breakout sessions to receptions and networking.

In October 2014, the small DMDII staff went to the International Manufacturing Technology Show (IMTS) with a list of desired equipment to request on consignment for the factory floor in a building that was mid-construction. By the time the facility opened the following year, many bays were occupied with CNC machines and high-tech measurement equipment to show the potential of digital technology to streamline manufacturing operations and tackle business problems with data. As the section below describes, the current layout is many times more functional and educational than the original use of the space with much greater partner and project involvement.

The innovation center has been a valuable convening space for visitors across the United States, in large part due to its central location and proximity to major airports. Facing the reality of COVID-19, MxD is now entering the next phase of collaboration by bolstering its digital-only and hybrid digital and in-person events, as well as installing safety and sanitation measures to protect the health of its team and guests. Once again, MxD is using its singular combination of digital leadership and on-the-ground agility to fabricate items in-house where possible, such as door openers and sneeze guards, and to provide clear guidance to building occupants as well as set an example for large and small manufacturers on what is possible.

MxD features several R&D projects on its factory floor, and its research has spanned topics from design to supply chain, fully encompassing the digital thread. From its initial cohort of projects focused on advanced manufacturing enterprise, advanced analysis, and intelligent machines, MxD's portfolio has grown in sophistication and range with the implementation of a strategic investment plan informed by its partners. Whether retrofitting legacy machines or capturing experts' institutional knowledge with augmented reality work instructions, MxD's projects have matched the ideas and ingenuity of leading researchers with the pressing needs of industry to help U.S. manufacturers make every part better than the last.

Workforce development has also been a key focus area since the early days of the Cooperative Agreement. Without retraining current workers with digital skills and building a strong pipeline of future talent, the skills gap in manufacturing will widen while marginalized workers remain on the sidelines. MxD's education and workforce development activities have established the first massive open online course for digital manufacturing and design, defined manufacturing roles of the future and organized them into a jobs taxonomy, and developed a high school curriculum for digital manufacturing and cybersecurity, as well as welcoming students and trainees into its innovation center for immersive educational content.

Another area that has been part of MxD's mandate since its launch but has had a renewed focus in the last two years is cybersecurity. As more manufacturing equipment is connected to the internet, the risk of cyber-attacks increases, with the possibility of controlling machines with an intent to harm workers or manipulate the items being produced. In 2018, MxD was designated the National Center for Cybersecurity in Manufacturing by the Department of Defense. Since then, it has convened stakeholders to discuss cyber threats to the manufacturing sector, built out sections of its manufacturing floor to demonstrate how to protect operational technology from common attacks, and incorporated a cyber component into several workforce development projects.

MxD has leveraged its DoD investment with the funding, ideas, and collaboration of its many partners to establish itself as the place where innovative manufacturers forge their futures. The highlights contained in this report are merely a sample of the wide range of activities performed over the course of the Cooperative Agreement.

## II. OPERATIONS

### Institute Standup

During the standup phase, which began in February 2014, MxD engaged in a number of activities to develop an institute membership agreement, identify space for institute operations and begin to advance internal processes to launch R&D projects. During that time, MxD established the first institute membership agreement and signed twelve Tier 1 and 2 partners including Boeing, Lockheed, Rolls-Royce, Caterpillar, John Deere, and Microsoft to name a few. The team also secured a lease buildout of a new headquartered facility on Goose Island in Chicago, Illinois, providing the institute the ability to have a 22,000 square-foot manufacturing floor to demonstrate and validate advance manufacturing technologies, the first of its kind for a Manufacturing USA organization. Additionally, MxD dedicated a significant amount of resources during the standup phase to developing an open competition project process that would enable public-private R&D project investments for MxD members.


*President Obama announces the launch of DMDII at the White House in February 2014.*

Since the institute's inception in 2014, the digital manufacturing environment has changed significantly. Organizations are no longer questioning the importance or need for advanced digital manufacturing technologies; rather, they are trying to understand how these technologies can and should be leveraged to obtain measurable impact. This new approach has transitioned MxD from building awareness to supporting digital manufacturing technology adoption. MxD, in collaboration with the DoD, leverages its knowledge of digital manufacturing technologies and acts as an intermediary between solution providers,

researchers, and manufactures to accelerate the adoption of innovative next-generation digital manufacturing technologies, which enables a more robust and effective manufacturing industrial base.

To accelerate the adoption of digital manufacturing technologies, MxD will carry forward and build upon the knowledge and learnings gained during the MxD performance period of the Cooperative Agreement, which include but are not limited to:

### A. Diverse Community

The network of U.S. companies and innovators in MxD's ecosystem is growing. We are partnering with innovators, competitors, customers, suppliers, and more; accessing new knowledge and insights that improve our companies' strategies; and tapping into two uniquely American assets: world-renowned research universities and the best startup ecosystem in the world. Nearly 300 organizations have partnered with MxD as of May 2020, catalyzing thousands of relationships among organizations. To support an end-to-end ecosystem in the U.S. for digital manufacturing, MxD will need to continue to grow membership and scale the number of relationships created within our network.

### B. Focused Investments

We leverage funds to drive better returns on investment, provide access to unique facilities and equipment, and offer a system to develop new products and processes more quickly and cost-effectively. SMMs benefit from the larger investment from industry and the federal government, and the large manufacturing and technology companies and federal government benefit from leveraged investments. As of May 2020, the federal government's $84.6M in investments has spurred $156.2M in matching investment. Going forward we will continue to use member cost share to leverage the federal governments investment and offset the risk to the U.S. industrial base in adopting new technologies, thus improving competitiveness.

### C. Agile Processes

MxD has embraced agile workstreams, which has given us the ability to rapidly respond to the changing needs of our partners and the manufacturing environment. Through these workstreams we have increased interactions with our partners, giving us a better understanding of their challenges and allowing us to be more responsive in matching customers' needs to the most appropriate technologies. Active project portfolio review involving our Technology Advisory Committee identified $2M in savings of Government funds in 2018. This maximizes value created for the DoD and our partners. Agile methodologies will continue to be supported and naturally accelerate all aspects of research and development throughout the product lifecycle as well as the technology adoption timeline.

### D. Continued Support for the Digital Manufacturing Ecosystem

The challenges posed by globalization and change require continuous transformation and innovation of manufacturing technologies. The institute will support the development of manufacturing facilities to scale up manufacturing process and support the DoD organic industrial base. This means providing an unprecedented capability to rapidly and flexibly produce prototype demonstrations in an operational

environment based on the use of validated computational design tools and a robust knowledge management system, all within a collaborative framework. These design tools and pilot manufacturing capabilities will be integrated to support manufacturing process improvements, maintain a community repository of design and performance data, and support validation testing to develop industry standards.

## Institute Governance

MxD's formal governance structure is comprised of the Executive Council (EC) and Technical Advisory Committee (TAC). The institute uses these forums to solicit input from partners and for key decisions in areas of membership, operations, capital investments, project selection, funding allocation, and progress towards self-sufficiency. Our current Membership Agreement and existing Cooperative Agreement with the DoD define the tiered partnership structure and govern membership policies including representation on the Institute's governing committees.

MxD publishes an annual Strategic Investment Plan (SIP), which functions as the ruling document to maintain alignment with institute objectives and includes a three-year technology roadmap highlighting the planned course of institute investments into the future. Inputs from individual members, monthly technical calls, and the TAC serve as the foundation for the SIP. The SIP requires approval from the EC.

## Cost Share Contributions

The table below indicates MxD's Cost Share values* over the life of the Cooperative Agreement.

| | | |
|---|---|---|
| Operations | | 2,867,750 |
| Facility Buildout | | 16,500,000 |
| 3rd Party R&D Projects | | 45,922,003 |
| Non-project | | 90,953,289 |
| **Total** | **$** | **156,243,041** |

*Values per the 2020 Q1 SF-425 submitted 5/14/2020

# III. TECHNOLOGY ADVANCEMENT

## Workshops + Technology Showcases

Technology showcases and workshops are events that include education and information about a digital manufacturing and/or cybersecurity topic, networking with manufacturing-focused individuals, and project brainstorming components. MxD curates speakers, panelists, and innovative technology solutions to create high-value, topic-specific events that create an opportunity for MxD partners to learn about the latest digital manufacturing technology advances and network with those who have similar interests. Through this combination of events, MxD collects insights and ideas from attendees, which ultimately influence MxD's technology investments.

Throughout the duration of the Cooperative Agreement, MxD hosted more than 25 technology showcases and workshop focused on specific topic areas including augmented reality, digitizing process manufacturing, blockchain in the supply chain, digital twin on the factory floor, cybersecurity, and advancing the design phase of manufacturing. These workshops included both educational and project development components. MxD curated speakers, panelists, and innovative technology solutions to create high-value, topic-specific events that created an opportunity for MxD partners to scope new project topics and provide insights on which technology areas are of the highest importance to U.S. manufacturers.

MxD's technology showcases and workshops have become a pillar of engagement with members. The events involve existing members – including consistent attendance and participation from existing top tier members – and expand the institute's overall reach, ultimately helping to secure new members. The events intentionally gather insights and data from a broad range of manufacturers in order to prioritize which project ideas will best serve MxD's mission to enhance the competitiveness of American manufacturing.

Hosting workshops has diversified MxD's membership due to the accessibility of the event itself coupled with the visibility into MxD's mission. By engaging all MxD members, regardless of membership tier, and extending invitations to other innovation-driven manufacturers, MxD workshops are home to a unique environment that fosters innovation and collaboration. Workshops allow for representatives from competing corporations, such as John Deere and Caterpillar, to identify common problems and work in partnership to develop solutions in which MxD can invest.

## Strategic Investment Plan

MxD's Strategic Investment Plan (SIP) provides a strategic vision of the technologies and investments that MxD, DoD, and our members believe critical for success in the next five years and beyond. While the industry and the enabling environment are changing quickly, the challenges faced by manufacturers of all sizes and from different sectors remain: how can these technologies best be leveraged for increased efficiency, competitive advantage, safety, and quality?

The SIP reflects MxD's focus on manufacturing's digital thread: the single authoritative source of truth that ties together facts and insights about an enterprise's products and systems. The digital thread brings together the right information to the right place at the right time and is comprised of three parallel elements (shown in Figure A) – the technology innovations that form the thread, the cybersecurity measures that protect the thread, and the workforce skills that lay the foundation and unleash its full potential. MxD invests in all three and works closely with members to ensure that roadmaps bring meaningful value to all three elements.

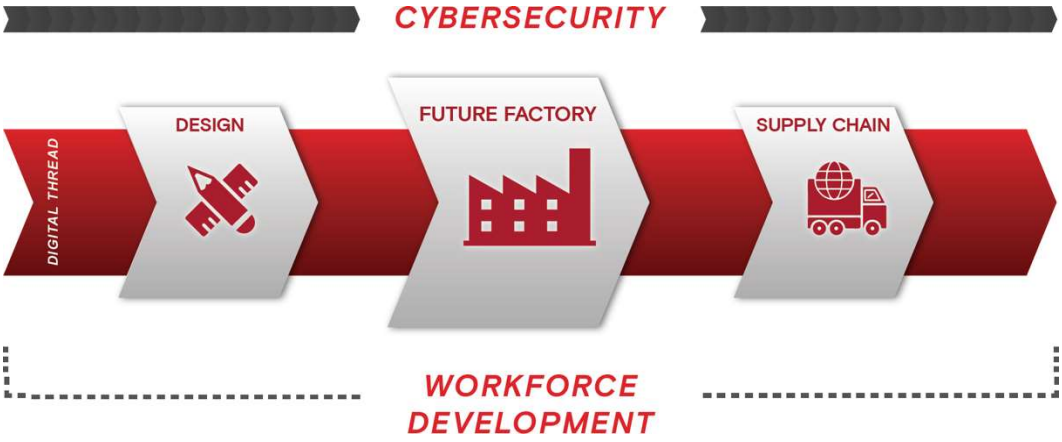



Figure A: MxD Thrust Areas - a holistic view to Digital Manufacturing

MxD leverages a collaborative and broad process to develop each year's SIP and Technology Roadmap. For the most recent SIP, this began with a review of the past project portfolio and development of a heat map to understand the technology areas where MxD has invested most. The SIP development also included an assessment of the global geopolitical, economic, and innovation trends affecting manufacturing and digital technologies coupled with extensive outreach to MxD's members and stakeholders. The Technology Advisory Committee meetings, workshops, and other events are used to develop a comprehensive portfolio of use cases and problem areas for further development and consideration. The resulting technology investment priorities were shared with the Executive Council, the Technology Advisory Committee, and the greater membership. One-on-one meetings were conducted with MxD Tier 1 and Tier 2 members to understand alignment with their specific priorities. MxD also issued a Request for Information seeking inputs, particularly from its academic partners, on interesting emerging technologies. All this culminates with a prioritized three-year roadmap of R&D projects across MxD's focus or Thrust Areas.

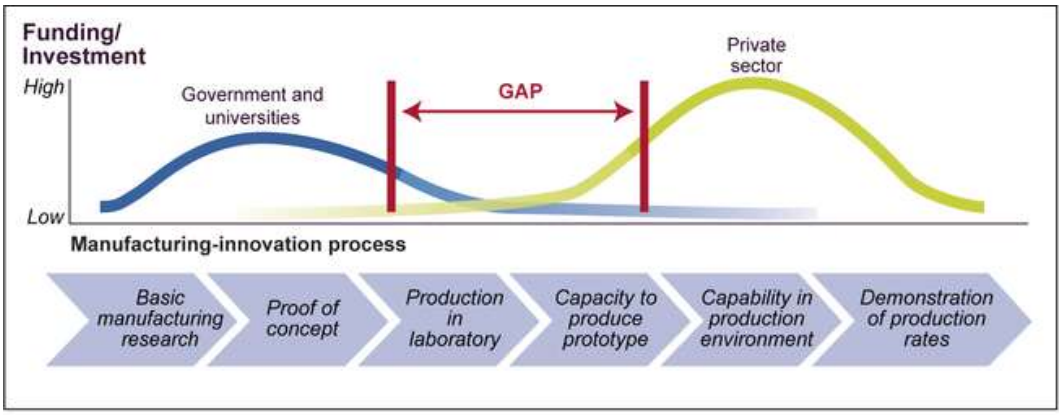
As industrial manufacturers find themselves in the midst of the Fourth Industrial Revolution, one thing is certain: change is an undeniable constant. The industry continues to experience change across all fronts: ecosystems, business models, technology, customer expectations, and workforce. Industrial companies, some of them more than a century old, are faced with the challenge of transforming to prevent extinction. To thrive, their leaders must understand and embrace the technology trends that are reshaping the industry.

Throughout the term of the Cooperative Agreement, MxD aligned its technology, outreach, and education investments on ensuring that U.S. manufacturing has the right tools to remain competitive globally and the Strategic Investment Plan is the vehicle for broadly sharing this vision and plans.

## R&D Portfolio Success Stories/Highlights

MxD and its members are working together to ensure the United States is the most globally competitive and innovative destination for manufacturing. In its first five years, under this Cooperative Agreement, MxD has invested more than $90 million of public and private funds in 63 projects with targeted outcomes

between Technology Readiness Levels (TRL) 4 through 7. MxD's projects bridge the gap in the innovation "valley of death" so named because of the high number of innovative concepts and ideas that fail when crossing from public sector research to private sector commercialization (shown in Figure B). Successfully bridging this valley accelerates the adoption of innovative technologies in manufacturing, providing competitive advantages to the early adopters.



Source: GAO adapted from Executive Office of the President.

Figure B: The "valley of death" gap between public sector research and private sector commercialization.

MxD's technology innovation investment strategy targets three primary areas along the digital thread: design, the future factory, and the supply chain. Over its five-year history, the institute focused its research and development (R&D) efforts on the digital technologies that enable all three areas. The primary focus areas benefit the entire manufacturing lifecycle, including the industrial internet of things (IIoT), artificial intelligence (AI), digital twins, information technology (IT) and operational technology (OT) integration, and augmented and virtual realities. Looking forward, MxD will build on that work to address the most pressing challenges facing its ecosystem, expanding the number and breadth of manufacturing use cases for these technologies on its Future Factory Floor.

Success Stories

**Supply Chain Risk Alert**

**Problem:** Manufacturers are frequently unable to identify – or predict – disruptions to their supply chains caused by emergencies, weather, or even natural disasters. Yet these disruptions can greatly affect freight and manpower costs, on-time delivery, and customer satisfaction. Manufacturers are looking for a tool that not only can alert them to supply chain disruptions, but predict them, analyze the potential impact and risks, automatically make plans to mitigate risks, and quickly communicate warning and options directly to supply chain managers.

**Outcome:** This project worked to improve and further automate the Supply Chain Event Management (SCEM) process by creating a framework to digitize, integrate, and automate the information pipeline and action workflow as well as offer recommendations based on prior mitigation actions. The primary use case is integration within a supply chain including an event management team, logistics teams, business

decision makers, and customer service representatives, where event mitigation actions can be determined using support data, tracked for cycle-time and where the output can be utilized to make faster informed decisions in similar situations in the future. Work on this project was split into five modules that perform independent actions and when linked, deliver the desired results. The modules are Predictive Transit, Risk Assessment, Mitigation Planning, SIMBA Chain Communications, and Performance Analytics. These modules were tested using Dow historical shipment data in the same form that data would be expected when being deployed for full use in daily operation.

**Digitizing Legacy Machines**

**Problem:** Manufacturers that are upgrading their operations often deal with costly older equipment that is difficult to digitize. Replacing or modifying these legacy machines sometimes is too expensive or would disrupt production or void a warranty. Manufacturers need a solution to enhance the capabilities of their legacy machines without having to replace them.

**Outcome:** The team developed a sensor retrofit kit that communicates data to a cloud dashboard. These turnkey kits are now commercially available and are compatible with multiple sensor types, making this a flexible option to help manufacturers gain transparency for a variety of use cases from cycle time tracking to machine health monitoring.

**Adaptive Machining Toolkit**

**Problem:** It is well known that early design decisions limit manufacturing options for a final component and drive the majority of the final cost. Currently, feedback from a potential manufacturer is often too late in the design process. Many existing DfM tools assume the designer knows what “M” they are after, ask for considerable detail, and/or require considerable time and skill to operate. In summary, we lack a simple digital link to the novice designer during the early conceptual design stage.

**Outcome:** The project resulted in a new software platform called ANA, with modules for machining, casting, die casting, and welding. The ANA manufacturability analysis software provides early-and-often feedback to guide the component being designed to more manufacturable characteristics in general. ANA also provides a base package with an initial set of process options and an ability to expand to many more in the future. The software allows designers to view iterations of their design over time, compare against different iterations, and compare across manufacturing options. Output can be read on the dashboard or outputted as shareable 3D pdfs. The other version being offered is a software add-in for CAD, currently Solidworks. The add-in is integrated in the functions of Solidworks, where the user’s design iterations are sent to ANA upon saving, or upon request.

**Manufacturing Work Instructions with Augmented Reality**

**Problem:** Manufacturing operations in the United States still heavily rely on paper-based documentation including work instructions, process routing sheets, and process quality documentation. Similarly, materials often used for training or document work instructions are available in electronic form but are

typically static documents. IT is challenged to keep these documents up to date and their format often does a subpar job at conveying the knowledge required to execute a manufacturing process.

**Outcome:** This project developed a complete system for building AR-enabled work instructions, including a methodology for distributing these electronic work instructions to workers. The tools provided as part of this system allows users to quickly build and deploy process documentation. Furthermore, a web-based authoring site was developed that allows for rapid process documentation, providing the worker more information than ever before. The viewer developed in this project is compatible with variety of devices and browsers, allowing for the maximum ease of use in reviewing work instructions.

## IV. TECHNOLOGY TRANSITION AND DISSEMINATION

### Institute Capabilities (Factory Floor)

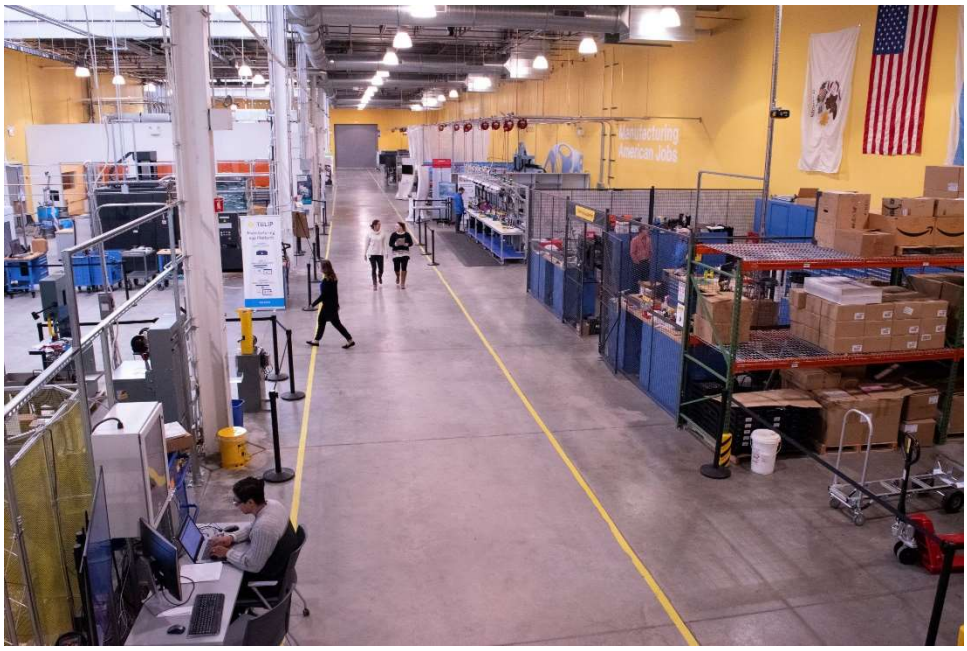
MxD's 22,000-square-foot Factory Floor is used to test and demonstrate new technology; train the workforce on new systems and tools; and demonstrate the critical need for cybersecurity in manufacturing. With an average of more than 1,000 visits each month, ranging from students to CEOs, the Factory Floor demonstrates the unlocked potential of a factory that utilizes advanced digital technology. Visitors who are already familiar with modern factories can further explore how the cyber-physical world of Industry 4.0 can transform their facilities to offer the customizability of craft manufacturing with the scalability of mass production.

MxD's manufacturing demonstration cells, such as the discrete manufacturing cell that machines MxD-branded souvenirs, show visitors practical examples of what Industry 4.0 enables: digital workflows, machine and environmental instrumentation, digital fingerprinting, analytics, and predictive maintenance. Data collected from the manufacturing of MxD souvenirs is available to members for use in research and development activities. The demonstration cells also provide members an opportunity to experiment with new ideas and test proofs-of-concept in a controlled environment prior to deploying in a production facility.

The manufacturing sector is the number one target for cybersecurity attacks and MxD's Cybersecurity Wall demonstrates how Programmable Logic Controllers (PLCs) found in manufacturing settings can be hacked and how businesses can mitigate these risks. A new demonstration cell was developed in late 2019 to demonstrate cybersecurity in process manufacturing and how manufacturers can detect, respond, and recover from a cyber-attack. In addition to its use for cybersecurity awareness, this cell is equipped with more than 28 sensors to continuously monitor the system. Like the discrete testbed data, the data collected on this testbed will be available to members for their use in machine learning and other artificial intelligence algorithm development and validation.

Select past project outcomes are often demonstrated, such as rapid prototyping using subtractive manufacturing, automated inspection programming, predictive maintenance scheduling, and low-cost digitization of legacy equipment. The Factory Floor is a dynamic and oft-changing space. MxD's team of engineers expand existing demonstration cells and create new cells and demonstrations, and members bring exciting new technology showcases to the floor, such as AT&T deploying a 5G cellular base station with multiple demonstrations of how 5G helps digital transformation. Visitors are encouraged to come

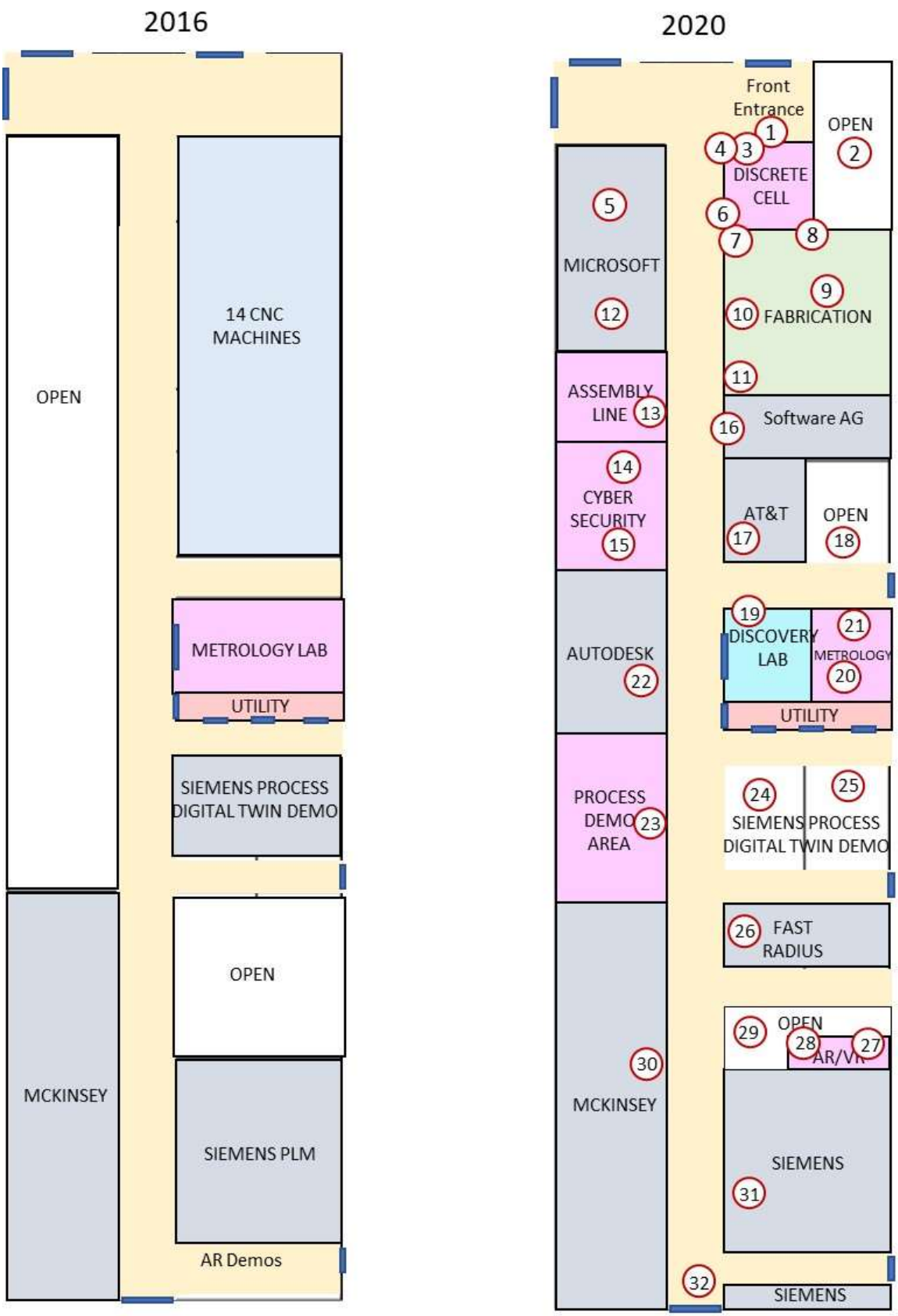
back often to experience these new solutions or dig deeper into existing solutions to increase their level of understanding about how the Fourth Industrial Revolution will help U.S. manufacturing continue to succeed.



As shown on the following diagrams, from 2016 to 2020 the Factory Floor has expanded not only with the number of partners showcasing their technologies but also with the addition of CA project outcomes and MxD demonstration cells.

Besides multiple partners (AT&T, Microsoft, Fast Radius, and Software AG) developing and installing their spaces in 2020, other Partners (Siemens, Microsoft, and Autodesk) continue to expand their existing demonstration spaces.

MxD is developing the Welcome Center (reference #2) concept that combines fabrication, control, and logistics technology in one experience with real-time souvenir customization choices for each visitor. Use cases include a digital thread for each souvenir with Supply Chain logistics captured and analyzed as part of the experience.


2016
OPEN
14 CNC MACHINES
METROLOGY LAB
UTILITY
SIEMENS PROCESS DIGITAL TWIN DEMO
OPEN
MCKINSEY
SIEMENS PLM
AR Demos
2020
Front Entrance
1
OPEN
2
4
3
DISCRETE CELL
5
6
7
8
MICROSOFT
9
12
10
FABRICATION
11
ASSEMBLY LINE
13
16
Software AG
14
CYBER SECURITY
15
AT&T
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AUTODESK
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DISCOVERY LAB
METROLOGY
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UTILITY
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SIEMENS PROCESS DIGITAL TWIN DEMO
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FAST RADIUS
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The following is a summary of Partners, Projects and MxD demonstrations (color coded under ‘Type’) currently or committed on the floor. There is not only a variety of types but also a broad technologies and ideas that are demonstrated and made real on the factory floor. The layout references correspond to the 2020 layout on the previous page.

| Layout Ref | Type | Name | Description |
|---|---|---|---|
| 1 | MxD Demo | MxD Discrete Cell | This cell machines an MxD token, collects data and demonstrates digital manufacturing concepts at a CNC work center. Multiple use cases are embedded in this cell while using common equipment |
| 2 | MxD Demo | Future - MxD Welcome Center | Concept is for a visitor customize their own token from options and have it produced real-time while data is collected. Digital Thread and automation |
| 3 | Project | CNC Retrofit Kit | 15-14-09 Perisense Bottom-Up Plug-and-Play Hardware/Software Toolkit for Monitoring, Diagnostics and Self-Correction. Vibration, temperature and speed were monitored and reported. |
| 4 | Project | CNC Predictive Maintenance | 16-04-01 Utilizes existing machine data from MTConnect to predict maintenance requirements for the CNC machine |
| 5 | Partner | Microsoft - in design | Construction planned for late summer 2020 |
| 6 | Project | Visual Digital Retrofit kit | 16-02-06 Convert analog dials, gauges, switches and other analog indicators to a connected, continuous digital readout using low cost |
| 7 | Project | Rapid CNC Prototyping | 16-03-01 Rapidly produce CNC machines prototype parts out of raw, cast, extruded, and forged material. This project significantly reduces the time and skill needed to go from CAD model to NC code that runs the CNC machine and produces the prototype part |
| 8 | Project | Sensor Digital Retrofit kit | 16-02-03 Collect data from legacy machines using low cost hardware. Digital solutions can have very economical hardware solutions driven by software to provide an innovative solution to |
| 9 | Equipment | MxD Fabrication Area | Includes CNC machines, 3D consumer printers, 3D industrial printers, a laser and associated equipment used for a variety of production and post processing needs |
| 10 | Project | Cloud Control & Monitoring | 15-06-01 Utilizes the Cloud to download files to a 3D printer and monitors the printing progress from a remote location. Can also be used to schedule and coordinate activity on multiple printers. |

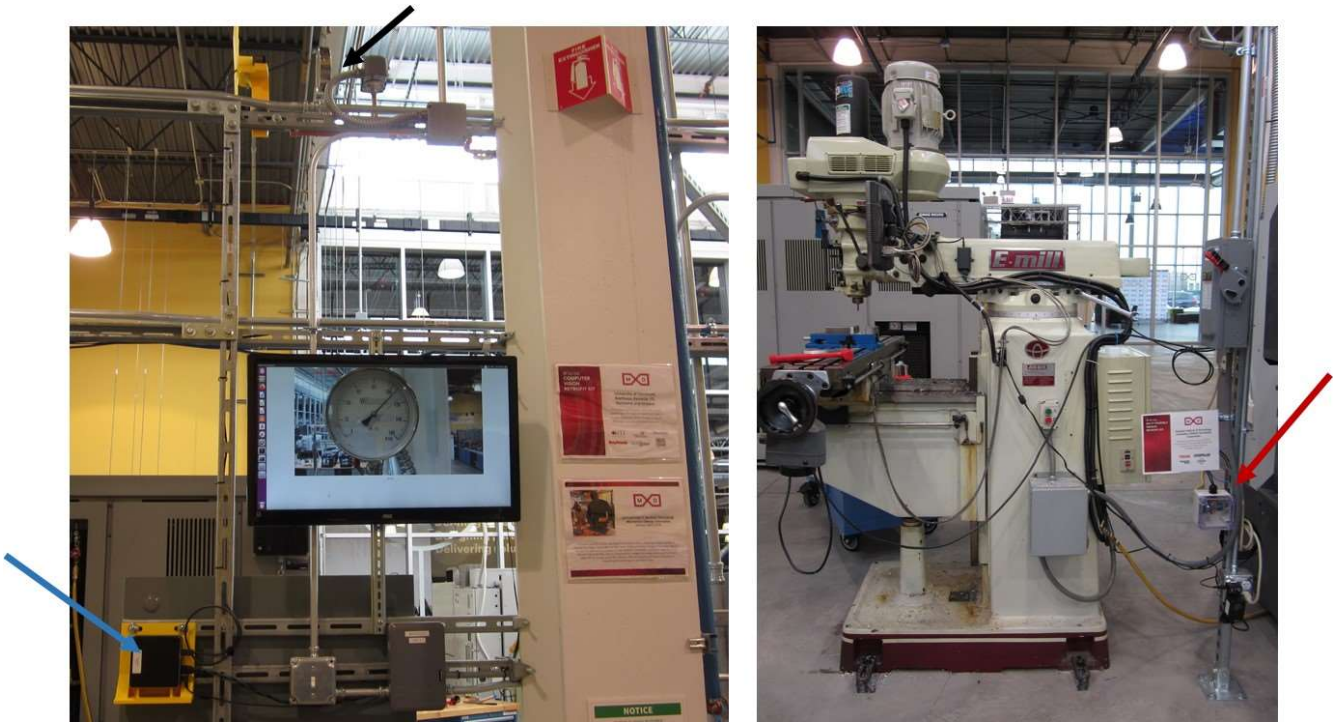
| Layout Ref | Type | Name | Description |
|---|---|---|---|
| 11 | Partner | Covisus Digital Thread Verification | This station is used to show how registered tokens can be verified to be authentic. Demonstration of a digital thread of production data tied directly to |
| 12 | Partner | Part of Microsoft space | MxD Tool Crib moved to back space to expand Microsoft demonstration |
| 13 | MxD Demo | MxD Assembly Line | Digitizes a manual assembly line while collecting real-time data. Multiple use cases demonstrated |
| 14 | MxD Demo | Cyber Security demonstration wall | Demonstrates how software and hardware can protect a PLC from intrusions. Utilizes NIST wheel to describe how hardware and software align to Identify, Protect and Detect |
| 15 | --- | Open for Cybersecurity dem | Open area for additional Cybersecurity |
| 16 | Partner | Software AG | Under development; Software AG demonstration of their enterprise software technology that connects, integrates and analyzes data. |
| 17 | Partner | AT&T | Under construction; AT&T demonstration will have a local 5G network interface with several use cases for real life applications and solutions. |
| 18 | --- | Open | Future partner space |
| 19 | WFD | MxD Learning Discovery Lab | Holds up to 18 people (including the instructor) for learning in a classroom environment on the factory floor. |
| 20 | Equipment | Metrology Lab | On the other side of the MxD Learning Lab. Variety of instruments for measurements including a Zeiss Prismo CMM (Coordinate |
| 21 | Project | Digital Thread CMM demonstration | 15-11-08 Demonstrates the automation of the inspection plan and execution of a master model part. This enables traceability of engineering data through the development of a standard data |
| 22 | Partner | Autodesk | AutoDesk utilizes their space to show various parts designed using Fusion 360 generative design software along with the fabrication equipment for a complete design to build cycle. |
| 23 | MxD Demo | MxD Cyber Process skid | This area is designed for six separate skids with the first being MxD cyber process skid that not only provides data from up to 28 embedded sensors but also demonstrates NIST Detect, Respond and Response to an intrusion |
| 24 | Partner | Siemens | Process Digital Twin demo; sensors along the conveyor capture data that is then used to update |
| 25 | | | |

| Layout Ref | Type | Name | Description |
|---|---|---|---|
| **26** | Partner | Fast Radius | Under development; Fast Radius demonstration of their additive manufacturing solutions and capabilities. |
| **27** | Partner | Vision3 | Virtual Reality exploded view of a Rolls-Royce jet engine that the wearer can interact with real-time |
| **28** | Partner | ScopeAR | Augmented Reality that shows content creation and interaction using a tablet or Hololens |
| **29** | --- | Open | Future partner space |
| **30** | Partner | McKinsey | The DCC (Digital Capability Center) is used by McKinsey to demonstrate the differences between an 'analog' factory and a digital version of the same operation. The operation is run in 'analog' mode with the audience observing and taking notes and then transformed to 'digital' so the before / after value of 'digital' is clear. |
| **31** | Partner | Siemens | Multiple use cases and experiences including in-depth demonstration of Siemen's PLM (Product Lifecycle Management) solutions as well as Mindsphere IoT solution that can connect across the entire supply chain with details and scenarios. |
| **32** | backspace | Storage & equipment | Used for MxD tool crib, equipment storage and other. Possible future expansion of the Factory Floor |

The following images are samples of some of the MxD demonstration cells, projects, and partner spaces on MxD's Factory Floor. There is a focus on demonstrating use cases and solutions to common problems experienced through manufacturing facilities.

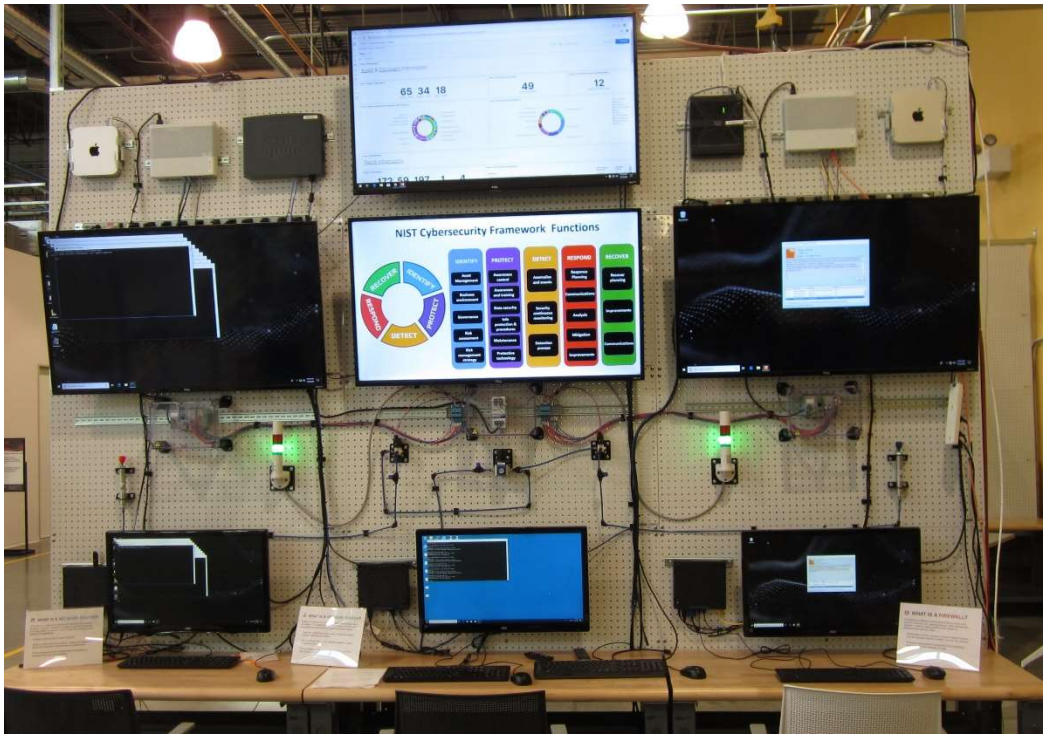
The MxD Discrete Cell (layout reference #1) demonstrates multiple use cases with a focus on sensors to collect basic data and how to use that data for quality trends, maintenance, and statistical control. Multiple partners' technology is also incorporated into the cell.


Two projects (16-02-06 and 16-02-03) demonstrate low-cost solutions for digitizing analog legacy equipment.



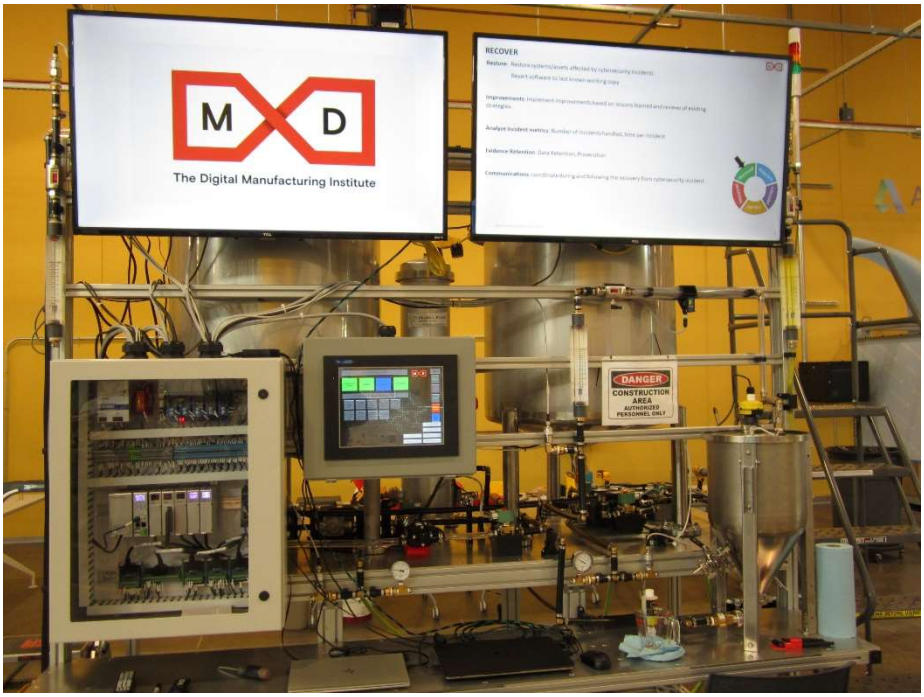

The MxD Assembly Line (layout reference #13) demonstrates a digital manual process. Multiple use cases are included along with partner technologies. As noted in the photo above, we demonstrate digital technologies on both the latest high-tech equipment as well as decades old legacy equipment found today in factories across the United States.

The MxD Cyber Wall (layout reference #14) demonstrates how hardware and software can be implemented to provide “Identify, Protect, and Detect” for industrial controls such as PLCs (Programmable Logic Controllers).




The MxD Learning Discovery Lab (layout reference #19) provides a classroom environment to discuss beyond the ‘what’ that is demonstrated and discussed on the Factory Floor to focus on the ‘how’ to go digital or any other relevant topics.


The MxD Cyber Process skid (layout reference #23) provides two functions with first of running a continuous process with up to 28 data streams that can be monitored for maintenance or other purposes. The second purpose is to demonstrate “Detect, Respond, and Recover” from an intrusion.




## R&D Technology Transition

In its first five years, MxD has invested more than $90 million of public and private funds in 63 projects with targeted outcomes between Technology Readiness Levels (TRLs) four through seven. MxD’s

projects bridge the gap in the innovation "valley of death" (as referenced in Figure B previously), so named because of the high number of innovative concepts and ideas that fail when crossing from public sector research to private sector commercialization. Successfully bridging this valley will accelerate the adoption of innovative technologies in manufacturing, providing competitive advantages to the early adopters. For broad market adoption, technology must complete the rest of the innovation journey and transition to fully commercialized solutions maintained and supported by independent, often private-sector organizations.

MxD's mandate for this Cooperative Agreement did not include the commercialization of project outcomes which severely limited our ability to invest in successful projects to ensure that they achieved TRL level 9 or full commercialization. Despite this limitation, MxD has supported technology transition through four paths: alternate funding, member organization internal development, member pilot programs, and independent commercialization.

- **Alternate Funding:** In 2019, MxD engaged with venture capital investment groups to discuss funding the commercialization of outcomes from the 63 projects. Although there is interest in this path, the VCs were brought into the discussion too late for any of the current portfolio. MxD has added IP reviews to our project management phase gate process to identify commercialization opportunities early on in order to engage the VCs appropriately. MxD was able to successfully secure $250k of additional funding through ManTech (OSD) to continue development of project **17-04-01: Docent - Digital Application for Manufacturing Readiness Level Assessments** to implement customer-specific enhancements with the ultimate goal of standing up a group of product owners within the MRL Working Group.
- **Member Organization Internal Development:** For some projects, the Tier 1 & 2 team participants continue to develop the project IP internally for research purposes as permitted under the membership agreement. Although members are not required to share these improvements back to other members or even make MxD aware of this work, we are aware of some such cases. An example is project **14-07-02: Integrated Manufacturing Variation Management** where Caterpillar continued development on some of the core software and expanded use cases to include additional scanning options.
- **Member Pilot Programs:** Tier 1 and 2 project participants will sometimes pilot successful project outcomes within their organizations to further test the developed solution against an actual production line versus the controlled environment often used within a project. Again, members do not always tell us about these pilot programs, nor do they always share the results because they are not willing to share the outcomes and learnings from this unfunded work with the rest of MxD's membership. An example of this is project **15-11-08: Capturing Product Behavioral and Contextual Characteristics through a Model-Based Feature Information Network (MFIN)** where project participants Lockheed Martin and Rolls-Royce planned to pilot the developed solution on one or more product lines within their factories. With the outbreak of COVID-19, all these pilots are currently on hold, but we hope that they will be revived.
- **Independent Commercialization:** For many members, this is the ideal technology transition path. An independent organization commits to completing development on the project developed IP to bring it to TRL 9 and provides ongoing maintenance and support for the product in the future.

Manufacturers could then adopt the solution without having to fund the commercialization of the IP. An example of this is project **15-14-09: Bottom-Up Plug-and-Play Hardware/Software Toolkit for Monitoring, Diagnostics and Self-Correction**, where a project participant from NCMS launched a startup, Perisense (www.perisense.io), to commercialize the project outcomes.

## V. OUTREACH AND ENGAGEMENT

### Innovation Ecosystem (conferences, events, public forums)

Over the past several years, MxD has developed a robust innovation ecosystem and become a leading voice in the national conversation around advanced manufacturing. In addition to contributing expertise and insights to national and international conferences, MxD has developed its own thought leadership platforms by hosting high-profile events and honing its content strategy and digital presence.

MxD has had regular involvement in landmark manufacturing, aerospace and defense, and technology conferences including the International Manufacturing Technology Show (IMTS), Hannover Messe, FABTECH, and the Defense Manufacturing Conference (DMC). Sharing the stage with luminaries in academia and industry, MxD has presented on its research and development portfolio and trumpeted the successes of its partner collaborations.

On a day-to-day basis, MxD welcomed members and guests for trainings, tours, and other programming, leveraging its unique gathering space for groups of up to several hundred. The appeal of the space has attracted a full spectrum of visitors: Partners including Microsoft and Siemens have held signature events utilizing the entire facility, and students and trainees from middle school through young adulthood have experienced the manufacturing floor through interactive field trips.

At events celebrating the launch of the institute, the opening of its innovation center and future factory, the announcement of the National Center for Cybersecurity in Manufacturing, and the rebrand and renewal of its contract, MxD has attracted the involvement of dignitaries and high-level executives. United States senators and congressmen, Illinois governors, Chicago mayors, C-suite leadership from manufacturing and technology companies, university leadership, and Defense Department and other executive agency officials have participated in press conferences and other MxD-hosted public events.

*MxD CEO Chandra Brown leads the celebration of the launch of the new brand in March 2019.*

MxD has received coverage of its announcements by a range of business and technology reporters and contributed to articles on manufacturing, cybersecurity, workforce development, and other topics as subject matter experts. Working closely with corporate, academic, and non-profit partners has allowed MxD to access media markets across the country and to appear in dozens of publications.

MxD's digital presence has grown substantially, with thousands of followers and active engagement across social media platforms. In 2019, coincident with the shift from the legacy name of DMDII to the current "manufacturing times digital" brand, MxD launched a revamped website. The website has served as a channel for delivering resources to stakeholders such as RFP opportunities, event and webinar registrations, and, more recently, specifications for face masks so that members of the community can contribute to the production of personal protective equipment (PPE) for healthcare workers treating COVID-19 patients.

In 2020, MxD has developed a content strategy that uses short, informative videos; an advice column for manufacturers starting their digital journey; and profiles of manufacturing workers to convey the value of digital manufacturing in an accessible way.

Along the way, MxD has received recognition for its Innovation Center and role in the community including:

- National Association of Manufacturers Manufacturing Leadership Award; Artificial Intelligence and Advanced Analytics Leadership Category, 2019
- Manufacturing Leadership Award; Talent Management Leadership Category, 2018
- Executives' Club of Chicago; Corporate Innovator of the Year, 2017
- Chicago Inno 50 on Fire Award; Civic Category, 2016
- Urban Land Institute; Chicago Vision Award Program Category, 2016
- Chicago Commercial Real Estate Awards; Special Achievement of the Year, 2016
- CoreNet Global Chicago Chapter REAL Awards; Project of the Year, 2015
- American Institute of Architects (AIA) Chicago; Design Excellence Award, 2015

## Strategic Partnerships

MxD developed a multi-faceted engagement approach that encompasses government, industry, and academia in order to best serve the U.S. manufacturing sector. In its first five years, MxD built a network of approximately 300 members and strategic partners and identified a tiered partner structure that provides specific and unique benefits to different organizations based on their role in the manufacturing realm. Each tier of membership has been structured to serve the needs of individual members, resulting in an ecosystem that includes startup manufacturing technology providers, non-profit organizations, academic institutions, standards bodies, government organizations, SMMs, and multi-national manufacturing leaders.

The benefit of working with MxD is clear: MxD leverages its position as a public-private partnership to invest in digital manufacturing solutions that enhance the competitiveness of U.S. manufacturers. The success of the Institute has attracted many organizations, some of which do not fit clearly into the membership model and, as such, MxD has developed a robust network of strategic partners. A prime example of this type of relationship is the NIST MEP National Network. With 51 centers across the U.S. and Puerto Rico, the MEP National Network reaches thousands of SMMs, many of which don't have the opportunity to attend MxD convenings or participate directly in federally funded R&D projects. MxD, chartered with advancing the small- and medium manufacturers across the nation, developed a strong relationship with the MEP National Network, both at the level of individual centers as well as at the overarching NIST level. MxD is able to provide expertise and resources to SMMs about digital manufacturing capabilities and cybersecurity for IT and OT systems through the regional MEP centers, ultimately leveraging another government network to expand MxD's reach.

Similarly, MxD has identified and built relationships with other organizations that provide resources to the manufacturing community, such as ARC Advisory Group, P33, ISACA, and various manufacturing associations across the U.S. By partnering with these organizations, MxD is able to expand our footprint in the manufacturing sector, provide additional resources to our members that are outside of the scope of our funded efforts, and encourage national collaboration for manufacturing initiatives.

## Government Engagement

National defense strategy calls for increased and sustained investment, innovation, and discipline from all aspects of America's Defense Industrial Base to guarantee the nation's ability to compete in an increasingly complex security environment. This environment is defined by rapid technological change that has allowed both revisionist-state adversaries and non-state actors to challenge America's long-standing military and economic dominance. The proliferation of knowledge and technology is eroding America's historic advantage, creating a hyper-competitive technology environment where the discriminators are speed and cycle time.

As the Department of Defense's Digital Manufacturing Institute and National Center for Cybersecurity in Manufacturing (NCCM), MxD prioritizes core elements of the National Defense Strategy to sustain technological overmatch in the face of increasing economic and technological competition from China and other revisionist powers. In its role, MxD accelerates the technical direction of DoD while championing and pursuing new capabilities, concepts, and prototyping activities in digital manufacturing and engineering for America's manufacturing base. Utilizing a holistic system of systems approach – engaging technology, people, and systems in tandem – MxD is the only DoD-funded Manufacturing Innovation Institute that is solely focused, from end to end, on the digital thread (the single, authoritative source of truth tying together facts and insights about an enterprise's products and systems).

Additionally, MxD is focused on directly supporting *Presidential EO 13806 on Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency* of the United States, while aligning with several DoD modernization priorities, to include artificial intelligence and machine learning, digital twins, cybersecurity, hypersonics, 5G, and workforce development. In order to maintain America's technical advantage, MxD – with its members from industry, academia, non-profits, and government – works hard to bolster these modernization efforts by piloting new acquisition pathways and concepts of operation while accelerating capabilities to the warfighter.

MxD's mission is to empower the near-real-time decision making capability – not just for DoD, but America's manufacturers writ large – by accelerating the adoption of digital technology and resilient cybersecurity in manufacturing. This requires more than research; it requires a cultural change as well. A critical component of this effort is formalizing the development, integration, and use of models to inform enterprise and program decision making; provide an enduring, authoritative source of truth; incorporate technological innovation to improve the digital engineering practice; establish a supporting infrastructure and environments to perform activities, collaborate, and communicate across stakeholder groups; and transform the culture and workforce to adopt and support digital manufacturing and engineering across the lifecycle.

Moving forward, as the largest DoD Manufacturing Innovation Institute with over 50 employees with diverse experiences in R&D and advanced manufacturing, MxD is positioned to play a dynamic, focused, and creative role in the Department of Defense's modernization efforts, specifically as it applies to defining standards, governance, and processes that promote the integration of digital technology while working to address roadblocks to transitioning America to more advanced, digital manufacturing.

## Office of the Secretary of Defense (OSD)

In March of 2018, in partnership with OSD, then DMDII (now MxD) announced the launch of the National Center for Cybersecurity in Manufacturing (NCCM) with $1M in seed funding from OSD to invest in high priority initiatives. During the Stand-up Phase (first 12 months), DMDII set out to establish an advisory committee, develop a DMDII cybersecurity roadmap, integrate high priority use cases onto the Future Factory, and develop both an in-person and remote training experience.

DMDII's 2018 National Center for Cybersecurity in Manufacturing activities included:

- Recruitment and hiring of the appropriate cyber professionals to support and execute programmatic activities
- Fostering relationships with a wide array of stakeholders including but not limited to NIST MEP program, ISACA, Y-12 National Security Complex, and Sandia National Lab
- Development and execution of a Cyber for Manufacturing Workshop
- Development of an initial proposal including initiatives that could be undertaken by the Center during the first 5 years of operation

As DMDII transitioned to MxD in 2019, the institute made a concerted effort to pair DoD government stakeholders with select R&D projects to expand the value the institute delivered to DoD. In order to achieve this, MxD targeted DoD program offices to identify project opportunities that increase warfighter readiness and diversify the relationships within the military services throughout the year. This manifested itself in several ways with MxD hiring a dedicated Government Engagement Manager in October 2019.

MxD further strengthened its relationships with the Air Force Research Lab (AFRL) and the Office of Naval Research (ONR) with members of both service labs participating as technology advisors on multiple projects and MxD committees. Additionally, MxD partnered with multiple arsenals within the Army Material Command (AMC) to conduct digital manufacturing needs assessments (DNAs), project calls, and targeted workshops focused on improving AMC Performance to Promise (P2P) output and maximizing immediate warfighter impact.

## Army Material Command (AMC)

In 2017, then DMDII (now MxD) provided direct project support to AMC component command Joint Manufacturing Technology Center (JMTC) at Rock Island Arsenal (RIA) on an initiative to transition to Net-Centric Model Based Enterprise (NCMBE) within the Army organic industrial base. As a strategic priority at RIA, this initiative continued into 2018.

Phase 1 of this initiative contracted a team of organizations to conduct a capability assessment to determine and document the baseline for RIA using the MBE Capability Index and provide recommendations for "Next Step" activities. This effort was completed in May of 2017.

DMDII's 2018 activities with RIA focused on coordinating a team to execute on recommendations that were outlined in Phase 1. The coordinated follow-on activity addressed 3 recommendations: 1) Creation

of a 3D CNC Tooling Library, 2) Product Lifecycle Management road-mapping, and 3) Light weight model visualization.

In 2019, MxD began targeted outreach, digital needs assessments, and project planning at Rock Island Arsenal, Pine Bluff Arsenal, and Crane Army Ammunition Activity (CAAA).

In late April 2019, with the goal of identifying problem areas and recommending improvements, members of the MxD engineering team visited **Pine Bluff Arsenal** in Arkansas to conduct a broad-based assessment and fact-finding mission focused on the Red Phosphorus Pellet production process.

The team identified several challenges facing efficient production of pellets, with variability in all supply sources playing a major factor in production delays. In fact, MxD concluded that variability in any or all of these sources impacted yields to such a degree that consistent, stable production of pellets was more a product of habit than quantitative analysis of the production process. In collaboration with members of the red pellet production team, MxD engineers outlined a number of improvements.

In August 2019, members of the MxD engineering team visited **Crane Army Ammunition Activity (CAAA)** in Indiana to assess the Countermeasure Flair Production Line and provide direct proposals for digital adoption and process improvement with the goal of increasing production. In moments like these, generally, MxD's goal is not provide specific solutions but to provide concepts and ideas that can be developed, learned and utilized by elements like CAAA across production lines to utilize digital manufacturing for improving yields, downtime, quality and efficiency.

Similar to Pine Bluff, it was clear production at CAAA was a product of yields + downtime + efficiency. The team noted variability in material, process, the environment, equipment, and sometimes people. This prevented consistent production and although some data was tracked, it was rarely aggregated together to capture individual impact on production. MxD made a point of warning that without proper, comprehensive data collection, any changes in process without a root cause analysis of what triggers those changes would have a long-term negative impact on production.

The intent of the recommendations is to provide Crane Army Ammunition Activity with ideas and potential solutions to measure key data and perform quality inspections. Once solutions are implemented, the data needs to be collected and consolidated so analysis can be done. With the sensitivity of the flair production, it is likely that slight variations can contribute to production problems. Understanding those variations and being able to compensate for them will help provide consistent and reliable production.

Additionally, in late 2018 and early 2019, the MxD projects and engineering and engagement teams worked in collaboration with leadership at **Rock Island Arsenal** and production managers at the **Joint Manufacturing Technology Center** to scope two potential projects designed to accelerate digital manufacturing at RIA-JMTC while mitigating specific problems or pain-points at RIA-JMTC.

After discussing multiple pain-points and exploring multiple obstacles to adopting digital manufacturing, RIA-JMTC identified a growing skills and training gap between long-time employees due to retire and new employees as a major problem. The MxD team proposed utilizing augmented reality or virtual reality

technologies as a direct labor multiplier to decrease time and costs associated with machine maintenance and setups while capturing the unique skills of more experienced employees for future training modules. MxD proposed a digital platform that improved comprehension, knowledge retention, and efficacy that would result in higher quality production, faster cycle times, and cost savings for RIA.

For the second pain point, RIA-JMTC noted that as a strategic national resource that is required to maintain certain manufacturing capabilities and capacities outside its normal production chain, it struggled with demand planning. It was determined that too often the nature of some of the high-mix, low-volume production requests that came in to RIA would stretch RIA planning resources to the limit, especially when it came to utilizing its pool of CNC machines efficiently. In response, the MxD team proposed an artificial intelligence solution for capacity planning that would integrate advanced scheduling technologies and methodologies into the RIA production workflow. MxD has proposed leveraging the previously developed asset library and automating the CNC planning process to optimize RIA-JMTC's production scheduling and process planning while ensuring efficient production schedules drove RIA-JMTC's commitment to 100% P2P.

Although these improvements were not selected for funding, the exercise itself strengthened the working relationship between MxD and RIA-JMTC, with numerous engagements – such as workshops, the MxD cyber road show, and projects – scheduled for 2020. These efforts led directly to Congress allocating $9 million for MxD, in partnership with Rock Island Arsenal and Pine Bluff Arsenal, to execute a three-phased technology validation and adoption pilot that will be used as a model to scale advanced manufacturing capabilities across the OIB. Starting sometime in 2020, with project scoping and ideation taking place under the new MxD Technology Investment Agreement (TIA) contract, it is intended that Phase 1 will optimize existing manufacturing processes, such as welding, by prototyping and adopting emerging digital manufacturing technology capabilities to speed production, increase quality, and increase manufacturing efficiencies. Phase 2 supports the demonstration, evaluation, and adoption of the advanced manufacturing technology capability within the RIA manufacturing process with workforce training, workflow mapping, solution vendor evaluation and selection, and integration support. Phase 3 will investigate the transition of the advanced manufacturing technology capability to the Pine Bluff Arsenal to demonstrate that the technology validation and adoption within RIA can be replicated and scaled more broadly across the Army OIB.

## Workforce Development

Enhanced manufacturing processes are only as good as the workforce supporting them. A 2017 report by the Institute for the Future for Dell Technologies cites that 85% of the jobs that today's students will be doing in 2030 haven't been invented yet. A skilled workforce that can design and implement the advancements happening in digital manufacturing is critical to manufacturers' ability to capitalize on the emerging process improvements. MxD Learn, MxD's workforce development arm, focuses on the identification of jobs that are necessary for the future of manufacturing, the training workers need to serve in these future jobs, and the tools those workers need in order to be successful in their roles. MxD Learn projects completed through the Cooperative Agreement set the stage for further buildout of digital manufacturing and cybersecurity curriculum, hands-on and virtual training and awareness activities, career pathways and apprenticeship development, and the extension of regional and national

partnerships to scale MxD programs through innovative technologies, pedagogies and evaluation tools with industry, academic, and government support.

In 2016, through a partnership with the University at Buffalo, MxD Learn developed the first digital manufacturing and design massive open online course (MOOC) providing a “101-style” digital manufacturing curriculum. The nine course modules provide over 40 hours of media and material introducing a range of technologies that use data to connect and improve each stage of the manufacturing process. Developed for both students and workers, the series introduces a broad range of digital manufacturing and design technologies and demonstrates how they can be used throughout a product’s lifecycle. Individual course content, including videos and readings, can be accessed at no cost. Tens of thousands of students across a range of backgrounds and skill-levels have accessed the course since its launch, and it has been incorporated into credential programs at several institutions. The course continues to be offered through Coursera, the world’s largest platform for MOOCs.

In 2017, MxD Learn and ManpowerGroup released a groundbreaking workforce analysis, a jobs taxonomy for digital manufacturing and design (DM&D), that identifies 165 data-centric jobs that will define the future of manufacturing in the United States. *The Digital Workforce Succession in Manufacturing* report is the first to offer such a comprehensive workforce playbook to help companies develop a talent pipeline for existing and future factories. The research includes in-depth profiles for 20 roles that span a range of digital technologies and business practices, such as virtual reality/augmented reality systems specialist. Descriptions for jobs such as collaborative robotics specialist, manufacturing cybersecurity strategist and enterprise digital ethicist give a window into the advanced skills and knowledge needed to put new technology into practice and remain globally competitive. MxD partners and stakeholders are now about to use this information in their workforce planning, including Dow Inc., which referenced the profiles to find the right skills and expertise in cybersecurity and digital thread roles for its Digital Operations Center.

Building from the success of the DM&D jobs taxonomy, and aligned to the institute’s designation as the National Center for Cybersecurity in Manufacturing, MxD Learn partnered again with ManpowerGroup in development and execution of a second taxonomy project, The Cybersecurity for Manufacturing Hiring Guide (Hiring Guide), that is scheduled for release in Summer 2020.

By creating a structure to define and classify the manufacturing industry’s cybersecurity work, the Hiring Guide enables the advancement of workforce development goals across the manufacturing ecosystem: industry, individuals, academia, government and workforce/community development initiatives. The Hiring Guide leverages the NICE Workforce Framework, utilizes the NIST Cybersecurity Framework, and integrates insights and review by subject-matter experts representing over 20 partner organizations across the manufacturing ecosystem. The Hiring Guide will provide manufacturers with the 247 most critical roles for cybersecurity in manufacturing and is complemented by tools such as career progression charts, cybersecurity workforce data analysis, and success profiles of key roles. The project outputs inform strategies for effective cyber and digital workforce planning and education strategies in collaboration with industry, academic, government, and community partnerships.

In 2019, MxD Learn received a $1.25 million private grant from the Siemens Foundation to support the buildout of an advanced manufacturing lab and launch of a new high school curriculum at Waukegan High School in NE Illinois. Over 130 high school students, grades 10-12, enrolled in the first-year cohort. The curriculum combines manufacturing fundamentals in STEM disciplines such as materials science and math, while providing students hands-on learning with digital manufacturing and cybersecurity technologies. The program also establishes career pathways for students through a partnership with a local community college offering dual credit enrollment and an advanced manufacturing apprenticeship program with apprenticeship costs for 24 students supported through the Siemens Foundation. Through the Cooperative Agreement, MxD Learn partnered with RYE Consulting to develop a playbook for implementing and scaling this high school curriculum with additional deployment of curriculum and lab buildouts as well as best practices in career pathway and employment development. Future expansion efforts will also focus on innovative strategies in virtual learning, including online and hybrid course development, AR/VR hands-on learning experiences, virtual internships and apprenticeships.

Throughout the duration of the Cooperative Agreement, the MxD Learn team regularly leveraged resources of the Future Factory, and expertise from across the institute, to host thousands of visitors to MxD for educational and awareness activities related to digital manufacturing and cybersecurity. Workforce development activities in the Future Factory, including national Manufacturing Day, have been implemented for K-12 students, teachers, and community groups; postsecondary and graduate students and professors; internships and career exploration activities for the Opportunity Works program serving under-resourced young adults; summer camps; and professional and executive educational workshops and seminars. MxD Learn continues to leverage the strong partnerships and project outcomes achieved through the Cooperative Agreement to be a national leader in providing effective workforce development solutions across the digital manufacturing ecosystem.