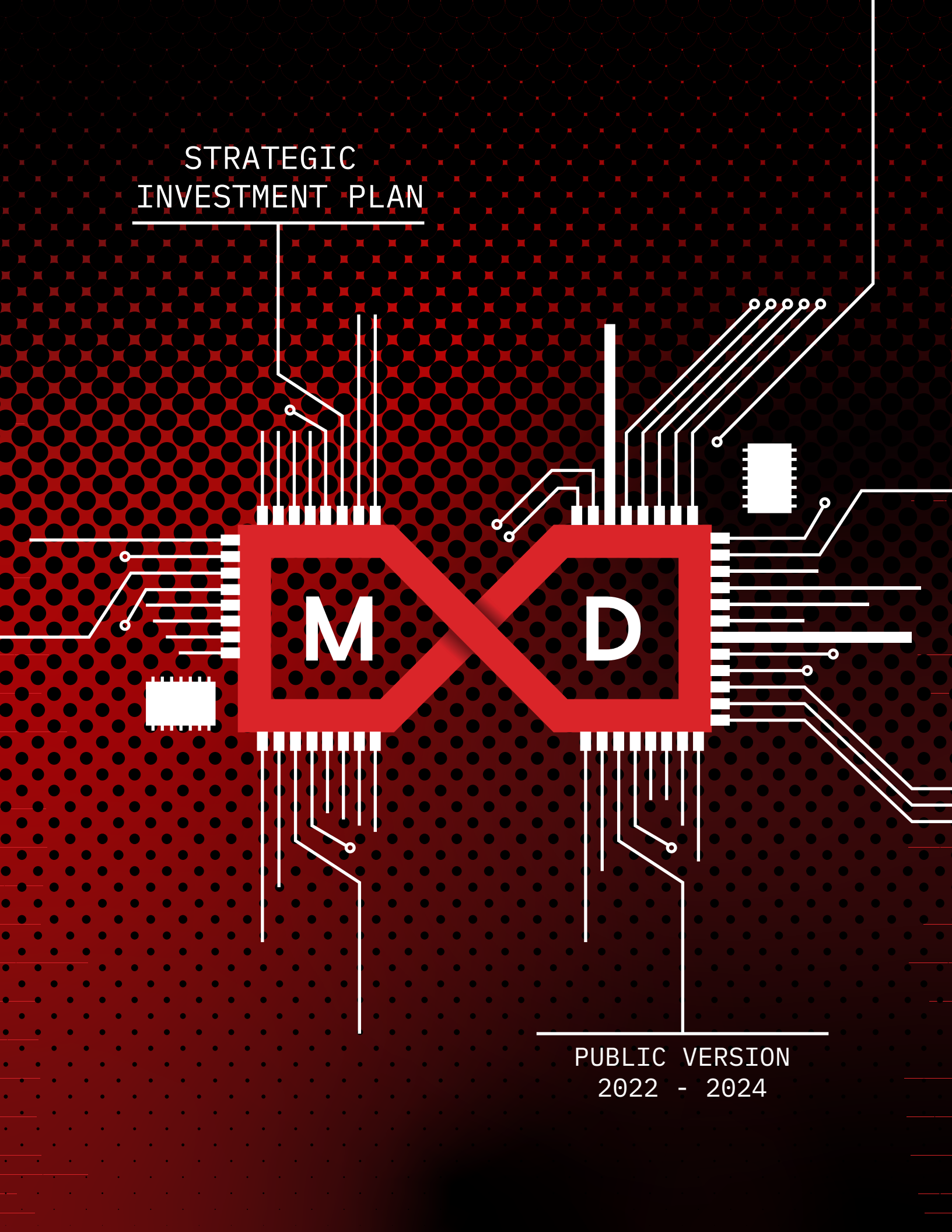
STRATEGIC INVESTMENT PLAN



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The Digital Manufacturing
& Cybersecurity Institute

Strategic Investment Plan

2022-2024

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The document was created in collaboration with MxD's member organizations of manufacturers, solution providers, academics, non-profits, government, and the Department of Defense all focused on advancing domestic manufacturing towards the vision of Industry 4.0. A special thank you to members of the Technical Advisory Committee and Executive Council for their input and review. MxD's goal is collaboration among disparate groups towards a common goal and this document reflects that spirit of collaboration.

Confidentiality

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Message from the CEO

To the MxD Ecosystem:

A look at U.S. manufacturing over the past year reveals a changing industry facing numerous opportunities – and numerous challenges. While supply chain disruptions, labor shortages and cyber threats continue to affect manufacturers and consumers alike, we are also hearing stories of those who have used technology to respond to the issues brought by the pandemic and to innovate out of them.

The same could be said for MxD. Over the past year, we've done more to drive digital technology forward, to increase adoption, to prepare and skill workers and to secure manufacturing operations than ever before – and, as outlined in this Strategic Investment Plan (SIP), we're preparing to supercharge that important work in the year ahead. In many ways, reading this strategy should feel familiar – a renewal of our commitment to tackling some of the biggest challenges facing manufacturers today and preparing them to compete in the decades to come.

Despite the pandemic, the challenges themselves haven't really changed that much. If anything, they are more pronounced. So we're doubling down where it matters to our members and where we stand to move the needle for American manufacturing at this critical time. And we're envisioning what that future looks like.

This is only possible through the partners in this public-private partnership – our members. Your contributions to technology development, to education, awareness, projects, programming and more enable an ever-improving ecosystem that grows and evolves with our members and contributes to a shifting paradigm for American manufacturing competitiveness.

So many contributed to the development of this SIP and we're excited to work on it with you throughout 2022 and beyond. Keep bringing us your ideas – and your manufacturing problems – and let's see what we can get done together.

Chandra Brown

Chandra Brown, CEO
MxD

Executive Summary

MxD's mission is more important today than ever before as the United States continues to concede ground to other nations and major economic regions in the size of the manufacturing industry (measured as value added), in the research and development investments (measured as R&D investments as a percentage of GDP), and in independence of its economy from other manufacturing economies (measured as manufacturing value added as a percentage of GDP). Digital industrial technologies are a major factor in strengthening the U.S. industrial base. The manufacturing industry is slowly adopting and implementing these technologies mainly because of a lack of understanding on their applications and value. This is at the heart of MxD's mission.

To aid in executing the mission, MxD's Technology Strategy group, MxD's members, and others in industry developed a Strategic Investment Plan (SIP) that identifies, defines, optimizes, and prioritizes key commercial and technology areas to mature. It also defines the initiatives for maturation and allocates resources to them. The objective is to maximize the creation of value to the U.S. industrial base, to minimize the time to deliver the value, and to minimize the resource requirements. The Technology Strategy group employs a five-phase approach with multiple inputs, reviews, and approvals by industry, the Technology Advisory Committee, the Executive Council, and MxD staff. The five phases are:

A key deliverable of the process is the technology project concept roadmap that sequences the execution of the project concepts over time. The roadmap is transitioned to MxD's Projects and Engineering group for execution. The execution process consists of five steps: Scoping, Project Down Selection, Pre-Award, Project Execution, and Close Out.

Within the five-phase technology strategic planning approach, MxD developed and applied an approach to predict the evolution of supply chain structures. This is important for MxD and its members because the evolution of supply chain structures affects the adoption of digital technologies. The effects of adoption include the reasons for the digital technologies, their characteristics and functionalities, their application areas, their timing, and their deployment methods. Adoption of manufacturing technologies is a stepwise process. Global supply chains are complex, tiered, and networked structure. Their complexity increases due to increasing demands for product functionality. We observe this increase in complexity in all manufacturing industry segments, such as complex electronics and medical devices, transportation equipment and industrial machinery, and process industries. The extent of complexity and fragmentation in supply chain membership is dictated by transaction costs, rights to supply chain resources, the nature of the resources, and the maturity of the technology. With emergent manufacturing technologies, there has to be a high degree of collaboration to bring all the resources together for success. The ultimate structure of these collaborations depends on the characteristics and type of resources contributed by each supply chain member and on the way the resources are applied.

This is important for MxD and its members because the evolution of supply chain structures affects the adoption of digital technologies.

Additionally, within the planning approach, MxD developed and applied a general method for forecasting the financial effects of digital technology adoption on supply chains as they evolve. The method consists of an economic growth model, a technology adoption model, expected productivity improvements in the supply chain and on the factory floor. The evolving structures of supply chain influence the development and deployment of digital technologies. Fully centralized, digitalized sites sit on one end of the spectrum and fully distributed digitalized networks sit on the other end. The place on this spectrum where deployment occurs depends on factors related to transaction costs, cost of capital, workforce development, asymmetry in labor markets, risk tolerance and dispersion, supply chain responsiveness, types of manufacturing processes, and the extent of engineering modifications. The dominant digitization and automation in supply chains will be for the management of the network. However, factory digitalization and automation will continue to make the localized process more efficient. Advanced planning and optimization systems, digital procurement, and digital twins for virtual certification and conformity assessment are examples of major digital technology deployments that affect the factory floor and the supply network.

Industry will deploy digital technologies at the process (factory) level and at the network (supply chain) level. MxD conducted an analysis of the effects of digitalization on advanced manufacturing to gain some insights into the deployment path for digital technologies. The analysis considered the industry's economic growth model, a technology adoption model, and expected productivity improvements for the process and network from digital technologies. The analysis indicated that deployments of digital technologies in the network would have higher returns, but deployments at the process level will continue. This strategic perspective is available only to MxD members, in the Members Version of this document.

As a key outcome of the planning process, MxD, working with industry members, developed a future state for industry with digital technologies. As a summary, this future state contains seven key characteristics:

- Increasing Supply Chain Complexity
- Increasing Economies of Scope
- Flexible, Modular, Intensified Manufacturing
- Interchangeable Control Systems
- Supply Chain Connectedness
- Increasing Automation
- Security and Privacy

The groups also defined strategic technology elements that enable the realization of the future state. A summary of the strategic elements are Data Management, Virtual Certification and Conformity Assessment, Wireless Process Control and Automation, Virtual Concurrent Engineering Design, Virtual Maintenance, Digitalization of Small and Medium Manufacturers, Interoperability, Process Automation, and OT Cybersecurity. The full future state outlook is another resource available only to MxD members, in the Members Version of this document. MxD Cyber and MxD Learn, the government engagement group, and the factory floor demonstration group bring their respective focus in executing initiatives within the strategic elements.

MxD, again working closely with industry members, employed six criteria and considered six dimensions in identifying and defining the project concepts in its portfolio. The six criteria include strategic fit & importance, competitive advantage, market attractiveness, competencies, technical feasibility, and rewards and risks . The portfolio consists of over 65 project concepts in five categories: Digital Engineering, Future Factory, Supply Chain, Cybersecurity, and Workforce Development. Over 40 project concepts amounting to over $50 million in total investments are scheduled to have requests for proposal from 2022 to 2024.

MxD's Digital Technology Strategy

Strategic Investment Plan

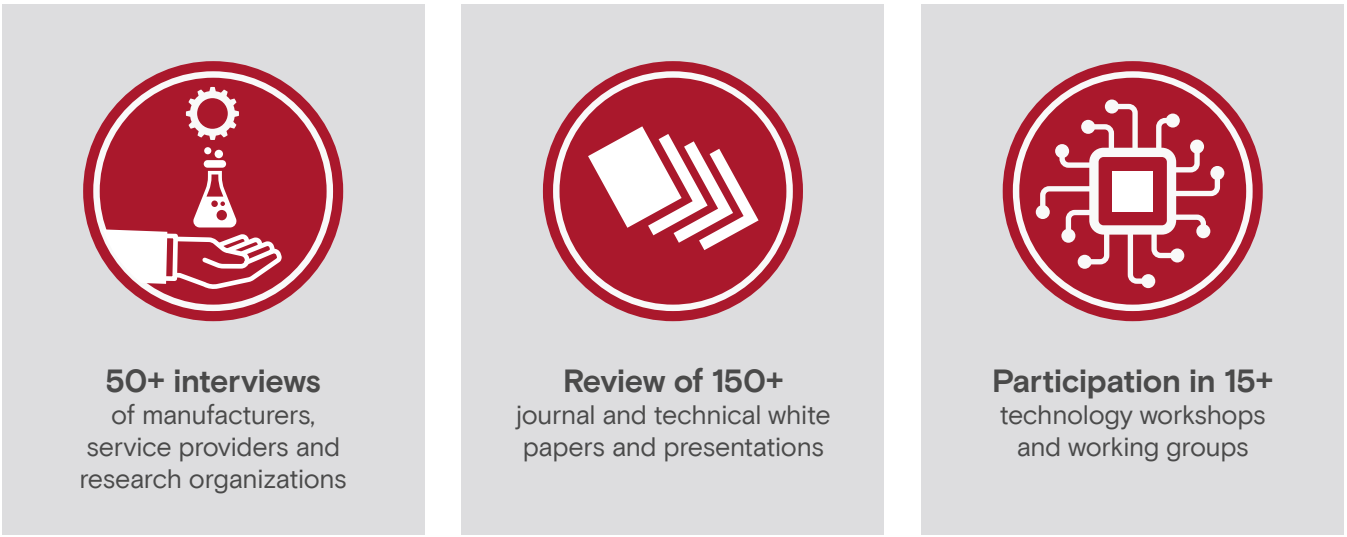
(2022–2024)

Digital Industrial Technology Strategy

MxD crafted a market-driven strategy to foster the adoption of digital industrial technologies across the U.S. industrial base. We adjust the strategy as the technological and commercial landscapes and the competencies within MxD and the member ecosystem evolve. We developed the strategy based on prior Strategic Investment Plans and on intelligence gathered from a broad set of sources (See Figure 1). In 2021, MxD conducted over 50 interviews and two surveys of manufacturers, service providers, and research organizations across the world. We also reviewed over 150 journal and technical papers and presentations on digital industrial technologies. We also participated in over 15 technology workshops and working groups that were led by MxD or other organizations. The strategy consists of a future state of industry and the applications of digital technologies, and the key strategic digital technology elements that enable that future state. As part of the strategy, MxD identified and defined project concepts to address the maturation of the strategic elements. The project concepts are categories of initiatives that have the largest and fastest influence in maturing the strategic elements. The initiatives include research and development, training and education, technology demonstrations, standards development support, and technical and commercial guidelines.

Figure 1

Technology Intelligence Sources



MxD bounded its intelligence gathering efforts to the effects of digital technologies on the two key industrial processes: Product Lifecycle Management (PLM) and Supply Chain Management (SCM). Figure 2 shows MxD's representation of the PLM process. The process consists of five phases that start at product or process ideation and conclude with retirement and disposal. The figure shows the key steps and activities for each phase. Figure 3 shows MxD's representation of the SCM process. It consists of six phases that start at cross-enterprise planning and end at return of defective or excess products or MRO. Both figures show the mean management spend of a U.S. manufacturer on groupings of phases to provide a relative cost scale. The mean annual revenue of a U.S. manufacturer was approximately $2.7 billion.

Figure 2

Representation of the Product Lifecycle Management Process[1]

PHASE I Product/Process Ideation	**PHASE II** Product Concept Portfolio Management	**PHASE III** Product Development and Realization	**PHASE IV** Maintenance and Sustainment	**PHASE V** Retirement and Disposal
MANUFACTURER MEAN MANAGEMENT SPEND				
$70MM - $150MM		**$60MM - $120MM**	**$20MM - $100MM**	

■ Strategic Innovation Planning
■ Sensing & Discovery
■ External Idea Capture and Response
■ Concept Generation
■ Idea/Concept Screening
	■ Product Concept Portfolio Balancing
	■ Detailed Project Scoping
	■ Business Case Development
		■ Front-End Engineering Development
		  ■ Identify implications & tech concepts
		  ■ Develop capabilities to produce samples
		■ Detailed Engineering
		  ■ Develop capabilities to product prototype components
		  ■ Develop capabilities to produce protype systems
		■ Supply Chain Design
		  ■ Develop capabilities to produce components systems
		  ■ Conduct pilot runs
		■ Supply Chain Management
		  ■ Conduct low-rate initial production runs
		  ■ Ramp to full rate production
			■ Criticality analysis of system
			■ Conduct historical analysis
			■ Optimize maintenance approach
			■ Collect equipment data
			■ Perform maintenance
			■ Update strategy
				■ Determine useful life and depreciation
				■ Assess obsolescence and replacement costs
				■ Determine expected maintenance and sustainment costs
				■ Determine recycle, salvage, and disposal costs
				■ Economic analysis to determine disposal

1 American Productivity and Quality Center, Supply Chain Benchmark Database, **https://www.apqc.org/**

Figure 3

Representation of the Supply Chain Management Process[2]

PHASE I Cross-Enterprise Planning	**PHASE II** Intra-Enterprise Planning	**PHASE III** Source	**PHASE IV** Make	**PHASE V** Deliver	**PHASE VI** Return (defective/MRO/excess)
MANUFACTURER MEAN MANAGEMENT SPEND					
$18MM - $85MM		**$8MM - $48MM**	**$35MM - $50MM**	**$37MM - $218MM**	
Develop and establish courses of action over time periods across enterprises that project appropriation of resources to meet requirements for the longest time fence constraints.	Develop and establish courses of action over time periods within enterprises that project appropriation of resources to meet requirements for the longest time fence constraints.	■ Identify sources of supply ■ Select final supplier and negotiate ■ Schedule product deliveries ■ Receive product ■ Verify product ■ Transfer product ■ Authorize supplier payment	■ Finalize production engineering ■ Schedule production activities ■ Issue sourced/in-process product ■ Product and test ■ Package ■ Stage finished product ■ Release product to deliver ■ Waste/surplus management	■ Obtain & respond to RFP ■ Negotiate contract ■ Order, commit, & launch ■ Schedule installations ■ Build loads ■ Route shipments ■ Select carriers ■ Receive product ■ Pick, pack, load, & ship product ■ Receive product by customer ■ Install product and invoice	Return and disposition determination of defective products as defined by the warranty claims, product recall, non-conforming product and/or other similar policies including appropriate replacement.

MxD conducted a survey of industry to gauge the potential impact of digital technologies on the phases of the PLM and SCM processes. Figure 4 shows the proportion of total respondents to the question: "For which phases of the Product Lifecycle Management process will digital technologies create the most value?" The results showed that digital technologies are critical for all phases of the PLM process. Phase III: Product Development and Realization and Phase IV: Maintenance and Sustainment were the top two with 32% and 25% of respondents, respectively. Figure 5 shows the proportion of total respondents to the question "For which phases of the Supply Chain Management process will digital technologies create the most value?" The results

2 American Productivity and Quality Center, Supply Chain Benchmark Database, **https://www.apqc.org/**; Association for Supply Chain Management, SCOR Model, **https://scor.ascm.org/processes/introduction**

showed that digital technologies are critical for all phases of the SCM process. Phase III: Source and Phase IV: Make were the top two with 23% and 22% of respondents, respectively. The two surveys clearly showed that product design, factory floor operations, and the execution of the sourcing of input materials were the highest priority areas for industry.

Figure 4

Survey Response to Prioritization of PLM Phases

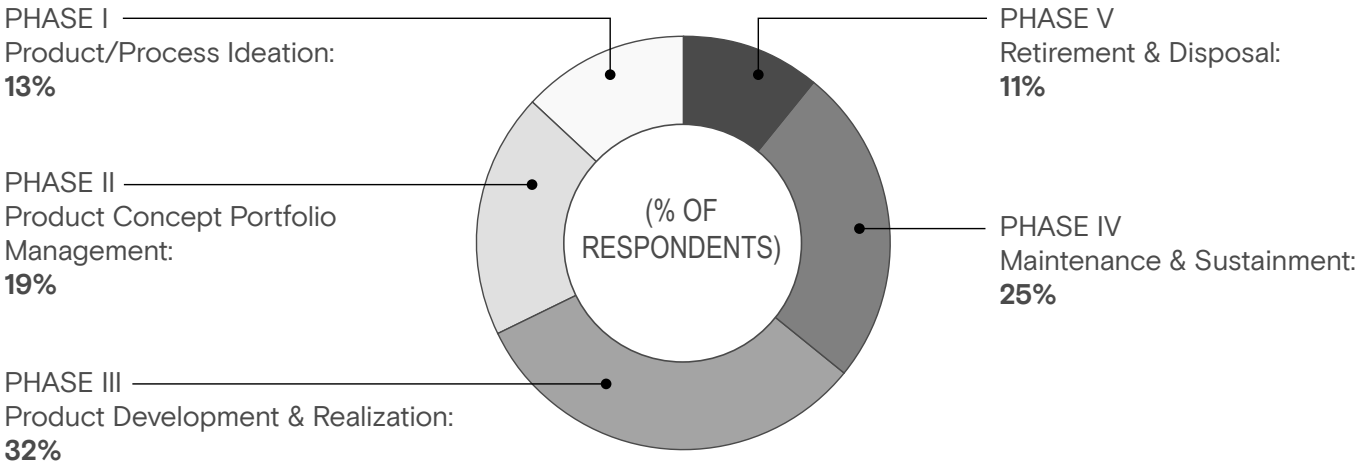
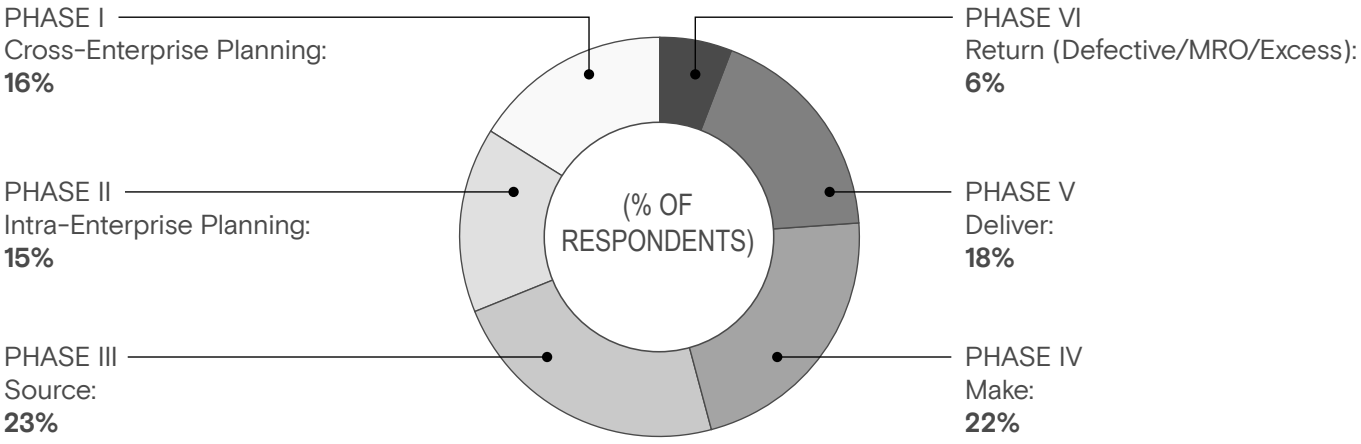


Figure 5

Survey Response to Prioritization of SCM Phases



MxD synthesized all the intelligence it gathered on the market segment trends, the evolution of supply chain structures, and digital technology maturation to form a future-state of the U.S. industrial base considering digital technologies. We summarize the key elements of the future-state below. These key elements broadly define what the future state looks like and orients MxD and the membership in a general direction that ensures value creation and delivery is maximized.

- [illegible]
- [illegible]
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Available to MxD members

- [illegible]
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MxD Cyber: Cybersecurity Strategy

MxD in its role as the National Center for Cybersecurity in Manufacturing, has grown its cybersecurity efforts in response to the rising security events experienced by the manufacturing sectors. Manufacturing is the fastest growing market for cybersecurity risk, moving from eighth to second place in the number of security incidents recorded in 2020 according to an IBM threat intelligence report. Manufacturers face unique challenges when it comes to securing their assets because of the need to secure both their information technology (IT) and their operational technology (OT) systems. Adding to the complexity of securing the manufacturing ecosystem, OT is increasingly susceptible to cybersecurity threats with ransomware, remote access trojans (RAT), and insider threats contributing to over 60% of all observed cybersecurity attacks.[3]

Many large manufacturers have initiatives in place to secure their assets, often dedicating significant resources to uncover and eliminate critical vulnerabilities in their IT and OT systems. But large manufacturers must also rely on a network of small and medium manufacturers (SMMs) to deliver critical components and would face a major crisis if their suppliers were comprised in a cyber-attack. SMMs often lack the people, time, and money needed to properly protect themselves and, as a result, create vulnerabilities across the entire supply

3 IBM Security, X-Force Threat Intelligence Index 2021, **https://www.ibm.com/downloads/cas/M1X3B7QG**

chain. As digital assets replace paper for transferring designs to sub-contractors, it becomes even easier for a competitor or a foreign nation to steal critical IP. The challenge this presents is immense. Of the 271,254 total U.S. industrial firms (NAICS 21, 22, 31, 32, 33) in 2018, SMMs, defined as those employing less than 500 people, comprise 98.3 percent. If SMMs are not secure, the entire supply chain is put at risk: a chain is only as strong as its weakest link.

As digital technologies are adopted by these small manufacturers, awareness of the risks – specifically cybersecurity risks inherent in digital technologies – is an increasingly important mission for MxD. It is critical for manufacturers to understand what and where their vulnerabilities are so they can protect themselves and mitigate any risks. MxD's 10,000 Manufacturers Awareness Campaign is a national initiative to educate manufacturers on cybersecurity risks. A multi-media approach is being developed to reach manufacturers big and small with relevant content geared towards manufacturers. This digital content is delivered via a series of webinars, virtual workshops, advice columns, and articles.

In partnership with MxD's membership base and the Manufacturing Extension Partnership (MEP) regional affiliates, the Cybersecurity Roadshows initiative will target hundreds of SMMs and will be offered virtually and in-person through regional pockets across the United States to reduce the burden of travel for SMMs. The Cybersecurity Roadshows will focus on overall awareness building for the manufacturing base and will help SMMs understand what steps can be taken to increase their cyber hygiene.

While there are many commercial offerings available to secure IT infrastructure, solutions for securing OT infrastructure are not broadly available.

While there are many commercial offerings available to secure IT infrastructure, solutions for securing OT infrastructure are not broadly available. When available, these tools are often expensive and difficult for an SMM to implement. There is a need for simple, easy-to-use tools that provide SMMs with the ability to determine their cyber risk and offer best practices on how to mitigate those risks. It also allows large manufacturers to better understand the vulnerabilities present in their supply base. As the DoD makes the Cybersecurity Maturity Model Certification (CMMC) mandatory for all DoD programs, the need for a practical cybersecurity solution and pre- or self-assessment instrument becomes more urgent. The MxD Marketplace will provide an easy to use and cost-effective foundation for small and medium manufacturers to assess their current cybersecurity compliance against NIST standards, identify any gaps, and formulate a plan to address the gaps including and identification of solutions and solution vendors uniquely tailored to meet the requirements of CMMC.

With the recent announcement of CMMC 2.0 from the DoD, the burden on manufacturers to demonstrate compliance to the CMMC requirements with third-party certification has been eased. Self-assessments are now possible for companies seeking Level 1 and a subset of manufacturers seeking Level 2 compliance

under the amended CMMC 2.0 program. While this change reduces the potential cost and timeline for compliance evidence, the need to conduct thorough and diligent self-assessments remains critical, particularly considering the increasing need to improve the security hygiene of the US manufacturing supply chain. Small and medium manufacturers will see increasing demand for cybersecurity assessments by their downstream customers. The need to have evidence-based assessment remains important. The MxD Marketplace will offer CMMC assessments, as well as others including NIST Cybersecurity Framework (CSF) and SP800-171 and facilitate compliance with CMMC 2.0 by offering tools and services to mitigate the security gaps identified by the assessments. MxD Cyber and MxD Learn continue to create a workforce development program with curriculum focused on training the next generation of manufacturers in cybersecurity. MxD Virtual Training Center underdevelopment with our partners UMBC and Drexel is a web-based, training portal that includes digital engineering courses, introductory cybersecurity curriculum, and advanced topics including cloud computing courses, artificial intelligence, business analytics, and others, all with the focus of upscaling and increasing the workforce skillset. For additional information, see the MxD Learn section of our Strategic Investment Plan

Small and medium manufacturers will see increasing demand for cybersecurity assessments by their downstream customers.

MxD Cyber continues to look for ways to build partnerships that could positively impact MxD's membership and the broader manufacturing ecosystem. In October 2020, MxD launched the Cybersecurity Steering Committee (CSC) comprising leading private sector and government cyber experts and end-users to guide the development and execution of MxD's cyber program. The CSC supports the identification and prioritization of projects within the MxD Cyber portfolio to continue our efforts to improve the cybersecurity posture of SMMs.

The 2022-2024 SIP sets out an ambitious and urgent set of project investments to provide the manufacturing industry with the tools and skills they need to be secure. The outline of MxD Cyber's 2022-2024 project execution strategy is shown in the Project Concept Portfolio section.

MxD Learn: Workforce Development Strategy

MxD's workforce development program, MxD Learn, fosters collaboration across industry, academia, government, and non-profit leadership to ensure the current and future workforce is connected to the roles and competencies needed for digital and cybersecurity manufacturing applications. Leveraging the capability and enterprise of industry partners with academic research and government and professional expertise, MxD Learn responds to local, regional, and national needs to bridge and build a more resilient and secure industrial base by equipping the manufacturing workforce for the jobs of the future.

A manufacturing skills gap study conducted by Deloitte and the Manufacturing Institute (2018) found that by 2028, 2.4 million manufacturing jobs are expected to go unfilled due to a skills shortage. This skills shortage could risk $454 billion in economic output in 2028, or 17 percent of US manufacturing's GDP contribution. These numbers are corroborated by industry, with 73 percent of manufacturers identifying the "workforce crisis" as their top concern. Why is it so difficult to find workers to fill these positions? The Deloitte study (2018) identified the "shift in desired skillsets due to the introduction of advanced technologies" and "retirement of baby boomers" as two of the major drivers.[4]

4 https://www2.deloitte.com/us/en/pages/about-deloitte/articles/2018-manufacturing-skills-gap-study.html

Today, impacts of the COVID-19 pandemic have further challenged both manufacturers and the education system across the world. The pandemic underscored the need for manufacturers to take a more critical look at workforce skills and needs, while continuing to put cybersecurity and digital innovation at the forefront of strategy with the increasing need for automation, supply chain adaptability and remote work. The 2020 Deloitte Global Human Capital Trends Study found that 75% of industrial organizations identified reskilling their workforce as important or very important for their success over the next year, but only 10% said they were very ready to address this trend.[5] In addition, the 2021 Deloitte Global Resilience Study found 57% of manufacturing respondents reported using advanced technologies to redesign job tasks (e.g., automating previously manual tasks).[6] Cybersecurity is a critical area where digital manufacturing and automation are creating new jobs. The cybersecurity unemployment rate has remained at or near 0 percent through 2021, continuing to offer STEM students and transitioning workers a bright career outlook.[7]

By 2028, 2.4 million manufacturing jobs are expected to go unfilled due to a skills shortage. This could risk $454 billion in economic output in 2028, or 17 percent of US manufacturing's GDP contribution.

Because of the pandemic, many academic institutions that were earlier reluctant to change their traditional pedagogical approach had no option but to shift entirely to online teaching and learning, now transitioning into more hybrid pedagogies that emphasize opportunities for hands-on learning that connect students to real-world career opportunities. Especially when considering the workforce adaptations required for digital adoption in manufacturing, there are increased demands for innovative educational delivery, expanded accessibility, and emerging skills development. MxD Learn responds to these challenges impacting the manufacturing workforce through programming and initiatives aimed at skilling, re-skilling, and upskilling the manufacturing workforce toward career opportunities in digital industry and cybersecurity. MxD Learn's workforce development strategy is built around a "Define, Develop, Do" model outlined below:

Define

The Define stage refers to the identification of the opportunities. In emerging areas like cybersecurity in manufacturing the jobs and roles are not clearly defined making it difficult for academia and industry to develop talent and accurately assess their needs. Equally important is the need to define the credentials that will be recognized and drive continuity and standardization. MxD Learn leverages two foundational reports to frame the roles, skills, business contributions, and career pathways of emergent manufacturing jobs,

5 https://www2.deloitte.com/cn/en/pages/human-capital/articles/global-human-capital-trends-2020.html
6 https://www2.deloitte.com/dk/da/pages/about-deloitte/articles/2021-deloitte-global-resilience-report.html
7 https://online.sbu.edu/news/cybersecurity-job-outlook

The Digital Manufacturing and Design Jobs Taxonomy (2017) and *The Hiring Guide: Cybersecurity in Manufacturing* (2020), developed in partnership with ManpowerGroup with input from a diverse network of subject-matter experts. MxD Learn projects both draw from and continue to update these important resources with continuous involvement from industry, academic, and government partners.

Develop

The Develop stage references the development of training programming that aligns with the roles and jobs identified in the Define stage. Development is the preliminary learning required to perform a job or role and can be a variety of things from curriculum to credentials. MxD Learn continues to successfully develop new curriculum for training the future manufacturing workforce alongside academic partners through efforts such as the Cybersecurity for Manufacturing Operational Technology (CyMOT) program with University of Maryland – Baltimore County, and the Drexel Digital Design and Advanced Manufacturing Program (D3-AMP).

Do

The Do stage refers to the actual hands-on experience and education. This can be through internships, apprenticeships, other job training, or postsecondary education such as community college degrees. In many ways it is the most critical piece because it allows both potential employees and potential employers to ensure the role or job is a good fit. The MxD Learn Virtual Training Center (VTC), which launches in early 2022, builds upon established resources and tools from MxD Learn's research-based and industry-approved portfolio of immediately executable virtual content. The VTC will adapt to the unique needs and capabilities of diverse manufacturers, economies, and people.

MxD Learn is perfectly positioned to drive the change that is needed to achieve a digitally savvy workforce and fill the skills gaps employers are experiencing. Fueling these efforts will require entrepreneurial and strategic initiatives geared toward systemic and long-term solutions. MxD Learn brings multiple parties together to solve unique, regional workforce development needs. The tools required to address those needs may vary from region to region, but the foundational approach remains the same.

A successful workforce development strategy is comprehensive. It provides information, guidance, and pathways to future employees, current employees, and employers, as well as academia and non-profit organizations. MxD Learn's workforce development portfolio is developed based on three core tenets:

- **Led by Industry:** With the goal of developing pathways to employment for current and future workers, employers must be at the table every step of the way and they must be invested in the development, success and sustainment of each program
- **Driven by Community:** Good programs in silos won't succeed. Success comes from a collaborative effort where the entire community is involved in the development and progression of a program
- **Focused on the Under-Engaged:** With an anticipated 2.4M job openings by 2028, it isn't enough to reach the current base – programs must target those who have traditionally not be served

A shift of this magnitude requires collaboration across multiple organizations and groups. As modeled in its approach to the development of digital manufacturing technologies, MxD understands that progress in the Fourth Industrial Revolution requires a holistic approach – engaging technology, people, and systems simultaneously. The same holds true for workforce development programs. Enhanced manufacturing processes are only as good as the workforce supporting them. For U.S. manufacturers to succeed, a comprehensive workforce development strategy for manufacturing is required. The outline of MxD Learn's 2022-2024 project execution strategy is shown in the *Project Concept Portfolio* section.

Government Strategy: Digital Modernization

The 2018 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 while rebuilding military readiness as the nation moves towards a more lethal Joint Force. 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.[8]

MxD prioritizes core elements of the National Defense Strategy and DoD Modernization Priorities to sustain technological superiority in the face of increasing economic and technological competition from China and other countries. In its role, MxD works hard to accelerate 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. Additionally, MxD is focused on directly supporting Presidential EO 13806 on

8 https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf

Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States, while aligning DoD modernization priorities.[9]

In 2019, in coordination with the Office of the Secretary of Defense, MxD shifted its focus towards projects already on the cusp of commercialization at TRL-7, defined as a "system prototype demonstration in an operational environment." This expansion of capabilities has created an opportunity to better leverage proven technologies not traditionally used in manufacturing and test them in a real-world-environment. Although MxD still maintains the bridge over the "valley of death" by directly interfacing with its 30+ academic members, it now means MxD projects have a "ramp" designed to accelerate the adoption of digital technology with both manufacturers and, importantly, America's warfighter in mind.

Since its inception, the Institute has developed important government partnerships. Alignment between government stakeholder priorities to the MxD's project investments, developing programs, and overall institute activities will enable an effective partnership framework that will reduce, and possibly eliminate, redundant investments and capture high-value collaborations. To facilitate collaborations in programming, research, and demonstration benefits with government partners, MxD created a Tier 3 Government Entity membership. This action helped clarify roles, responsibilities, and benefits for DoD Fourth Estate entities, non-DoD, and state government partners.

Over the next year, MxD will continue to engage with organizations like the Army Materiel Command, Defense Logistics Agency and others to ensure we're driving meaningful input to roadmaps, policy development and technology adoption. Additionally, MxD will continue to explore collaborations with other federal executive agencies, including the National Institute of Standards and Technology, the Department of Homeland Security, the Department of Labor and the Federal Development Agency as the Institute identifies synergies and aligned interests.

MxD's mission is to empower near-real-time decision making capability—not just for DoD, but America's manufacturers writ large—by accelerating the adoption of digital technology and a resilient cybersecure supply chain in manufacturing. As an organization, MxD understands that it requires not only research, but a cultural change as well. For this reason, MxD government engagements involve a cross-section of its projects, engineering, and workforce development teams.

A critical component of this effort is to formalize the development, integration, and use of models to inform enterprise and program decision making. Consequently, these modernization efforts provide an enduring and authoritative source of truth, which incorporates technological innovation to improve the digital engineering realm. A supporting infrastructure and environment will be created for collaboration and communication among stakeholder groups, thus transforming the culture/workforce to adopt to digital manufacturing and engineering across the DoD Organic Industrial Base lifecycle.

9 https://www.whitehouse.gov/presidential-actions/presidential-executive-order-assessing-strengthening-manufacturing-defense-industrial-base-supply-chain-resiliency-united-states/

MxD's experience performing digital capability assessments and visits to arsenals, depots, and industry manufacturing facilities, well equip the Institute to accelerate modernization efforts within the Organic Industrial Base (OIB). MxD efforts in 2021, in partnership with key DoD partners, will focus on technology testing, validation, and adoption while applying advanced commercial technologies and best practices from the greater U.S. manufacturing industry to the unique environment and conditions presented by the OIB.

As part of its commitment to directly supporting the Department of Defense in its modernization efforts, MxD has worked closely with DoD entities, such as Army Materiel Command, Defense Logistics Agency, USMC Marine Maintenance Depot Command, and others, to ideate, scope, and execute several R&D and Demonstration projects and digital modernization roadmaps. MxD plays a growing and dynamic role in the Department of Defense's digital modernization efforts in 2021, specifically as it applies to defining standards, governance, and processes that promote the integration of digital technology within applicable DoD Modernization Priorities, including artificial intelligence, automation, cybersecurity, supply chain resiliency, 5G and workforce development.

A critical component of this line of effort is ensuring the arsenals, depots, and shipyards—plus their respective supply chains—are making significant progress in digital modernization.

A critical component of this line of effort is ensuring the arsenals, depots, and shipyards—plus their respective supply chains—are making significant progress in digital modernization.[10] A gap exists within the military services between the introduction of emerging technology and the adoption of the technology throughout the Organic Industrial Base (OIB). In the next decade, a significant amount of effort will be required to identify and overcome obstacles to digital modernization while ensuring there is an adequately trained workforce to leverage these advances and a secure environment to adopt them.

Looking forward, MxD will leverage DoD funds to expand outreach to military arsenals, depots, and shipyards by developing digital modernization roadmaps and conducting applicable manufacturing workforce and supply chain cybersecurity assessments. MxD will also continue to work closely with service level research partners like the Air Force Research Lab and the Office of Naval Research, major component commands like the Army Material Command, NAVSEA/LOGCOM, and 4th estate entities like the Defense Logistics Agency (DLA) to achieve the digital transformation in development, logistics, and sustainment needed to enhance warfighter readiness and ensure a more lethal fighting force in the future. Also, MxD will make every effort to ensure as many R&D projects have a quantifiable impact on the warfighter and DoD modernization priorities.

10 https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf

Recognizing that a significant portion of the DoD's supply chain includes small businesses, MxD is increasingly called to support this community. In the last quarter of 2020, 61% of all new members and 60 total new Tier 3 members had some affiliation with the Department of Defense. As a result, MxD is continuing to explore and develop tools and resources that will assist small businesses like the recently published Hiring Guide as well as content development underway within MxD Cyber: National Center for Cybersecurity in Manufacturing. The Institute will also continue to explore leveraging existing programs such as AFWERX and DoD SBIR to further advance the technical merit, feasibility, and commercial potential of RD&D efforts.[11]

In the last quarter of 2020, 61% of all new members and 60 total new Tier 3 members had some affiliation with the Department of Defense.

11 https://www.sbir.gov/about

Factory Floor Technology Demonstrations

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 per month under normal operations, 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. For those visitors who are learning about digital manufacturing, the Factory Floor also shows how to get started thinking about how digital solutions can be used to solve basic manufacturing problems.

Since its inception, the MxD Factory Floor testbeds have been designed and implemented to demonstrate digital manufacturing use cases and solutions to its visitors. In 2017 the MxD digitized manual assembly line opened and in 2019 the discrete manufacturing testbed, the cybersecurity wall, and the cybersecurity process testbed all opened.

MxD's manufacturing testbeds, such as the discrete manufacturing testbed that machines MxD-branded tokens, show visitors practical examples of what Industry 4.0 enables: digital workflows, machine and environmental instrumentation, digital fingerprinting, analytics, and predictive maintenance. The testbeds 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 Factory Floor demonstrates the unlocked potential of a factory that utilizes advanced digital technology.**

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. MxD's Cybersecurity to demonstrate cybersecurity in process manufacturing and how manufacturers can detect, respond, and recover from a cyberattack. In addition to its use for cybersecurity awareness, the testbed 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 testbeds and create new testbeds 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.

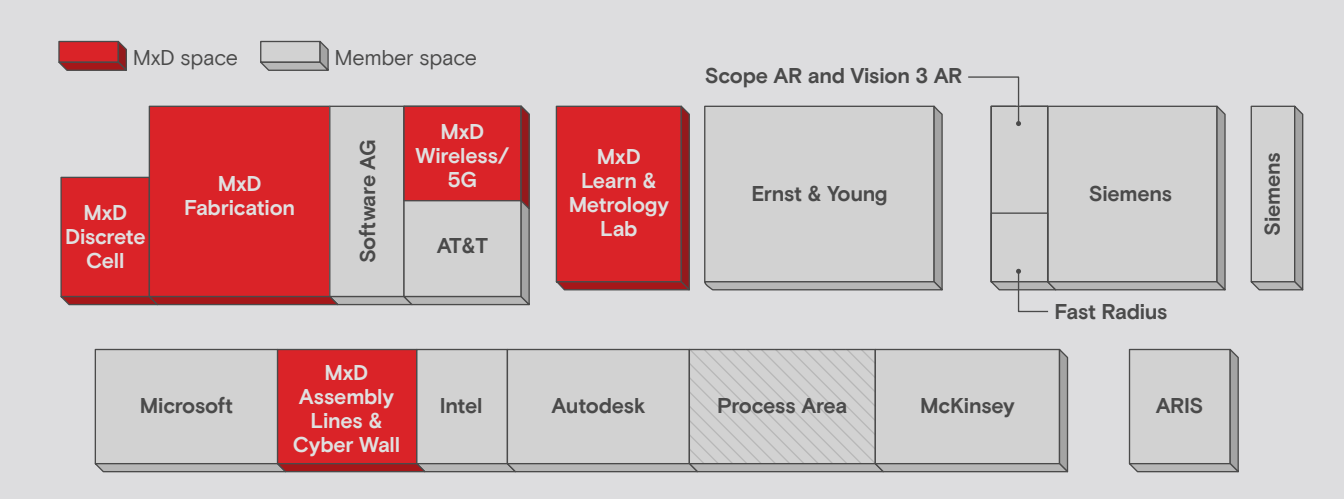
Factory Floor 2021 Updates

The MxD Factory Floor has evolved significantly over time and will continue to do so. As the Covid-19 limitations are being lifted, MxD and its Members have been transitioning into normal operations including updating and utilizing the Factory Floor. The diagram below highlights floor updates that have been made or are in process during 2021.

Along with in-person Factory Floor tours, a virtual tour is also available at **https://virtualtour.mxdusa.org/**

Figure 6

The MxD Factory Floor (2020 Update)



2021 MxD Updates

- Open area cleared and opened for a Tier 1 or 2 Member.
- Currently being used as a build area for additional MxD Cyberboxes. The Cyberbox is a scaled down version of the MxD Cybersecurty Wall and will be used to take the cyber demonstration on the road. Future space for Wireless / 5G development.
- The MxD Cybersecurity Wall was physically moved closer to the Assembly Demonstration to create an open area for the Intel space.
- The MxD Cyber Process Demonstration was physically moved in the Process Area. Projects 19-04-03 Digital Twins for Process Manufacturing: Open Architecture and 19-04-04 Digital Twins for Process Manufacturing: Mobile Worker were both installed along with supporting equipment.
- Open area was created with the move of the McKinsey space.

2021 New Member Space Updates

- The AT&T Member space was completed and demonstrates how video intelligence can provide actionable insights into factory floor operations to help increase safety and efficiency. Video intelligence applies 5G millimeter wave (mmWave) cellular and Internet of Things (IoT) technology to video camera footage to monitor, automate, and perform functions on a near-real time basis. Visitors discover how manufacturers can use video intelligence on a 5G network to monitor conveyor belt speed, production accuracy, equipment temperatures, and inventory levels and location within a defined space.

- The Ernest & Young Member space is a recent addition and is currently being developed.

- The Fast Radius Member space was moved to its current location. The Fast Radius platform embraces and employs the latest manufacturing technology, tools of design, and Industry 4.0 practices to make new things possible for our customers and the world.

- The Scope Augmented Reality and Vision 3 Virtual Reality Member spaces were consolidated to create additional room.

- The Microsoft Member space was completed and demonstrates how smart manufacturing can be propelled through Azure cloud and edge computing, artificial intelligence, data analytics, digital twins, and HoloLens augmented reality. Visitors will experience solutions for agile factories that demonstrate real-time quality assurance, workplace health and safety, knowledge and enterprise asset management, digital feedback loops, and workforce transformation.

- The Intel Member space demonstrates how Intel's video intelligence combined with AT&T's 5G low latency connectivity can provide real-time sensing to detect people in keep out areas to stop equipment based on a potentially unsafe condition while differentiating from objects being in the keep out area which would allow the equipment to continue running.

- The McKinsey Member space was consolidated and updated to describe a holistic 'transformation playbook' that is designed to implement and capture the value from technology for organizations to then build strategic roadmaps that can then be used to build and implement to scale and drive the change.

- The ARIS Member space demonstrates the ability to scan an existing part to create a three-dimensional point cloud of that part. The technology utilizes an automated robot path to expedite

Factory Floor 2022 Plans

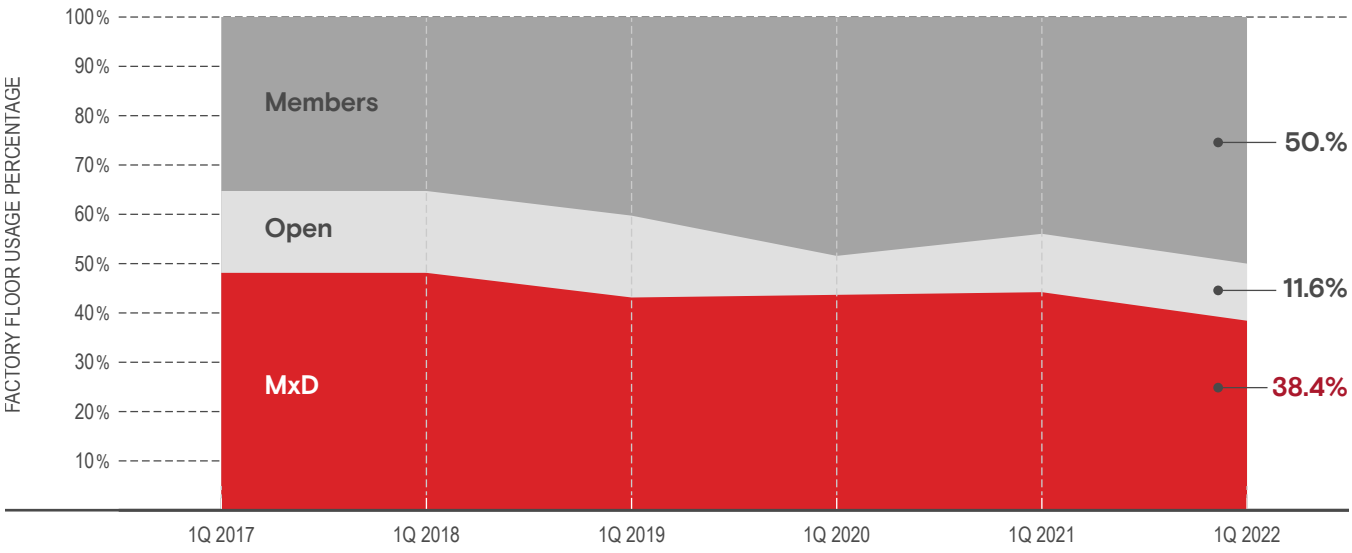
MxD Factory Floor activity is expected to continue into 2022. The chart below shows MxD Factory Floor space usage trends. Note that Member space usage has gradually increased and MxD and open space has gradually decreased over time. Expansion of the Factory Floor space are being considered.

The MxD Factory Floor will continue to evolve as new Members are added, projects are demonstrated on the floor, and new and updated digital capabilities are installed. Besides support for existing and future Members, major projects include:

- 21-07 Secure Wireless for Factory Operations project that provides an overview of wireless technology choices and a testbed that demonstrates selected wireless technologies with various use cases that include Cybersecurity considerations.
- 5G demonstration that will configure and install a 5G system, based on recommendations from 'Ambiguity Within 5G Technologies and Applications'. This system will then be used to (a) demonstrate several use cases concerning data integrity over 5G wireless in an industrial setting and (b) serve as a training testbed for future workforce development.
- Identify and develop a method to 'cloudify MxD Factory Floor data' that allows Members to access data generated from various sources while maintaining Cybersecurity measures.
- The current Cybersecurity Wall has been an excellent tool for helping the manufacturing community understand the basic concepts of cybersecurity in manufacturing. Expanding the availability from the prototype Cybersecurity Boxes will require the build and test of additional devices that then be used by manufacturers to understand the threats of cybersecurity attacks and how to proactively decrease the risk of their occurrence.
- As MxD works with DoD agencies and facilities to increase digital manufacturing capabilities, it is expected that the MxD Factory Floor will be used to provide Proof-of-Concept validation and provide testbeds as appropriate. Multiple projects are in current discussion and are expected to be realized in 2022.

Figure 7

The MxD Factory Floor Usage Trends



Technology Project Portfolio

Strategic Investment Plan

(2022–2024)

Overview

MxD follows the technology strategic planning process to collect and synthesize intelligence from several sources to develop the technology project portfolio. In 2021, MxD conducted over 50 interviews of manufacturers, service providers, and research organizations in the U.S. and abroad. We also reviewed over 150 journal and technical papers and presentations submitted to use by members and external contacts. We also participate in over 15 technology workshops and working groups hosted by MxD, member organizations, or industry partners. MxD members support the synthesis of intelligence, the development of project concepts portfolios, and the prioritization of the project concepts within the portfolios them. MxD and supporting members use the following six criteria to identify and prioritize project concepts:

- **Strategic Fit & Importance:** The degree to which the idea aligns with technology vision and strategy. The importance of the project concept to providing a solution to industry. The impact on industry growth.
- **Competitive Advantage:** The extent to which the project concept provides differentiated benefits relative to competing solutions. The industry's perception of value of the solution for the investments. The extent to which the project concept provides a competitive advantage to U.S. industrial base. The extent to which the project concept a market demand.
- **Market Attractiveness:** The size of the market that is addressed by the project concept. The ability of the solutions from the project concept to penetrate the market. The rate of growth for the market being served by the solutions. The size of the margins in the market being served by the solutions. The degree of competition within the market.
- **Competencies:** The extent of ability to use core competencies in developing solutions within project concept. Expected complexity of plans to address resource gaps.
- **Technical Feasibility:** The size of the technical gap to provide solutions. The degree of technology complexity to provide solutions. Level of difficulty to achieve technical solution for pilot and for repeatable commercial product. The size and complexity of legal, regulatory, and commercial requirements.
- **Rewards and Risks:** The size of the expected returns. The level of financial, regulatory, and technological risks.

Furthermore, MxD considers nine dimensions in applying the criteria above to identify and prioritize projects. These nine dimensions are as follows:

- **Technology & Industrial Base:** An analysis of the capability of the technology and industrial base to support the design development, production, operation, uninterrupted maintenance support of the system.
- **Design:** An understanding of the maturity and stability of the evolving system design and any related impact on manufacturing readiness.
- **Cost & Funding:** An analysis of the adequacy of funding to achieve target manufacturing maturity levels. Examines the risk associated with reaching cost targets.
- **Materials:** An analysis of the risks associated with materials (including basic/raw materials, components, semi-finished parts, subassemblies, hardware, and software)
- **Process Capability and Control:** An analysis of the risks that the manufacturing process can reflect the design intent (repeatability and affordability) of key characteristics.
- **Quality Management**: An analysis of the risks and management efforts to control quality and foster continuous improvement.
- **Workforce:** An assessment of the required skills, availability, and required number of personnel to support the technology.
- **Facilities:** An analysis of the capabilities and capacity of key manufacturing facilities (e.g., primes, subcontractors, suppliers, vendors, and maintenance/repair)
- **Manufacturing Management:** An analysis of the orchestration of all elements needed to translate the design into an integration fielded system.

MxD has five major project concept portfolios define by thrust areas: Digital Engineering, Future Factory, Supply Chain, Cybersecurity, and Workforce Development. Project concepts are categorized by their primary thrust area even though they may be relevant to other areas. We show descriptions of the thrust areas below and the 2022-2024 project concept roadmap in Appendix A (Figures 9-14). We also show in the Appendix B (Figure 15) the entire project concept portfolio, including project concepts not scheduled in 2022-2024.

Digital Engineering

Digital engineering is an integrated digital approach using authoritative sources of system data and models in a streamlined process throughout the development and life of a system. Digital engineering updates traditional systems engineering approaches to unlock the benefit of computational technology, modeling, analytics, and data sciences. Digital engineering is a necessary practice to increase the speed, accuracy, and responsiveness of the conceptualization, development, and delivery of new technologies in an increasingly volatile global environment. Digital engineering is an extension of product lifecycle management, which involves the creation and storage of a system's lifecycle artifacts, in digital form, and which can be modified as a system evolves throughout its lifecycle. Digital engineering involves a single source of truth that contain artifacts maintained in a single repository, and stakeholders work from the same models rather than copies of models. Model-Based Enterprise and Digital Twins are examples of components of digital engineering.

2021 Projects

21-01-05 AI Design Advisor

As product complexity grows designers face an ever-increasing challenge of understanding the impact of their design time decisions on downstream activities like manufacturing, assembly, quality, service, and repair. New designers lack a deep experience pool to draw upon to help guide them so must often be supervised by more experienced engineers until they have developed enough experience to guide themselves. This project will leverage past projects that focused on the movement of data along the digital thread such as 15-11-08: Capturing Product Behavioral and Contextual Characteristics through a Model-Based Feature Information Network (MFIN). Digital Twins of the manufacturing and sustainment phases, as well as material specifications and other critical data, can be leveraged to highlight gaps between as-designed versus as-manufactured. The tool can also guide designers to choosing the best manufacturing process (e.g. subtractive vs additive) in order to best achieve their design goals. The data and associated framework may leverage an artificial intelligence algorithm which learns from previous design decisions or leverage more traditional logic to guide designers through the design process to increase initial quality and reduce downstream rework reducing overall project time and associated cost.

21-19 Paladin Howitzer Model Based Enterprise R&D Demonstration

The aim of this project is identifying or creating a minimum viable PLM/PDM that meets the requirements of SMMs, establishing capabilities and translating 50-part designs into modern technical data packages, and obtaining engineering authority approvals for variances and fabricating sample parts that pass First Article Inspections. Industry needs the implementation and dissemination of a low-cost, cloud-based scalable, limited-functionality PLM/PDM to facilitate the SMMs adoption of digital technologies and execution of associated work. SMMs currently do not have access to PLMs or PDMs that fit their functional and cost requirements, nor do they have sufficient know-how to operate and maintain them. Industry also needs SMM's to have working knowledge of the PLM/PDM and of the model-based definition that unlocks the value of digital engineering. Having this PLM/PDM and working knowledge will support SMMs and their OEM customers in improving speed, lowering cost, and increasing competition in procurement.

21-30 Cross Institute Collaboration (CIC) Structural

The Collaboration Team will develop a secure, transcribing framework that enables future virtual validation, and verification of additively manufactured parts across additive manufacturing platforms. The multi-year, long term goal is to produce a fit-for-purpose EAS approved additively manufactured structural component for the DoD using this framework. This proposal focuses on the first-year activity to understand the minimum requirements needed to establish such a secure, transcribing framework. This will include things such as: 1) structure of data, 2) type of data, 3) amount of data, and 4) interdependence of data. Data entail AM design, material, and process variables and part performance. Utilizing existing data sets from America Makes, LIFT and MxD the goal is to determine minimum data needs to ensure interoperability of framework across various platforms. The team will also identify gaps for future phases to build out.

2022 Projects

22-01 Technical Data as a Service

Request for Proposals Release: March 2022

"Completeness" of technical data packages (TDPs) has different meanings to users, and it is impractical to define or exchange a complete TDP. A complete TDP would also have sensitive data that a user may not need or to which they may not have rights. Technical Data as a Service (TDaaS) aligns with the new DoD IP Policy and the emergent needs of DoD and industry for access to part data. The TDaaS concept is to establish priced contract options for future data access/delivery, and to maintain a product data system that can generate from a complete digital TDP the technical data set (TDS) needed for a particular use at the time of need.

22-05 Digital Twin of Product Sustainment Phase

Request for Proposals Release: April 2022

Digital Twin of a part (or product) to predict performance during a part (or product's) sustainment phase. Leverage MBD research and standards from project 15-11-08 and new advances in asset connectivity, computing and standard data models to map quality, manufacturing, performance data back to the 3D model to inform advanced analysis (or AI) to drive better decisions across product lifecycle.

22-02 Model-Based Enterprise Readiness Index and Maturity Model Upgrade and Harmonization

Request for Proposals Release: July 2022

Organizations are at various stages of maturity of MBE. They need a clear roadmap that covers fundamental pre-requisites to full adoption of MBE technologies and practices. The current model-based-enterprise capability index requires revisions to better guide successful maturation of MBE technologies and practices. The revised index would cover all stages of adoption and define clear maturation plans for organizations. This index would inform adopters of the technologies on the benefits at each stage of adoption as well as the expected investments.

22-09 2022 Design Project

Request for Proposals Release: November 2022

This is a project to develop or demonstrate digital engineering technologies on key design topics.

2023 Projects

PP-079 Rapid Innovation with Digital Technologies

Request for Proposals Release: May 2023

The solution concept would employ AI to gather market intelligence to develop project concepts (e.g., web scraping). The solution will also use a digital twin to gather performance data from limited product releases to improve the design of the project and market acceptance.

PP-076 Virtual Cradle to Grave Design Environment

Request for Proposals Release: October 2023

Create a virtual design, manufacturing, and sustainment environment to provide the ability to make decisions at the design phase that will create the lowest total lifecycle cost solution.

2024 Projects

PP-080 Design for Sustainability in Products and Supply Chains

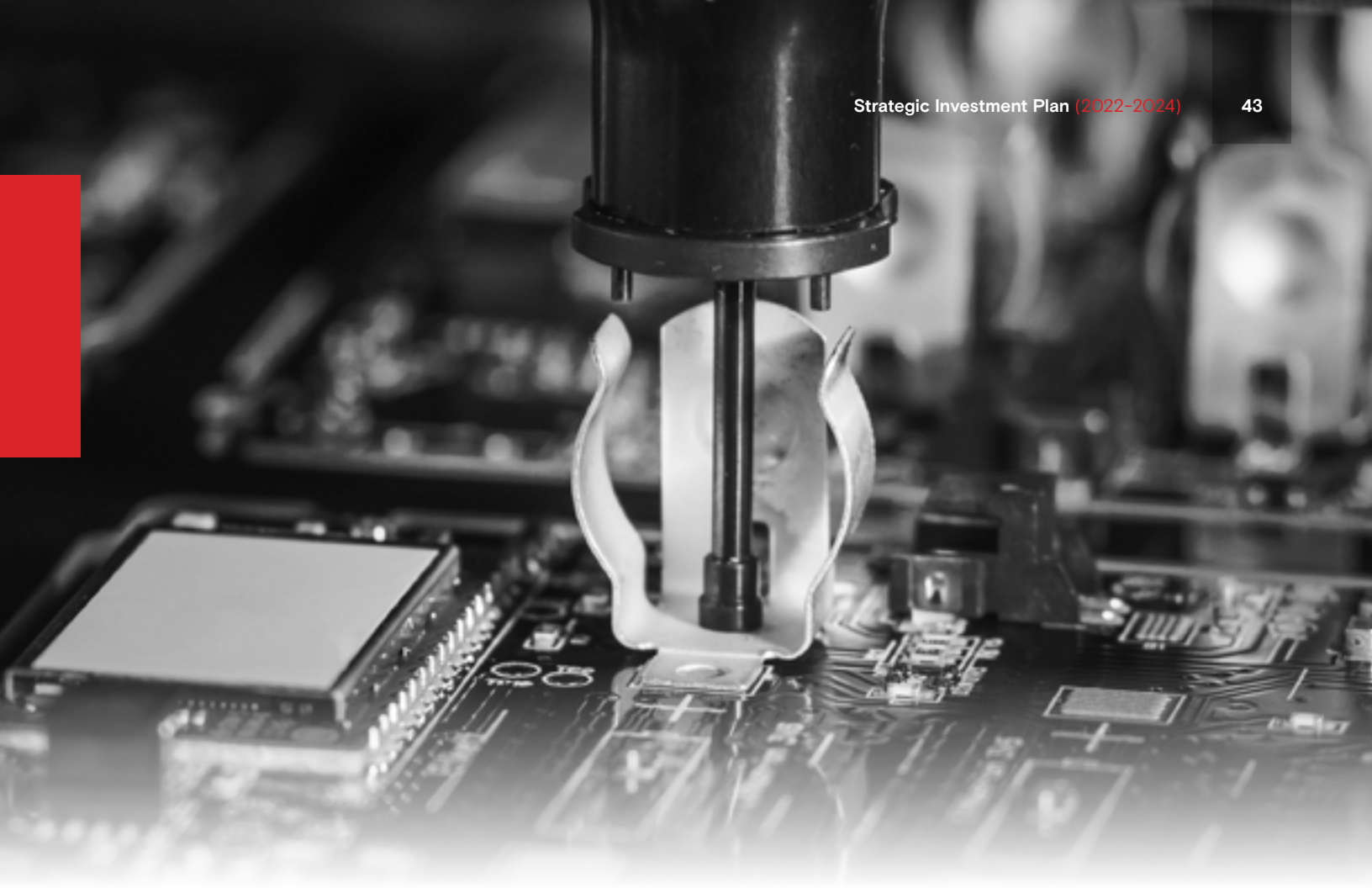
Request for Proposals Release: February 2024

The solution will integrate with existing PLM and SCM systems. It will also provide recommendations to optimize the product design, manufacturing process planning, and supply chain.

PP-090 Design for Sustainment in Products and Supply Chains

Request for Proposals Release: July 2024

The solution concept will enable standardization, modularization, functional packaging, interchangeability, accessibility, malfunction annunciation, fault isolation, and identification. The solution will collect data from products in the field or from CMMSs and synthesize the information into redesign recommendations.



Future Factory

MxD's mission is to enable U.S. manufacturers to make every single part better than the last. This requires production lines to be embedded with software that communicates with sensors and is hooked up to the cloud—a so-called future factory. Only with this ability to send and receive data can the equipment improve itself and learn from every part produced in real time. In the future factory, information and communication technology and automation technology are fully integrated. All subsystems are networked and consolidated into a central one. This makes it possible to simulate the results in full by changing the parameters. All relevant requirements for manufacturing and production capacity are already confirmed during product development. The entire process can be considered and managed in real time holistically from the initial step. Network and transparency foster a shift from centralized to local production. A central supervisory system organizes, monitors, and controls the intelligent network of subsystems, enabling them to work more independently. Humans define requirements through interfaces while process management is automated.

2021 Projects

19-04 Process Testbed Digital Twin

Properly mastering the digital twin is central to achieving the promise of industrial digital transformation. MxD members developed a simple definition of digital twin at the 2018 Future Factory workshop: "A digital model that communicates with a physical system to achieve a benefit in that system." In a digital twin, a physical system is modeled in the digital realm with respect to critical functions. Internet of things (IoT) sensors measure critical parameters of the physical system that feed analytics to the digital replica to drive improvements that are realized in the physical realm. It is through the creation of closed cyber-physical loops that digital technologies achieve their highest purpose and greatest return on investment (ROI). According to Deloitte, "with the creation of the digital twin, companies may realize significant value in the areas of speed to market with a new product, improved operations, reduced defects, and emerging new business models to drive revenue." Hence, the most advanced manufacturers are focusing their digital manufacturing efforts on implementing the digital twin concept in their own operations.

These projects focus on the first step to achieving digital twin benefits: development and execution of a plan to collect, aggregate, and analyze all the sensor data necessary to build a digital twin of a product, process, or equipment. In order to do this, new technology solutions must be evaluated in the context of a process or discrete manufacturing application for tradeoffs to be properly considered. Manufacturers need to vet commercially available sensors, data aggregation solutions (enterprise and open architecture), AI data analytics packages, and cybersecurity solutions to understand utility and value for different process and discrete applications. Yet, large manufacturers' business environments often constrain their ability to experiment with the full array of sensor technologies, commercial offerings, and architectures.

19-04-03 Open Architecture

This project focused on the creation of an Open Automation testbed designed to provide low-cost, plug-and-play connectivity of equipment and software from different vendors. The developed Integration Test Environment (ITE) combines off-the-shelf industrial computing components with ADI's ADEPT framework to provide connectivity across legacy and future interfaces. By centralizing within this framework, various applications such as the developed Digital Twins for pump condition monitoring, control loop performance, and process health have access to real-time data and compute. This capability is enhanced by single-board computers that can emulate new devices or technology in the system. By leveraging the ADEPT framework or other open automation architectures, manufacturers can benefit from low-cost unobtrusive experimentation where changes to the process and production equipment can be modeled and evaluated prior to making physical changes. This enables manufacturers to develop, test, and evaluate new technologies without interrupting production operations and without costly R&D investments. ADI now offers Integration Test Environments as a commercial product and service with the existing ITE testbed located on MxD's factory floor.

19-04-04 Mobile Worker Proof of Concept

This project explores the ways in which manufacturing roles in the process industries could transform with the advancement of industry 4.0 technologies. This is achieved through the demonstration of the "mobile worker" proof-of-concept which proves how digital twins can enable operators in the field to make more data-driven decisions and enhance communication with leadership and other operators. Additionally, the process testbed provides a basis for on-going research and development of use cases in this rapidly evolving industry 4.0 landscape. Manufacturers will be able to get a hands-on experience on how to use digital and mobile solutions to improve their employees' work functions. It will allow manufacturers to get more data to the people that do the work so they can make smarter and faster decisions.

20-13-01 Docent Technology Transfer

MxD member- Ekta completed project 17-04-01: Docent - Digital Application for Manufacturing Readiness Level Assessments in 2019 to support the Defense-wide Manufacturing Science & Technology (DMS&T) Manufacturing Technology (ManTech) Program initiative to modernize the Manufacturing Readiness Level Assessment (MRA) process for new defense acquisitions. The previous process for MRAs was effective but there was a need for a digital tool which offered flexibility, collaboration and scalability across the enterprise. MxD and Ekta developed Docent, an application for MRA execution, collaboration and reporting. Docent is available as a standalone desktop application, a web-based application, and as Android and iOS mobile applications.

In this follow-on effort, MxD, with the support of Ekta, is pursuing an active transition of the Docent tool through customer-specific enhancements, ultimately standing up a group of products owners within the DoD Manufacturing Readiness Level Working Group. The primary objective of this continuation is to drive adoption of the Docent tool through pilots, allowing the team to identify value-adding features that end-users would ultimately be willing to pay for. These features will be built into the tool with commitment from those customers that they will sustain Docent for the government community moving forward.

19-13-05 Operator 4.0 via Fatigue and Motion Analyses in a Human Digital Twin Enabled Framework for Smart Manufacturing

The objective of this research is to develop a new framework for human-centered digital twin towards the construct of Operator 4.0. This is where new sensing capability and human cyber-physical models are developed to augment operator capabilities, improve their knowledge through real-time performance feedback, and inform micro and macro level continuous process improvement. The project will create a human-centered digital twin that uses novel information to estimate operator fatigue condition and make proactive safety recommendations to improve health and productivity. Data is provided by flexible, wearable multi-function biometric sensors. Sensor fusion is performed with a 3D camera system to incorporate relative interaction and global position of operators. These data are then provided to the human digital twin model in order to study worker ergonomics, emulate human behavior, predict performance considering fatigue conditions, and give suggestions to improve workflow and safety.

21-06 Dynamic Production Scheduling and Optimization

As manufacturing environments increase in complexity, scheduling systems must account for the inevitable risks and uncertainties inherent to them. Traditional scheduling tools and manual methods such as spreadsheets cannot respond dynamically to unexpected changes and quickly become obsolete when disruptions do occur. Improved scheduling can directly impact operational performance in the form of increased throughput, more efficient machine utilization rates, and improved worker productivity. However, manufacturers often lack the expertise needed to choose and successfully deploy real-time scheduling solutions. This project will document the implementation and validation of a real-time, dynamic scheduling and optimization solution that can provide manufacturers with actionable insights into plant scheduling. The solution should incorporate factory floor data and demonstrate ROI to manufacturers seeking to implement tools that address and optimize scheduling.

21-14 Predictive Maintenance in Manufacturing

A core value of Industry 4.0 is that factory equipment will become smarter in how it is monitored and maintained through the use of IIoT (Industrial Internet of Things) and intelligent sensors, raising the bar on asset performance requirements. Today, most maintenance is performed using schedule-based maintenance which is based on statistical historical data such as MTBF (Mean Time Between Failure) to decide when service needs to be done or service is performed after an equipment failure occurs. There is a demand for making maintenance more proactive using either Condition Based Maintenance, which uses actual asset conditions to decide when maintenance needs to be performed, or predictive maintenance which uses artificial intelligence (AI) based predictive algorithms and real-time asset conditions to predict when maintenance will be needed which avoids unnecessary repairs, costly shutdowns from failures, and degradation of operating efficiency. In addition, key indicators such as output, or machine performance can also be benchmarked to create thresholds for prompting maintenance activity or investigation.

This exploratory project will look at the current state of predictive maintenance and performance of equipment in a manufacturing environment. The project may look at discrete and/or process-based manufacturing environments but will focused on how predictive maintenance can improve overall equipment effectiveness (OEE). Additionally, through the use of Digital Twins (follow-on of 19-04-04), predictive maintenance will be simulated to better understand the effect of failure modes on equipment uptime and performance. The project will develop a comprehensive playbook for designing and implementing a predictive maintenance solution for manufacturing equipment and share ROI, OEE and other key metrics.

21-18 Instructional Methods, Applications, and Effectiveness of 5G Cellular Technology for Industrial Facility IIoT Applications

5G is often used in a singular context when talking about technology. However, 5G is made of several types of architectures and variables. These include variations in spectrum, hardware, software, and physical location of assets. When taken holistically, there are dozens of 5G configurations that provide both advantages and disadvantages depending on the use case.

These configurations then result in interdependencies between cost, complexity, availability, risk, and performance. Most literature and marketing materials are targeted at consumer use applications and are skewed toward service providers. One of the impediments to the adoption of 5G wireless technology in manufacturing is the confusion caused by this ambiguity.

The goal of this outcome is to determine an optimal configuration of 5G, in a neutral and objective manner, for use in industrial buildings specifically for IIoT and digital applications and make this information publicly available for broad industry use including DoD.

21-36 Rock Island Arsenal Modernization Projects

The overall objective of this initiative is to assess, develop, pilot, and implement a common set of processes and tools to modernize the manufacturing and maintenance repair capabilities of the Joint Manufacturing and Technology Center (JMTC) at Rock Island Arsenal (RIA). This initiative will help improve the JMTC's ability to manufacture, maintain, repair, and overhaul various ground systems and their associated components in a more efficient, effective, and affordable way. To accomplish this objective, the government will work closely with industry to advance the state of the art in digital commercial technologies and processes to modernize critical systems, processes, workflow packages, and tools across JMTC's manufacturing and maintenance repair operations. This initiative will save significantly on long-term costs by conducting a detailed analysis of the previous commercial manufacturing modernization efforts while focused on improving key JMTC performance metrics which control program risk, as well as cost and schedule requirements. Overall, this initiative will increase the knowledge of the Army to determine which technology advancements and processes will best equip the organic industrial base to ensure technological dominance into the future. This initiative will also generate lessons learned for potential implementation of these processes and tools across the Army and other Service shipyards, depots, and arsenals which is critical to national security and a strong economy.

2022 Projects

22-03 Digital Manufacturing Playbooks

Request for Proposals Release: May 2022

As companies plan their adoption of Industry 4.0 technology they are looking for "best practices" they can follow to reduce risk and accelerate adoption. Small and medium-sized manufacturers (SMMs) are especially challenged because they often lack the resources (people, time, and money) to experiment. They seek recommendations on what works and doesn't work. This project will develop a series of "How To" playbooks focused on helping SMMs and larger manufacturers deploy Industry 4.0 concepts in their factories: where to start, how to identify and mitigate risks, ROI, cybersecurity needs, and more. While the playbooks will focus on retrofitting brownfield facilities, the learnings will be applicable to greenfield facilities, as well.

22-06 Operator Health Tracking

Request for Proposals Release: August 2022

Utilization of emerging or current technologies to capture an individual's "health" while in the factory. Provide feedback on how fatigue affects production and long-term effects of repetitive motions. Alert the worker when they are overexerting themselves.

22-07 Track and Trace Spanning the Factory and Supply Chain

Request for Proposals Release: September 2022

The supply chain track and trace project would enable manufacturers to verify quality, on receipt, of raw materials from their upstream supply chain. Additionally, expanding on PP-014 and PP-019, track and trace systems also enable low-cost barcoding/ RFID signatures to be placed on raw material or WIP allowing inventory levels to be monitored automatically rather than manually. Lastly, the technology can be deployed further downstream in the supply chain to customers or a storage setting to enable expeditious asset location tracking and/or recovery of asset's unique quality documentation. The benefits from Track and Trace can range from instant verification of raw material authenticity, critical in high hazard processes, to accurate inventory management and tracking in long lead time processes.

2023 Projects

PP 010 Digitalization and Visualization of Component Defects

Request for Proposals Release: February 2023

AR / AI combined with x-ray/FPI to detect, highlight, and address defects in order to reduce delays caused by rework.

PP 100 Data Interoperability for Industry 4.0

Request for Proposals Release: May 2023

Several reference architecture and standards have emerged to addressed interoperability for Industry 4.0. DIN's RAMI 4.0, NIST's Big Data Interoperability Framework, Industrial Internet Reference Architecture, IEC 62443, ISO 27000, IEC 62541 OPC UA, and IEEE 1722 are reference models and standards considered for Industry 4.0. The solution concept will address the gaps outline in the reference architecture and standards. It will also demonstrate their application.

PP 041 Unifying the Model-Based Definition and the Digital Twin (Follow on to 15-11-08)

Request for Proposals Release: July 2023

Leverage MBD research and standards from project 15-11-08 and new advances in asset connectivity, computing and stan¬dard data models to map quality, manufacturing, performance data back to the 3D model to inform advanced analysis (or AI) to drive better decisions across product lifecycle.

PP 017 Predictive Maintenance in a Process Environment Using a Digital Twin

Request for Proposals Release: October 2023

Analytical tool to track sub-assemblies/components in real-time to ensure that parts will be available on the line when needed.

2024 Projects

PP 077 Virtual Inspection of Manufacturing

Request for Proposals Release: February 2024

The solution concept will allow inspectors to inspect independently manufacturing facilities for conformity to specification and standards. The inspection could be witnessing of production runs and visual examination of products.

PP 011 Integrated CNC Digital Twin

Request for Proposals Release: May 2024

Leverages work done on 15-07-05 which focused on using additive manufacturing. This project would create a Digital Twin of an MxD CNC to identify issues prior to physical production.

PP 019 Real-Time Inventory Tracking

Request for Proposals Release: July 2024

Implementation of real-time inventory tracking in order to avoid the necessity for large “buffer” stock Component quantities should be tracked at all areas in the plant (shipping, warehouse, cell, etc.).

PP 102 AR/VR in Maintenance

Request for Proposals Release: October 2024

The solution concept will use virtual reality technologies to train technicians on the maintenance and repair of complex equipment. The solution concept will also use virtual/augmented reality technologies to carry out the maintenance activities successfully.

Supply Chain

The supply chain is the network of all businesses, resources, activities, and technology involved in the creation and sale of a product, from the initial raw materials to delivery of the assembled product to the customer. Manufacturing's next advances on this frontier will include predictive analytics. Systems will warn manufacturers of potential disruptions in a supply chain before they happen and also will forecast which materials and components customers will want— when and why. The supply chain today is a series of largely discrete, siloed steps taken through marketing, product development, manufacturing, and distribution, and finally into the hands of the customer. Digitization brings down those walls, and the chain becomes a completely integrated ecosystem that is fully transparent to all the players involved — from the suppliers of raw materials, components, and parts, to the transporters of those supplies and finished goods, and finally to the customers demanding fulfillment. This network will depend on a number of key technologies: integrated planning and execution systems, logistics visibility, autonomous logistics, smart procurement and warehousing, spare parts management, and advanced analytics. The result will enable companies to react to disruptions in the supply chain, and even anticipate them, by fully modeling the network, creating "what-if" scenarios, and adjusting the supply chain in real time as conditions change. Once built the digital supply "network" will offer a new degree of resiliency and responsiveness enabling companies that get there first to beat the competition in the effort to provide customers with the most efficient and transparent service delivery.

2021 Projects

20-17-01 Rapid and Secure Deployment of Medical Devices and Instrumentation

The objective of this project is the creation of a digital framework for processes that are executed repeatedly and efficiently in order to quickly design, manufacture, and validate medical devices and components. This project explores two additive manufacturing use cases, one for personalized unique medical devices and one for rapid redesign of an existing medical device (ventilator) to double patient load. A digital methodology framework (DMF) will be created in parallel to the actual devices being created. This framework has clear connection points to existing FDA requirements as well as physical, performance, and safety requirements to help facilitate approval and tracking the process from start to finish. The goal is to provide all medical device manufacturers a common platform from which they can build their devices through this digital process and enable FDA to have access as needed. This system will enable manufacturers to iterate on existing designs or generate new ones with greater clarity as to the impact of design changes and choices to requirements compliance, ultimately enabling more confident and expeditious review.

20-18-01 Capacity and Mobilization Assessment of the Pharmaceutical Industry

One critical aspect of the ability for American manufacturing to adapt and proactively respond in times of crisis is the creation of response plans for emergencies before they happen. Due to operational impact, especially in an FDA regulated context, there is little opportunity for manufacturers to test emergency scenarios on physical assets which limits their ability to develop mitigation strategies in advance. Through this project, MxD is implementing digital twin technology to correlate cyber representations of a process and then run emergency scenarios to identify opportunities to increase capacity and throughput. This digital twin will enable multiple scenarios of resource and product mix which empower production planners to model the effects of an emergency and respond. The project will produce a guidebook for other manufacturers' transformation efforts, exploring practical roadblocks such as digitizing legacy equipment and managing enterprise data streams. Additionally, surveys and assessments of the life sciences manufacturing industry will be deployed to baseline the industry's current progress towards transformation and readiness to deploy digital twin technology.

20-16-01 Supply Chain Risk Alert for Wearables

Industry 4.0 is built upon the movement of data along the digital thread. A key challenge experienced by manufacturers in the digital transformation of the supply chain is developing a culture of trust for sharing data between suppliers. Supply chain resiliency is limited by timely access to supply chain data. In addition to moving data along the supply chain, gaining greater visibility into the full supply chain back to the raw materials allows for a deeper analysis of growing risk. The COVID19 pandemic has disrupted supply chains on a global scale and highlighted the need for broader supply chain visibility and greater data sharing to properly identify and proactively mitigate risk.

This program will focus on developing and demonstrating a middleware solution for supply chain risk management that brings together data sources and advanced artificial intelligence (AI) analytics and overlays them with a supplier network:

- Support informed, efficient, and systematic decision making by providing end-to-end visibility into a manufacturer's supply chain
- Improve resiliency by providing advanced warning of supply chain risks to promote proactive risk management
- Mitigate risk by providing a tool to explore alternate supply chains

20-05-01 Achieving Resilience through Proactive Supply Chain Risk Management (Follow-on to 17-02-01)

MxD and its members have identified the need for proactive supply chain analytics solutions that provide advanced warnings of supply chain risks. The COVID-19 pandemic has shined a spotlight on the challenges most manufacturing companies face when it comes to mapping multi-tier supply chains; notably the absence of quantitative methods and metrics for evaluating resilience, anticipating disruptions, and obtaining visibility into manufacturing parts, suppliers, and raw materials. This project will combine best-in-class technology to produce a modularized machine learning-enabled software component (Dynamic Risk Mitigation Engine) that integrates supplier, bill-of-material, and event-based risk information to produce recommendations aimed at preventing supply chain disruptions before they happen.

21-12 Virtual Interaction with Supply Chain Using Digital Twins

A digital twin operating in isolation is useful, but the real rewards that few organizations are able to realize are achieved through making connections. Data integration between multiple sub-components of a digital twin, between multiple digital twins, or between digital twins on separate IT/OT networks, is key when advancing beyond initial use cases. This next step in the evolution of the technology focuses on the ability to connect digital twins across organizations within a supply chain. There are at least three types of relationships for which a digital twin can integrate. The first is Hierarchical, in which digital twins can be grouped together into increasingly complex assemblies. The next is associational, where a virtual twin for one system is connected to a virtual twin in another system. The last is peer-to-peer, for similar or identical equipment or systems working together. The ability to integrate digital twins with each other across organizations within a supply chain will be a differentiating factor in the future as physical assets and equipment evolve.

2022 Projects

22-08 Blockchain for Supply Chain Exploration

Request for Proposals Release: October 2022

Develop a foundational set of use cases with a business benefit and fundamentals of blockchain to begin introducing manufacturers to high impact uses of blockchain. This project will leverage Blockchain work from 17-02-01 and provide demonstrations of Blockchain use cases to explore implementation challenges.

2023 Projects

PP 119 Framework for Interoperability and Integration- Phase 0: Discovery

Request for Proposals Release: February 2023

This project must examine a variety of data formats for a given use case and determine what the gaps in the current models are. For example, what are the data standard requirements for an ERP system technology to communicate seamlessly to another ERP technology.

PP 120 Framework for Interoperability and Integration- Phase I: Data Strategy

Request for Proposals Release: May 2023

A data collection strategy will be the first key element that is required. This strategy will define what data is being collected and how that data will be used to determine X, Y, Z that is of value to the organization (i.e., using absolute vs relative location on a part to determine fitment with a mating part).

PP 121 Framework for Interoperability and Integration- Phase II: Data Cleanse

Request for Proposals Release: July 2023

The requirements of phase 2, utilizes AI/ML algorithms to parse data in a usable fashion. Harmonizing a specific organization's data formats with AI/ML into a standard format can allow the data to be shared with other organizations (assuming they too have API's setup to ingest data in a specific format).

PP 106 Deploying Digital Technologies in SMMs

Request for Proposals Release: October 2023

The solution concept will be a curricula and demonstrations that transfer knowledge in key areas to SMMs and service providers focused on them (e.g., MEPs). These service providers and select SMMs will be trained to train other SMMs and to support the implementation of digital technologies.

2024 Projects

PP 075 Cross-Enterprise Advance Planning and Optimization

Request for Proposals Release: February 2024

The solution will have the ability to exchange data up and down the supply chain (i.e., across the boundaries of firms) in a secure manner to facilitate the planning and optimization by existing applications.

PP 104 Data Collection for Maintenance and Sustainment

Request for Proposals Release: May 2024

The solution concept will define categories of equipment and their failures to create standard Ishikawa diagrams for each category. The solution concept will identify data sources, methods for collecting, transmitting, storing, synthesizing, and visualizing the data to plan maintenance and sustainment activities.

PP 021 Impact of Climate Change on the Supply Chain

Request for Proposals Release: July 2024

Model and predict the impact of climate change on OEM's supplier base for long-range planning.

Cybersecurity

Operational Technology (OT) is hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes and events in the enterprise. OT is common in Industrial Control Systems (ICS) such as a SCADA System. In the world of critical infrastructure, OT may be used to control power stations or public transportation. As this technology advances and converges with networked tech the need for OT security grows exponentially. For many years, industrial systems relied upon proprietary protocols and software, were manually managed and monitored by humans, and had no connection to the outside world. For this reason, they were a fairly insignificant target for hackers as there was no networked interface to attack and nothing to gain or destroy. The only way to infiltrate these systems was to obtain physical access to a terminal and this was no easy task. OT and IT integrated little and did not deal with the same kinds of vulnerabilities. Today, it's a very different story as we see more industrial systems brought online to deliver big data and smart analytics as well as adopt new capabilities and efficiencies through technological integrations. IT-OT convergence gives organizations a single view of industrial systems together with process management solutions that ensure accurate information is delivered to people, machines, switches, sensors and devices at the right time and in the best format. When IT and OT systems work in harmony together, new efficiencies are discovered, systems can be remotely monitored and managed and organizations can realize the same security benefits that are used on administrative IT systems. This transition from closed to open systems has generated a slew of new security risks that need to be addressed. As industrial systems become more connected, they also become more exposed to vulnerabilities. The high cost of industrial equipment and the devastation to communities and economies that an attack could generate are key

factors for organizations looking to protect their industrial networks. Add legacy equipment, safety regulations that may prohibit any modifications being made to equipment and compliance regulations that require sensitive data to be made available to third parties, and you have quite a challenge on your hands. The good news is that it is possible to secure industrial networks without disrupting operations or risking non-compliance. By using solutions that allow complete visibility of network control traffic and establishing the right security policies, you can put an effective OT strategy in place that will protect your processes, people and profit and significantly reduce security vulnerabilities and incidents. More good news is that industrial environments usually have lower volumes of traffic than IT environments. Much of the traffic is traveling between determined endpoints and therefore can be baselined and inventoried more easily than traffic that is generated on an IT network. Using monitoring and analysis tools can help to identify and protect against unauthorized changes and other anomalies that could signal an attack in full progress or in its initial stages.

2021 Projects

20-01-A Supply Chain Cybersecure Dashboard Enhancements (DFARS / CMMC compliance) (Follow-on to 15-01-02)

MxD, in partnership with the Critical Infrastructure Resilience Institute (CIRI) at the University of Illinois at Urbana-Champaign (a DHS Center of Excellence) and several industry partners, developed and delivered the Cybersecure Dashboard (Dashboard) – a cloud-based Software-as-a-Service tool that eases and accelerates implementation of the NIST cyber risk management process. The Dashboard was designed specifically to guide SMMs through the process of assessing and securing their systems by employing an innovative "learn-by-doing" design. All the instructions, reference materials, templates, and tools required to manage the process are contained within the Dashboard, allowing individuals to meet, assess, certify, and manage all aspects of cybersecurity practices postures such as the DFARS[12] and CMMC.[13]

This project builds upon the initial Dashboard, developed through MxD project 15-01-02, to provide DoD contractors and/or DoD acquisition agents with cybersecurity compliance visibility across their supply chain. Tools and reporting capabilities to help inform decision makers about coordinated approaches to find and resolve non-compliance issues will be created. MxD will be offering a 1-year Business Cybersecure Dashboard license from project 20-01-A, to allow prime contractors the ability to assess, not only their own cybersecurity posture, but also providing them with the capability to view and verify their supply chain is certified against NIST/CMMC standards before contracting.

12 https://www.acquisition.gov/dfars
13 https://www.acq.osd.mil/cmmc/

21-39 Cybersecurity Roadshows

Manufacturers face a unique set of challenges in their need to secure both IT and OT assets. MxD launched Cybersecurity Roadshows in 2020 that address these challenges and increase awareness of the cybersecurity threats that manufacturers face, particularly across a supply chain. In partnership with MxD's membership base and regional affiliates, the Cybersecurity Roadshows are a series of programs that target SMMs and will be offered as virtual events as well as in-person in regional pockets across the U.S. to reduce the burden of travel for SMMs. The pilot series will focus on overall awareness building for the manufacturing base and will help SMMs understand what steps can be taken to increase their cyber security.

19-12-02 Enabling Cybersecurity for the Digital Manufacturing Supply Chain

There is a lack of tools and expertise needed to identify and mitigate manufacturing cybersecurity risks, especially for SMMs in the supply chain. MxD released a Request for Proposals in late 2019 for benchmarking and evaluation of intuitive and effective tools for assessing vulnerabilities and providing automated penetration testing of IT/OT assets. These objectives are consistent with the requirements in the NIST Cybersecurity Framework (Version 1.1) for the identification and protection of IT/OT assets. Protection measures are motivated by the risks associated with the information and data about each of the assets in the operating environment. Expected output may include reports on performance of the benchmarked tools, results of asset inventory and vulnerability assessments at various SMMs and opportunities for enhancements to existing tools to better meet the needs of the users in the supply chain.

21-40 Cybersecurity Tabletop exercises

To further enhance the cybersecurity posture of SMMs, MxD and its partners will host a series of Tabletop exercises focused on advanced manufacturing and cybersecurity professionals. MxD will bring participants together in a collaborative environment to increase critical thinking and preparedness under a simulated cyber incident. Those new to Tabletop exercises will learn to respond as a team to coordinate decisions and to uncover cybersecurity gaps that can be corrected with the support of MxD and industry experts.

20-25-01 Pathfinder Phase II: Securing 3D Printers in Manufacturing (Follow-on to 20-15-01)

This project will leverage the risk assessment report, Security Technical Implementation Guide (STIG), and System Security Plan (SSP) from 20-15-01: Pathfinder Phase I: Securing 3D Printers in Manufacturing and work with one 3D additive printer equipment manufacturer to address as many of the solutions that were identified in the initial project. Increasing 3D printer security and reducing barriers to adoption will allow these printers to fully connect to the DoD's enterprise networks thereby increasing across the DoD's facilities.

Additional assessments will be completed after the implementation of Phase I outcomes which will be documented and leveraged for the development of an Additive Manufacturing Cybersecurity Playbook and a Risk Management Framework. The AM Cybersecurity Playbook, which will be made available to the public, will contain a general guide of security best practices for configuration for AM hardware/software components.

21-04-01 Cybersecurity Marketplace

More than 98% of U.S. manufacturers are SMMs, which are defined as having less than 500 employees. Most SMMs view cybersecurity as too complex or too expensive to address. Additionally, SMMs often lack the tools, guidance, and resources (people, technology, and money) to invest in cybersecurity the same way as larger manufacturers and SMMs generally do not know where to begin to implement a cybersecurity program. To be competitive and viable in the United States, SMMs must be prepared to protect their businesses from common cyber-attacks such as ransomware, identity theft, spear phishing, web attacks, and spam. Cybersecurity incidents can have serious impacts on SMMs such as damage to information and systems, production losses, client losses, fines, legal fees, and impact the organization's reputation.

As the National Center for Cybersecurity in Manufacturing, MxD will empower SMMs to kickstart their journey in the world of cybersecurity. MxD is launching the Cybersecurity Marketplace (Marketplace), a one-stop shop for tools and services ranging from security assessments to endpoint solutions. The Marketplace will serve as a web portal offering tools and services that empower Small and Medium Manufacturers (SMMs) to assess and act on their cybersecurity needs quickly and cost-effectively. The portal will provide affordable cybersecurity surveys utilizing the National Institute of Standards and Technology (NIST), the Cybersecurity Framework (CSF), and SP800-171 as well as DoD's Cybersecurity Maturity Model Certification (CMMC) to allow SMMs to understand their current status. MxD intends to stand up the Marketplace through a "white label" partnership with RealCISO, the Marketplace partner. Bringing together established 3rd party security providers to address the unique needs of manufacturers will help increase the overall cybersecurity hygiene of the U.S. manufacturing supply chain.

21-07 Secure Wireless for Factory Operations

Manufacturers are looking to adopt emerging wireless technologies into their facilities to benefit from communication protocols such as 5G cellular, WiFi 6, Ultrawideband (UWB), and other protocols. This project will provide manufacturers with information about the strengths and weaknesses of each protocol including cybersecurity related issues. Tools along with "best practices" will be identified to minimize or mitigate any risks. A testbed will be developed and installed at the MxD future factory to help visitors understand the strengths and weaknesses of the different protocols. This testbed, once completed, will be made available to members to allow testing of their hardware and software solutions.

21-11 Security Solutions for OT Factory Equipment

With a growing number of digital manufacturing solutions available for manufacturers to increase operations efficiency, a connected factory floor with networked OT equipment is quickly becoming a necessity to remain competitive in American manufacturing. As more manufacturing equipment is connected to a network, the risks and vulnerabilities grow. Many manufacturing companies lack the cybersecurity resources to understand the cyber threats and how to prepare for a connected shop floor. Manufacturers are not sure where to start, what cybersecurity tools they need, or how to implement them effectively in their operations. Making cybersecurity tools available to keep OT equipment secure without interrupting operations is a key need for the manufacturing community. This project seeks to create an easily understood step-by-step guide for achieving proper cybersecurity measures on a connected manufacturing floor. MxD aims to accelerate the availability and adoption of cybersecurity tools in the manufacturing OT environment to protect both new and legacy factory equipment.

2022 Projects

22-10 Operations Technology Test Methods

Request for Proposals Release: April 2022

Successfully testing and securing IT/OT environments requires clear justification of the need for assessing them and it must address OT system sensitivity and proliferation. The solution concept will demonstrate the application of these methods, identify gaps in technologies, and create an implementation guide.

22-11 Addressing Security Gaps/Vulnerabilities in 3rd Party COTS Solutions

Request for Proposals Release: June 2022

The objective of this project is to explore controls that can be implemented to secure production assets and enable operations for manufacturers with these COTS products.

22-12 Cybersecurity for Operations Technology

Request for Proposals Release: August 2022

The solution concept will identify and bridge gaps in the ISA and NIST documents. The solution concept will define deployments representative of key market segments (e.g., complex electronics and medical devices, transportation and industrial machinery, and process industries). The solution concept will demonstrate the deployment of the updated standards and guidelines. The solution concept will create an implementation guide for the key market segments.

22-13 Attack Simulation using AI and Digital Twins

Request for Proposals Release: November 2022

Develop a set of tools which will a) Simulate future potential cybersecurity attacks by building an AI that learns from historical attacks to create new scenarios, b) Educate DoD and manufacturing personnel on how to identify and respond to these new types of attacks, c) Generate data for Predictive and Prescriptive AI for Securing the Factory and Predictive and Prescriptive AI for Securing the Supply Chain.

2023 Projects

PP 109 Application of Existing Standards and Guidelines to OT

Request for Proposals Release: February 2023

The solution concept will identify and bridge gaps in the ISA and NIST documents. The solution concept will define deployments representative of key market segments (e.g., complex electronics and medical devices, transportation and industrial machinery, and process industries). The solution concept will demonstrate the deployment of the updated standards and guidelines. The solution concept will create an implementation guide for the key market segments.

PP 111 Managed Detection and Response for OT

Request for Proposals Release: June 2023

OT threat analysis should focus on suspicious activities and on the semantics of the industrial processes running on critical devices. A methodological approach to address growing advanced OT cyber-threats starts with an understanding of the system that needs to be protected. The solution concept will demonstrate the application of these methods, identify gaps in technologies, and create an implementation guide.

PP 027 Cybersecurity in a Process Environment Using a Digital Twin

Request for Proposals Release: October 2023

Follow-on to 19-04 (Digital Twins for Process Manufacturing) focused on implementing Cybersecurity use cases on the physical skid and its digital twin.

2024 Projects

PP 118 Approaches to Address Insecure Operational Protocols in OT

Request for Proposals Release: February 2024

Industrial control protocols were designed without strong security requirements and their operation was assumed within a secure environment. The solution concept will explore ways to secure these industrial protocols, demonstrate the application of these methods, and create implementation guides.

PP 026 Authentication and Validation of End Points for Wireless-Enabled Factory Operations

Request for Proposals Release: June 2024

The objective of this project is to better understand the scope of the changes and risks brought on by these deployments and seek solutions for the identification, validation, and authentication of these devices.

PP 113 Protecting OT Data with Edge Computing

Request for Proposals Release: October 2024

Newer instrument technologies will communicate with resources in the cloud as well as with traditional IT-OT systems. This will increase complexity and cause challenges in visibility across the IT-OT-cloud divides. Future visibility technologies will have to work across a wide gamut of disparate systems that make use of the whole IT/OT Cloud system.

Workforce Development

2021 Projects and Beyond

19-06-01 Advanced Manufacturing High School Curriculum

MxD Learn offers a three-year high school curriculum program designed to develop the "multi-skilled technician." The curriculum ranges from basic IT and employability skills to materials science to core and advanced technology. The curriculum offers enough breadth to raise awareness of career opportunities in advanced manufacturing and the skills required for specialties, while also offering enough depth to provide students with hands-on learning opportunities and the potential for dual enrollment at a local community college. The Siemens Foundation generously provided a grant to support the launch of this program in the fall of 2019 in partnership with Waukegan High School and the College of Lake County. Over 150 students are currently enrolled in the program at Waukegan High School. In response to the Covid-19 pandemic, strategies for virtual learning have been employed including the development of a hands-on "toolbox," supported by inputs and resources from industry partners, for the students to engage with manufacturing-related skills development while learning and attending school from home.

19-09-01 Community College Advanced Manufacturing and Cybersecurity Apprenticeships

Perhaps the most critical component of a workforce development program is providing the opportunity to actually DO the job. Providing internship and apprenticeship opportunities benefits future workers by allowing them the chance to try the work, ensuring a good fit and providing workers with portable and recognized credentials, while getting paid for the job. Internships and apprenticeships also benefit employers. According to the Department of Labor, 91 percent of apprentices that complete a registered apprenticeship are still employed 9 months later.[14] Additionally, apprenticeships boost retention. A study by the Department for Business, Innovation & Skills and the Department of Education in the UK found that the average retention rate for apprentices in England – across all sectors – was 73 percent.[15] Funding awarded to MxD Learn through the Siemens Foundation is supporting apprenticeships at the College of Lake County (Grayslake, IL) in the areas of ARM (Automation, Robotics and Mechatronics) and CNC (Computer Numerical Controls). The funding has also supported development of a pipeline of talented youth and young adults with increased manufacturing career interest in ARM & CNC, and integration of cybersecurity for manufacturing skills. Development of the apprenticeship pipeline program continues to target under-resourced school districts, and employer outreach strategies have been targeted toward Small and Midsize Manufacturers. Apprentice living stipends and tuition are funded through the grant while they continue attending school to complete an Associate degree or career certificate. In Fall of 2021, 10 manufacturing apprentices were supported at College of Lake County through the Siemens Foundation funds administered by MxD Learn. MxD Learn continues to collaborate in future plans for the partnership including opportunities to leverage College of Lake County's Advanced Technology Center which is slated to open in Fall 2022.

19-08-01 FlexFactor: Introducing Students to Advanced Manufacturing Engineering Education and Careers in Multidisciplinary Design and Manufacturing Environments

MxD Learn was awarded a grant through the Office of Naval Research Manufacturing Engineering Education Program (MEEP) and NextFlex, to scale and launch the NextFlex FlexFactor program in expanding education and awareness of digital manufacturing careers. FlexFactor challenges students to work in teams to identify a real-world problem, conceptualize an advanced hardware solution, and build a business model around it. At the end of the program, what students will do will be to pitch their ideas to a professional panel.

14 https://www.dol.gov/apprenticeship/toolkit/toolkitfaq.htm#2a
15 https://www.americanprogress.org/issues/economy/news/2014/07/14/93768/the-bottom-line-apprenticeships-are-good-for-business/

Through direct industry engagement with future-focused companies and high-performance workplaces, FlexFactor brings real-world experiences to students, allowing them to see how advanced materials and electronic devices combine to create innovative solutions for a diverse range of problems. In addition, students engage with the education pathways at local colleges and universities that will help them gain the knowledge and skills needed in order to join the workforce of the future. The program's agile framework allows it to embed in any classroom in a way that's very easy for the classroom teacher. It is applicable across a wide range of subject areas, including English, economics, fashion design, robotics, biology, engineering design, and many others, making any classroom a career technical education classroom. The program is structured in a way that is appealing and fun, using a student-led learning approach that allows participants to address real-world problems that hold meaning for them, including everything from cancer treatment and infant mortality to waste management and athletic performance.

20-09-01 Cybersecurity for Manufacturing Operational Technology Curriculum (CyMOT)

Through a grant awarded by the Office of Local Defense Community Collaboration (OLDCC), University of Maryland, Baltimore County (UMBC), a leader in cybersecurity education, and MxD Learn, collaborated in DEVELOPING a curriculum that addresses the cybersecurity workforce needs for operational manufacturing technology (OT). Leveraging the MxD Learn Hiring Guide and the development and dissemination of training opportunities and career pathways, this project created a curriculum that targets adult learners who are looking to increase their skills at the intersection of cybersecurity and manufacturing. The objective of the curriculum program is to provide current workers with learning opportunities that result in professional certification(s), giving them the tools necessary to execute careers in cybersecurity in manufacturing and increasing the security of U.S. manufacturers from cyber-attacks.

Phase I of the project, completed in September 2021, developed an initial framework for CyMOT on top of the Moodle open-source learning platform and three short courses focused on Cybersecurity Fundamentals, Manufacturing Cyber Systems Operation, and Operational Technology Cybersecurity. The Cybersecurity Fundamentals course was piloted in February 2021 with 25 students attending from ten manufacturing companies, including large, midsize, and small manufacturers. The Cybersecurity Manufacturing Systems Operator Fundamentals course was piloted in April with an 88% retention rate and 80% completion rate in the first two pilot courses. Operational Technology Cybersecurity for Manufacturing was offered in August. The three courses offered in CyMOT Phase 1 validate the 14 competencies of the Manufacturing Cybersecurity Systems Operator role as defined in the MxD Hiring Guide. With the completion of the three CyMOT pilot courses, participants met the requirements of a first- of-its-kind Certificate in Manufacturing Cybersecurity Systems Operation. The Manufacturing Cybersecurity Concept Inventory developed by the team was used to establish a baseline of student knowledge before taking the course and as a post-course exam and assess the quality of instruction based on student performance. A beta version of CyMOT is available (**https://cymot.org**). The Cyber Systems Operator Certificate courses have also been adapted to asynchronous delivery and ported to the MxD Virtual Training Center with an anticipated launch of March 2022.

The Phase II proposal for CyMOT follow-on funding was submitted to OLDCC in 2021 with the goal of additional course and certificate development. Further opportunities to expand the impact of CyMOT include adapting content to community college students, transitioning service members, and under-served populations. The goal of CyMOT is to upskill employees of manufacturing companies in the Defense Industrial Base (DIB) and create a pipeline of talent in cybersecurity for manufacturing for the DIB. With the growing need for workforce in the area of cybersecurity for the DIB, CyMOT is poised to play a critical role. Our pilot with the first cohort has already demonstrated the effectiveness of CyMOT. Both qualitative and quantitative metrics of evaluation, CyMOT is already having an impact in producing the next set of experts in cybersecurity for manufacturing.

20-20-01 NIST Manufacturing USA National Emergency Assistance Program

MxD Learn collaborated with America Makes in the Career Pathways Roadmap (AMCPR) project funded by the NIST Manufacturing USA National Emergency Assistance Program, issued in response to the critical challenges facing the manufacturing workforce resulting from the Covid-19 pandemic. AMCPR will offer several opportunities to prepare the workforce for the current and future crises, specifically through diverse eLearning content and validated credentials. The advanced manufacturing supply chain would greatly benefit from an integrated pathway starting with a high level of awareness related to enhanced agility during times of national crisis – as well as during times of normal operation – by reducing barriers impeding entry into new markets or initiating new approaches as national demands naturally evolve.

The project engages in the creation and deployment of diversified content for the “new normal” of virtual instruction. MxD Learn played an important role in building, piloting and deploying a series of eleven eLearning modules created in collaboration with America Makes and Bull City Learning utilizing institute established and vetted content and curricula. Dynamic eLearning modules will align to America Makes Digital Badges, which was created in collaboration with FabLab Hubs within Safety, Introduction to 3D Printing, and FDM Processes. MxD Learn was employed in building content areas focused on cybersecurity and digital manufacturing. Engaged learners will reskill and upskill through micro-learning, gaining industry built Digital Badges. MxD will employ MxD Learn for full integration of cyber-security and digital manufacturing linkages.

In 2022, MxD will continue in partnership with America Makes to promote these eLearning modules to K-12 students, through outreach to teachers and parents. This learning content can also be used to engage with students visiting the MxD Future Factory on fundamental knowledge related to additive manufacturing and cyber-security. A landing page for access to the program will be made available through the MxD website in early 2022.

20-21-01 The Connecticut Defense Manufacturing Community Consortium (CDMCC)

Through the Office of Economic adjustment, $1.4 million was awarded to the Connecticut Department of Economic and Community Development to establish a Defense Manufacturing Community Support Program (DMCSP). The CDMCC will undertake a project to enhance in-state defense prime manufacturing vertical supply chains and bring Model Based Definition technology to each, in an effort to transform the supply chain from a 2-dimensional design and manufacturing platform to a 3-dimensional platform. The technology and processes developed through the Digital Model Initiative will provide a foundation for subsequent digital transformation initiatives in the defense manufacturing supply base. MxD Learn, as a sub awardee, will contribute the workforce development component to this project in building from and expanding upon the emerging work roles identified in the Digital Manufacturing and Design Jobs Taxonomy, developed in partnership with ManpowerGroup.

MxD Learn is supporting this pilot program initiative to introduce the Connecticut Defense Manufacturing Region to MBD technologies and methods, with a long-term goal of facilitating larger integration among upwards of 700 supply chain companies through lessons learned during an initial pilot program. To complement the adoption of this technology by the Connecticut Defense Manufacturing Region, the necessary workforce development training will be developed to facilitate know-how and upskill incumbent workers and new workforce entrants.

Project outcomes include development of a 24-month pilot program that would take two companies from each OEM supply chain to learn about, integrate, and fully transition to MBD. Lessons learned throughout this process will be used to build a “Digital Playbook”, which will contain the educational and technical principles necessary for wider adoption by the State’s upwards of 700 defense supply chain companies beyond this pilot. MxD Learn will lead the effort on transformational skills and roles definitions needed to align with the technology and business outcomes while developing long-term demand-driven education and training resources.

20-22-01 Digital Design & Advanced Manufacturing Workforce Development Program

With funding awarded through the Defense Logistics Agency (DLA), MxD Learn has partnered with Drexel University to **DEVELOP** and launch the Drexel Digital Design & Advanced Manufacturing Program (D3-AMP). D3-AMP is an education and workforce development program for professionals working in engineering-related industries, including automotive, aerospace, biomedical, naval, and manufacturing. D3AMP is designed to provide hands-on experience on digital design workflows, while it also leverages advanced manufacturing methods and emphasizes Industry 4.0 practices. Specifically, the workshop aims to provide digital modeling training, related to digitally threaded production concepts, and enhance it with simulation and optimization methodologies within model-based requirement definition approaches. The program also emphasizes customization based on stakeholder and performance needs that fit the emerging digital enterprise practices.

The D3-AMP is comprised of three interconnected modules which are designed to accommodate participants with varying levels of experience. Specifically, a level-setting, online and asynchronous pre-program offered through the MxD Learn Virtual Training Center (Module 1) focuses on digital design fundamentals. Next, a synchronous, onsite or remote learning experience of digital manufacturing methodologies has been developed, leveraging the capabilities of the MxD facility in Chicago, IL (Module 2). The D3-AMP concludes with a final project where participants work on their own products, while being offered individualized and project-specific consultation in a one-to-one basis (Module 3). The overall objective of the program is to guide the participant through a digitally connected design path that includes all stages from conceptualization to final product manufacturing and lifecycle. D3-AMP will emphasize both the fundamental and applied elements of digital design, utilizing Drexel University's educational experience in partnership with MxD.

21-03-01 Virtual Training Center Platform

The MxD Learn Virtual Training Center (VTC) will enhance MxD's manufacturing partner capabilities, collaboration, and accessibility by effectively enabling: (a) virtual manufacturing workforce education and development, including serving as a repository of curriculum, career pathways information, and other workforce-related resources; (b) risk management and compliance for adoption of cybersecurity for manufacturing practices; and (c) digitization/innovation for defense manufacturing processes and supply chains.

Core content will be hosted by MxD, while member partners and their broader networks of Industry, Academia, Government, and Workforce and Economic Development organizations will provide guidance, assist with content creation and dissemination. The platform will host both existing workforce content in cybersecurity and innovation from the MxD portfolio, as well as content to be developed via Institute partnerships. The goal of the VTC is to provide regional manufacturers with a first of its kind platform to recruit and develop workers, innovate and utilize cutting edge technologies, and secure the resiliency of their individual organization and throughout the supply chain. Platform users will include learners, educators, job providers, and manufacturing technology professionals. Users will be able to access, complete, and track virtual training programs, career pathways information, webinars, and other professional development tools such as micro-credentials, skills assessments, and mentorship opportunities.

21-08-01 Digital and Cybersecurity Awareness for the Blue Economy/Water Workforce

MxD Learn has identified the Chicago-Milwaukee Interstate 94 (I-94) Corridor as a critical region for innovative education and workforce development programs related to digital manufacturing and cybersecurity for manufacturing. The defined I-94 Corridor region faces challenges in filling significant skills gaps with a geographically fragmented and increasingly aging workforce and transportation infrastructure. In partnership with strategic regional stakeholders, across what is described as the "world's freshwater hub", MxD has identified the region's freshwater resources as providing a key industrial, social, environmental, and political link to fostering innovation in manufacturing workforce development. Partnerships such as The Milwaukee Water Council and The Freshwater Collaborative of Wisconsin, and Current, a water innovation non-profit in Chicago, are dedicated to fostering sustainable economic growth through renewed relationships between industry, people, and the freshwater resources driving the region's "blue economy".

MxD will function as a convener and coordinator across labor sheds and jurisdictions, to spur strategic efforts toward a resilient manufacturing workforce pipeline. This initiative will be achieved through a series of one-day topic-focused workshops leveraging the assets of MxD's Future Factory in Chicago. MxD will foster new collaborations with leaders of the regional water economy to identify digital and cyber water workforce needs and opportunities, and to partner in promotion of the Regional Jump-Start Initiative. The MxD workshop series will be targeted toward water industry facilities such as water plants, and manufacturers of food, beverage, pharmaceuticals, and chemicals. The workshop topics and content will draw from several key demonstration testbeds of MxD's Future Factory, allowing participants to engage in hands-on training and real-life application of digital and cyber skills and knowledge. Worker profiles defining job roles and capabilities of water industry cybersecurity professionals will be developed to complement the workshops and help define the target workforce.

Success in this Regional Jump-Start Initiative will open the door to continued opportunities for collaboration in workforce development strategies between the freshwater and manufacturing industries and infrastructure of the Chicago-Milwaukee region. Leveraging the opportunities available through MxD's Future Factory, further initiatives to integrate digital and cybersecurity technologies into regional workforce development efforts would include pipeline development and career awareness centered on K-12 and community college programs, as well as the creation of training materials and competency-based credentials targeted toward displaced workers and veterans.

21-20-01 Sinclair Community College Digital Manufacturing Training

Sinclair Community College (Dayton, OH) has received $4.1 million, over 3 years, from global aerospace and defense contractor ARCTOS Technology Solutions to develop smart manufacturing technologies and training programs for students and employers. Sinclair is one of three community colleges receiving funding from ARCTOS through a $13 million Task Order by the Air Force Research Lab (AFRL). Sinclair will use the funding to develop "digital thread" smart manufacturing programs for students and employers involving digital design/digital manufacturing, Industry 4.0 technologies, and industrial IoT (internet of things).

MxD Learn's role in this project is to lead on employing a Train the Trainer virtual program designed to provide "hands-on" experience on a digital product design and manufacturing workflow, support Sinclair in development of credit-based and non-credit-based training and education programs that are industry-informed, and advise on Sinclair's plans in developing a Smart Manufacturing Learning Center to give employers and students hands-on experience with digital thread technologies, introducing a new short-term digital thread certificate program, and developing training programs for Dayton region companies to increase awareness and adoption of digital thread technologies. Use of MxD's Cyber Box to visually show how the use of cybersecurity standards and protocols protect digital manufacturing enterprises is included as a component of this project.

21-22-01 TRACKS-CN

Technologies involving robotics/automation have become prevalent in US manufacturing and service sectors. Business leaders who adopt these technologies must prioritize cybersecurity to ensure the safety and security of their cyber-physical systems. As a result, the interrelated areas of robotics/automation and cybersecurity are vital to US manufacturers. This project will create an Advanced Technological Education (ATE) Coordination Network that includes community colleges with active ATE projects, Manufacturing Extension Partnerships, Manufacturing USA Institutes, and the National Initiative for Cybersecurity Education. The goal of this Coordination Network is to increase members' understanding of the knowledge and skills required to operate and maintain connected machines securely in a manufacturing setting.

Through workshops, virtual communication, and other modalities, MxD Learn's participation in this Coordination Network intends to facilitate the sharing of best practices about how to develop community college students' knowledge and skills in robotics/automation and cybersecurity. It will also promote awareness of organizations and resources that connect students to work-based learning opportunities. This Coordination Network will connect community college students to potential employers in the Manufacturing Extension Partnerships client base. By establishing connections and nurturing relationships among members, it is expected that the efforts of the Coordination Network will create synergies that magnify and broaden the impact of individual efforts. The Coordination Network's web portal will make education and training materials available to non-members.

21-35-01 The Hiring Guide: Cybersecurity in Manufacturing

MxD's *Hiring Guide: Cybersecurity in Manufacturing* (the Hiring Guide), was released in August 2020 and addresses an urgent need facing all of U.S. manufacturing, the building of a manufacturing cybersecurity workforce. In collaboration with MxD, representatives and contributors from over 25 organizations, and in partnership with ManpowerGroup, MxD Learn is leading the release of the Hiring Guide and subsequent outputs keeping pace with the evolving cybersecurity needs of manufacturers and the continued demand for skilled cyber workers.

Essential to the **DEFINE** phase of the MxD Learn strategy, the Hiring Guide identifies 247 cybersecurity job roles in manufacturing — some current, some future — that span across 7 work domains of the manufacturing enterprise, holistically addressing the critical hubs of cybersecurity integration into digital manufacturing from readiness and change to governance and policy, IT and OT integrations, compliance, legal and cyber forensics. The Guide builds on the Digital Manufacturing and Design Jobs Taxonomy completed in 2017 and integrates resources from MxD's digital and cybersecurity project portfolio and Future Factory. The Hiring Guide components, initially including three detailed role Success Profiles and eight Career Paths, address and consider future technology horizons for cybersecurity in manufacturing including AI/machine learning, blockchain, cyber-physical systems integration, 5G networking, cloud and edge computing, and biometrics.

The Hiring Guide is targeted toward manufacturing executives, HR departments, educators and policy makers. The goal is to illuminate the path for upskilling current workers, inform high school and college curricula, and become an indispensable playbook for cyber in manufacturing workforce planning.

Funding awarded through the Siemens Foundation has launched the development of seven additional Success Profiles and seven additional Career Pathways. This next phase of work on the Hiring Guide focuses on future technology horizons in cybersecurity for manufacturing. Additional focus is placed on the buildout of success profiles and career paths targeted to supporting underserved populations. It is important to expand diversity and inclusion in the manufacturing workforce and address the key challenges that arise in digital innovation. There is an emphasis placed on cybersecurity for SMMs and on fortifying supply chains impacted by Covid-19. This is a continuing project with the first set of deliverables released in 2021, and a second set to be released by June of 2022, providing additional opportunities for industry investment into developing additional Hiring Guide outputs and implementations.

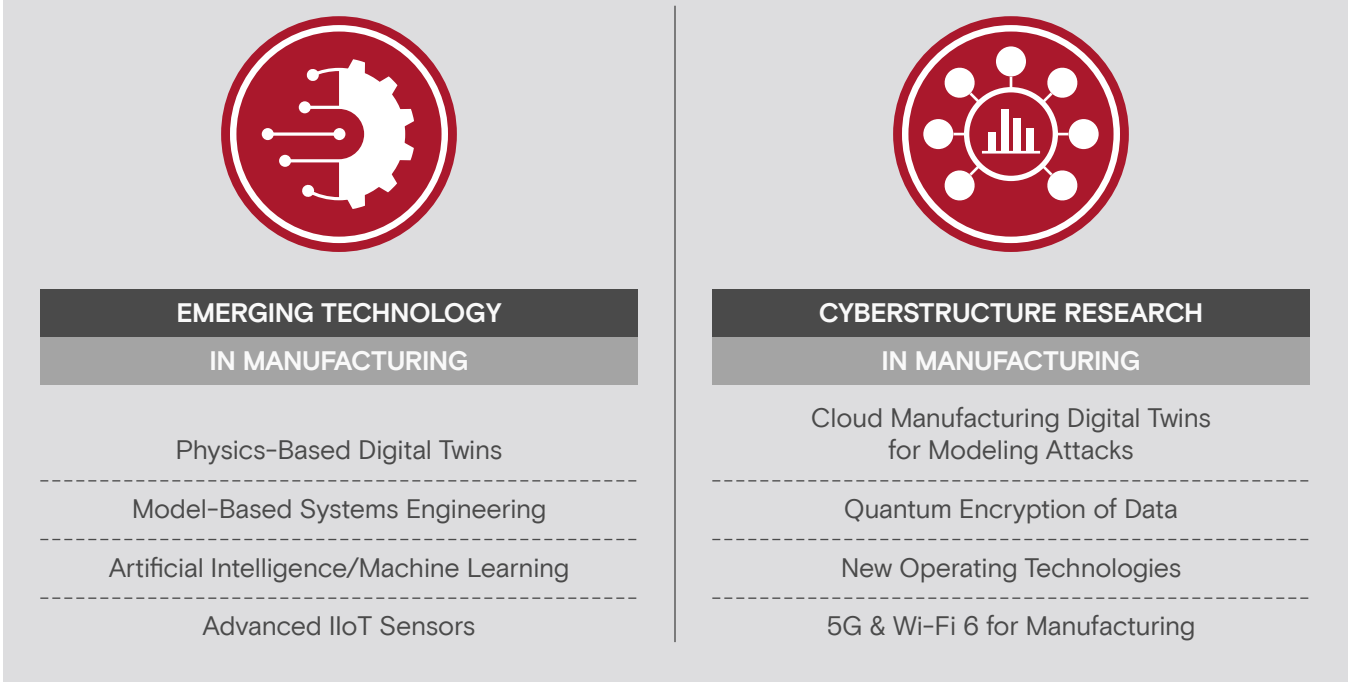
Emerging Technologies

MxD is committed to improving U.S. manufacturing competitiveness and engaging at the leading edge of emerging digital technologies that can deliver innovative capabilities giving manufacturers that critical advantage. Technology breakthroughs can be unpredictable, but MxD keeps a pulse on emerging technologies through its cross-cutting partner network and internal expertise. In this space, MxD plays an important role in connecting industry partners with the resources they need to better understand novel technologies that will have the highest impact on their businesses. MxD is coming together with its industry partners to provide funding, guidance, and feedback for early stage, applied research in emerging technologies. In this effort, MxD released a project call for a series of rapid de-risking projects of one or more emerging technologies in 3Q20 (See Figure 8) and again in 3Q21. Through early engagement with industry stakeholders, MxD established broad subject areas to provide researchers the flexibility to shape their work to have maximum impact in the future based on their expertise. MxD is funding multiple projects (from each category) to support academic institutions in the furtherment of early stage (TRL 3-6) applied research in the areas of emerging technology in manufacturing, and cybersecurity research in manufacturing. MxD is committed to finding an industry match for these proposals which ensures projects are focused on delivering value to the MxD ecosystem.

The value for these projects will be developed over a three-year period with the assumption that the team has met the annual deliverables to continue funding the project over that time. At the end of the three years, these projects will either feed into future R&D projects at MxD or be picked up by the industry sponsor. The roadmap below shows the timeline for the initial projects and ensuing calls, which will generally fall in the Q3 timeline. This enables a streamlined process so that currently funded teams can submit requests for follow on funding.

Figure 8

Emerging Technology Topics Areas



While there will continue to be an emphasis on the topics listed in Figure 8, additional topics of interest will be considered throughout 2022-2024. This program is a great opportunity for industry to leverage and find ways to help expand on their interests. Overall, in this space, there are three main themes that appear critical to the future development of the digital thread for MxD membership. These themes are:

- Physical process knowledge and improvement
- Digital process knowledge and improvement
- Cybersecurity

The objective of the physical process knowledge and improvement theme is to better understand critical metrics within the physical space (machines and process) and develop physics-based models that can assist in optimizing either the machine parameters or entire processes. This will improve predictive quality to ensure corrections can be made in real-time and thus minimize scrap. Naturally, this will require investment in AI and ML as it applies to sensors and platforms that can be utilized to model and predict machine capabilities across the supply chain.

The digital process knowledge and improvement theme revolves around enhancing the digital twin by moving away from singularly focused digital twin solutions towards a holistic model of interconnected digital twins that represent the entire manufacturing lifecycle. To achieve this, it is important to establish a framework that will enable models from multiple inputs to communicate easily though various methodologies. A critical foundational element of this work is enhancing the standard model-based definition (MBD) by including additional components beyond shape and then merging the MBD with the digital twin. Once successful, it would be possible to develop a digital twin for a discrete manufacturing process that could then grow into other areas. This could run in parallel with the physical process knowledge described above to match and learn from the physical outcomes to help build the connections quickly.

Another area for consideration in this theme is connecting design to production with virtual digital assembly. The goal of this work is to create the foundation of the product-level quality system for the digital thread. By using data captured from the product in the physical space, it is then possible to provide feedback to an engineer so they can see what manufacturing processes are available and what the outcomes of product would be, if selected. The merger between the physical and virtual space is critical.

The final theme, cybersecurity, is integral because digital advancements can create organizational vulnerabilities if not properly secured. MxD provides members two-fold benefit: research and development opportunities in emerging technological advancements coupled with cybersecurity solutions to protect enhanced manufacturing assets. The projects listed in the previous section are taking the step at defining some of the essential areas that are required for the growth in the digital arena. It is critical to develop more technologies in the physical space as well as understanding how to take advantage of technologies 5G & Wi-Fi 6 for Manufacturing while maintain the needed security.

2021 Projects

A total of six projects were selected for funding in 2020 (three in Emerging Technology in Manufacturing and three in Cybersecurity Research in Manufacturing). These projects all have an industrial partner and clear metrics that will need to be met to ensure continued funding. This section provides a general overview of the topics that are currently being supported to ensure future proposals are in alignment with, and not duplicative of, the current efforts.

EMERGING TECHNOLOGY IN MANUFACTURING

20-11-01 Securing Voice Control Technology in Manufacturing Via Cross-Domain Low-Effort Authentication

This project will utilize the similarity between the unique voice characteristics in the aerial speech vibration and the traditional audio domain voice to protect highly critical commands from various audio attacks in voice assistants in manufacturing. This project aims to design cross-domain low-effort authentication to defeat various attacks on manufacturing voice assistant systems including impersonation attacks, replay attacks and hidden voice attacks.

20-11-04 Physics-Guided Machine Learning (PGML) for CNC Milling

This project will combine machine learning, physics-based models, and in-process data to provide physics-guided machine learning (PGML) that improves the accuracy, physical consistency, and generalizability of model predictions over traditional machine learning and physics-based methods individually. Through the PGML approach, a 50% reduction in machining costs for a non-proprietary integral blade rotor are expected.

20-11-09 Model-Based Systems Engineering for Digital Manufacturing: A Proof-of-Concept

This project will provide decision makers with a methodology aimed at capturing manufacturing and production system considerations in a model-based environment, hence allowing for the connection and integration of product design, manufacturing and production models and data through an authoritative source of truth. The approach considers the “As Designed”, “As Buit,” and “As Used” phases of the product’s lifecycle and will be demonstrated on a representative aircraft system (e.g., wing).

CYBERSECURITY RESEARCH IN MANUFACTURING

20-11-10 Cyber Threat Mission Builder

This project will design and implement a Graphical User Interface (GUI)-based Cyber Threat Mission Builder System that will be augmented by a robust virtual environment and a database of Techniques, Tactics, and Procedures (TTPs) and Common Vulnerability Exposure (CVE) data. The system would facilitate the development of attack models and implementation of a testbed for training of future cybersecurity professionals for the manufacturing sector.

20-11-11 Development of Manufacturing Equipment Digital Twin and Integration with Cyber-Physical Emulation Test Range

This project will develop a digital twin platform for networked manufacturing equipment that models both the physics-based movement of the machine and the controller of the machine. This Manufacturing Equipment Digital Twin (MEDT) will be connected to an existing network test range for evaluation of the robustness of the machine to cyberattacks attempting to modify the parameters of production parts.

20-11-13 Privacy-preserving Analytics for Smart Manufacturing

This project will develop a new privacy-preserving technique, Mosaic Gradient Perturbation (MGP), to reduce the risk of model inversion attacks in manufacturing applications. The proposed approach will capitalize on the power of data analytics to protect data privacy and build smart manufacturing systems. In addition, the goal is to develop a distributed computing version of privacy algorithms for the IIoT space.

2022 Projects

Four Emerging Technology in Manufacturing projects were selected for funding in 2021. These projects all have an industrial partner and clear metrics that will need to be met to ensure continued funding. This section provides a general overview of the topics that are currently being supported to ensure future proposals are in alignment with, and not duplicative of, the current efforts.

21-10-02 Machine Learning-based Quality Improvement for Thermal Energy Cutting Processes

This project will develop and validate a smart digital tool that automatically collects process and quality data and uses the data to directly provide process control feedback to the operator and process planner to assist part quality control for a manufacturing process.

21-10-03 Product Lifecycle Data Analysis and Error Identification Using Deep Learning

This project will develop a transfer learning, artificial intelligence model to characterize the PLM system in use at one of MxD's academic partners. The model will ingest the thousands of parts in the PLM system and provide automated analysis on naming conventions, metadata, duplicates and other anomalies in the data populating the PLM system.

21-10-04 Secure Digital Twin Incorporating Physics-Aware Machine Learning for Additive Manufacturing

This project will develop and deploy a near-real-time digital twin framework to securely, reliably and efficiently achieve the best part quality and desired graded material microstructure. The digital twin with leverage physics-aware machine learning capabilities to connect sensor and process parameter output to microstructure and properties, high speed GPU computing to enable real-time control and cybersecurity principles to support trust/assurance and provenance in manufacturing line security.

21-10-06 Understanding Discrepancy Between Design and Implementation of Inventory Policies

This project will develop a framework to investigate the discrepancies between designed inventory policies and their practical implementation. The framework will be implemented in Python and will enable the inference and interpretation needed to determine the causes for discrepancies between the model optimization and practice and provide the mechanism to harmonize them.

APPENDIX A:

2022–2024 Project Concept Roadmaps

Strategic Investment Plan

(2022–2024)

Figure 9

Digital Engineering Project Roadmap 2022-2024

ID#	Program Name	RFP Release/ Project Start	Period of Performance
21-01	AI design advisor	3/25/2021	12
21-30	Digital data management for transcribing structural part performance across manufacturing platforms	3/1/2022	18
22-01	Technical data as a service	3/1/2022	12
22-02	Model-based-enterprise readiness index and maturity model upgrade and harmonization	4/1/2022	9
22-05	Digital twin of product sustainment phase	7/1/2022	12
22-09	2022 design project	11/1/2022	9
PP-079	Rapid innovation with digital technologies	5/1/2023	9
PP-076	Virtual cradle to grave design environment	10/1/2023	12
PP-080	Design for sustainability in products and supply chains	2/1/2024	12
PP-090	Design for sustainment in products and supply chains	7/1/2024	12

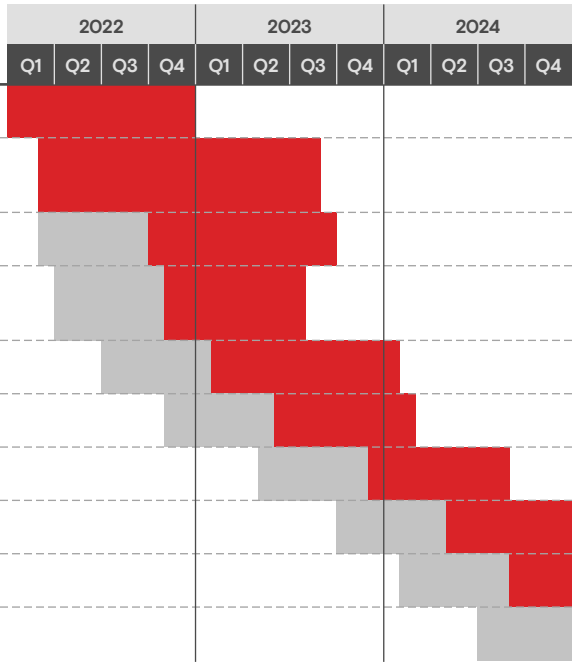


Figure 10

Future Factory Project Roadmap 2022-2024

ID#	Program Name	RFP Release/ Project Start	Period of Performance
20-13-01	Docent technology transfer (Follow-on to 17-04-01)	9/16/2020	18
19-02-01	Closed-loop measurement control for enhanced robotic performance	8/27/2019	18
19-13-05	Operator 4.0 via fatigue and motion analyses in a human digital twin enabled framework for smart manufacturing	12/13/2019	12
20-02-07	Smart monitoring and automated real-time visual inspection of sealant application	3/12/2020	18
20-04-01	Maximizing your ROI from digital technology as a small manufacturer	4/9/2020	8
21-19	Paladin Howitzer Model Based Enterprise R&D Demonstration	1/1/2022	18
21-36	Rock Island Arsenal modernization	2/1/2022	18
21-18	5G manufacturing testbeds for military and dual-use applications	3/1/2022	24
21-06	Dynamic scheduling & control for factory operations optimization	9/9/2021	15
21-14	Predictive maintenance in manufacturing	11/17/2021	9
22-03	Digital manufacturing playbooks	5/1/2022	9
22-06	Operator health tracking	8/1/2022	9
22-07	Track and trace spanning the factory and supply chain	9/1/2022	12
PP-010	Digitalization and visualization of component defects	2/1/2023	9
PP-100	Data interoperability for industry 4.0	5/1/2023	9
PP-041	Unifying the model-based definition and the digital twin	7/1/2023	12
PP-017	Predictive maintenance in a process environment using a digital twin	10/1/2023	9
PP-077	Virtual inspection of manufacturing	2/1/2024	9
PP-011	Integrated CNC digital twin	5/1/2024	9
PP-019	Real-time inventory tracking	7/1/2024	9
PP-102	AR/VR in maintenance	10/1/2024	12

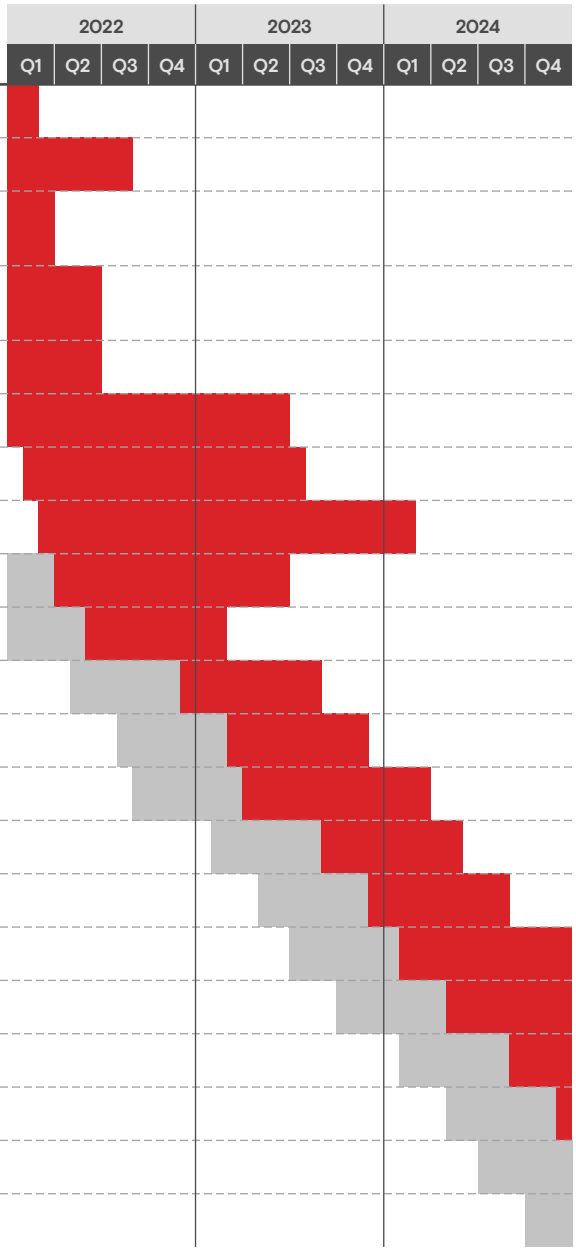


Figure 11

Supply Chain Project Roadmap 2022-2024

ID#	Program Name	RFP Release/ Project Start	Period of Performance
20-16-01	Supply chain risk alert 2 (SCRA 2)	11/1/2020	18
20-17-01	Rapid and secure deployment of medical devices and instrumentation	2/1/2021	12
20-18-01	Capacity and mobilization assessment of the pharmaceutical industry	12/1/2020	18
20-05-01	Achieving resilience through proactive supply chain risk management	7/9/2020	18
21-12	Virtual interactions with the supply chain using digital twins	9/30/2021	12
22-08	Blockchain for supply chain exploration	10/1/2022	9
PP-119	Framework for interoperability and integration (Phase 0: discovery)	1/1/2023	6
PP-120	Framework for interoperability and integration (Phase 1: data strategy)	6/1/2023	6
PP-121	Framework for interoperability and integration (Phase 2: data cleanse)	11/1/2023	6
PP-106	Deploying digital technologies in SMMs	12/1/2023	9
PP-075	Cross-enterprise advanced planning and optimization	3/1/2024	12
PP-104	Data collection for maintenance and sustainment	6/1/2024	9
PP-021	Impact of climate change on the supply chain	8/1/2024	9

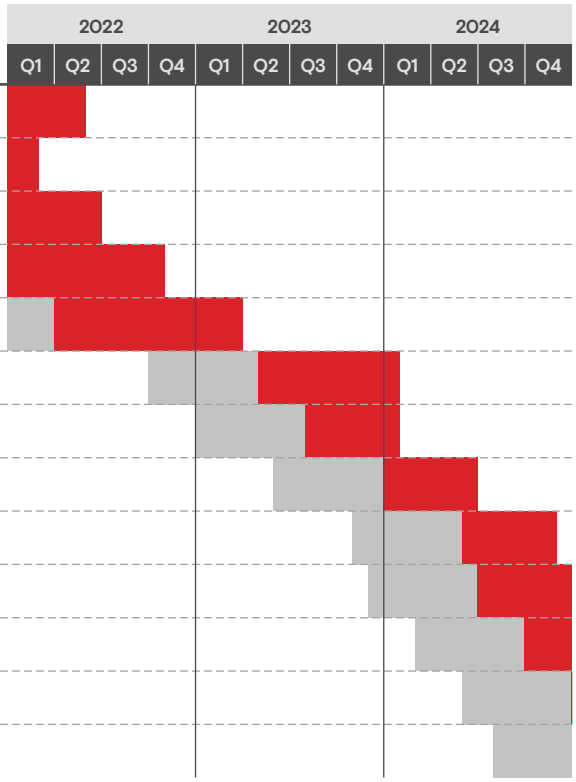


Figure 12

Emerging Technology Project Roadmap 2022-2024

ID#	Program Name	RFP Release/ Project Start	Period of Performance
20-11-09	Model-based systems engineering for digital manufacturing: a proof-of-concept	7/17/2020	9
20-11-11	Development of manufacturing equipment digital twin and integration with cyber-physical emulation test range	7/17/2020	12
20-11-13	Privacy-preserving analytics for smart manufacturing	7/17/2020	12
20-11-01	Securing voice control technology in manufacturing via cross-domain low-effort authentication	7/17/2020	12
20-11-04	Physics-guided machine learning for CNC milling	7/17/2020	24
210-11-10	Cyber threat mission builder	7/17/2020	24
21-10-02	Machine learning-based quality improvement for thermal energy cutting processes	7/8/2021	12
21-10-03	Product lifecycle data analysis and error identification using deep learning	7/8/2021	12
21-10-04	Secure digital twin incorporating physics-aware machine learning for additive manufacturing	7/8/2021	12
21-10-06	Understanding discrepancy between design and implementation of inventory policies	7/8/2021	12
22-04	Emerging technology and cybersecurity research in manufacturing	6/1/2022	12
PP-044	Emerging technology and cybersecurity research in manufacturing	6/1/2023	12
PP-044	Emerging technology and cybersecurity research in manufacturing	6/1/2024	12

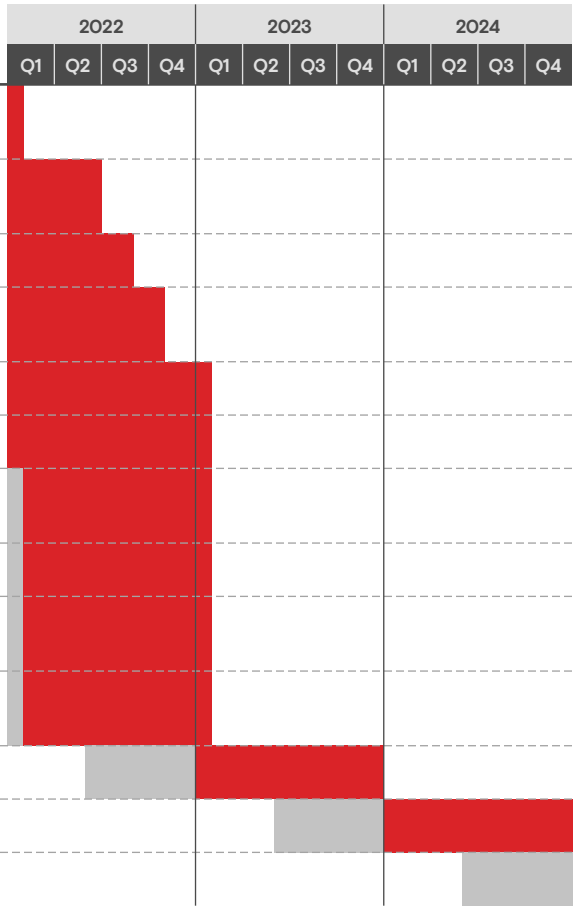


Figure 13

Cybersecurity Project Roadmap 2022-2024

ID#	Program Name	RFP Release/ Project Start	Period of Performance
20-25-01	Pathfinder phase II: securing 3D printers in manufacturing	9/28/2021	20
21-39	Cybersecurity Roadshows	1/1/2021	Ongoing
21-40	Cybersecurity Tabletop Exercises	1/1/2021	Ongoing
21-07	Secure wireless for factory operations	6/1/2021	9
21-11	Security solutions for OT factory equipment	9/20/2021	12
22-10	Operational technology test methods	4/1/2022	9
22-11	Addressing security gaps/vulnerabilities in 3rd party COTS	6/1/2022	9
22-12	Cybersecurity for operational technology	8/1/2022	9
22-13	Attack simulation using AI and digital twins	11/1/2022	12
PP-109	Application of existing standards and guidelines to OT	4/1/2023	12
PP-111	Managed detection and response for OT	8/1/2023	9
PP-027	Cybersecurity in a process environment using a digital twin	12/1/2023	9
PP-118	Approaches to address insecure operational protocols in OT	4/1/2024	9
PP-026	Authentication and validation of endpoints for wireless-enabled factory operations	8/1/2024	9
PP-113	Protecting OT data with edge computing	12/1/2024	9

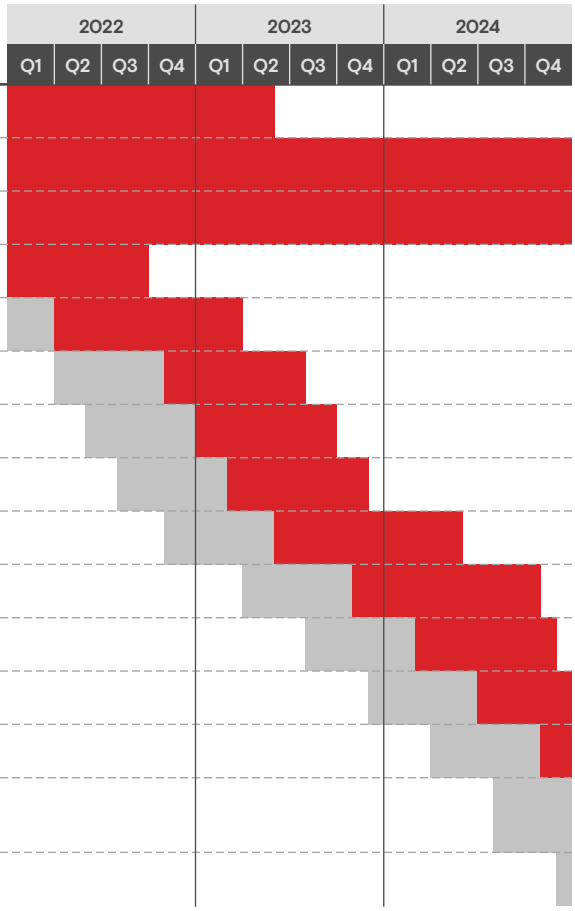
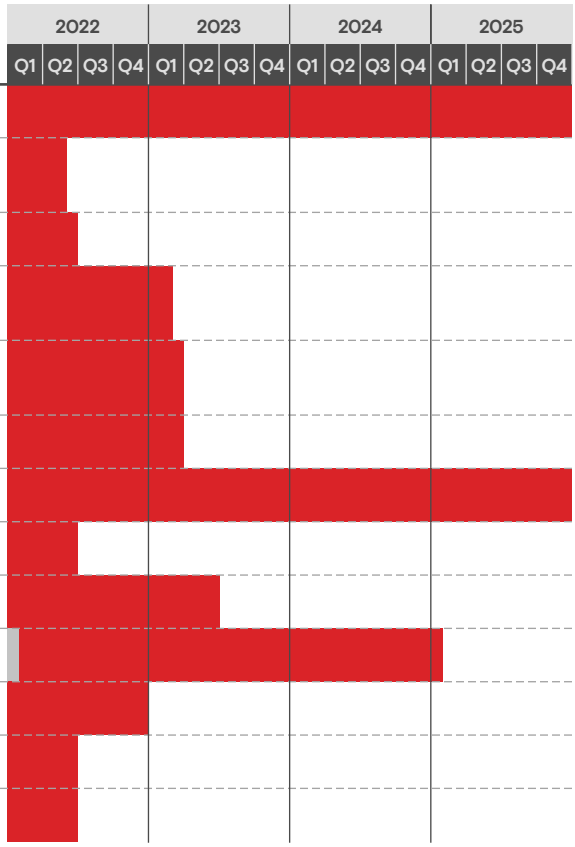


Figure 14

Workforce Development Project Roadmap 2022-2024

ID#	Program Name	RFP Release/ Project Start	Period of Performance
19-06-01	Advanced manufacturing high school curriculum – Waukegan High School	7/1/2019	Ongoing
19-09-01	Community college advanced manufacturing and cybersecurity apprenticeships – College of Lake County	6/1/2019	36
20-21-01	The Connecticut Defense Manufacturing Community Consortium (CDMCC)	2/1/2021	24
19-08-01	FlexFactor: Introducing students to advanced manufacturing engineering education	3/1/2021	24
20-22-01	Introduction to Digital Manufacturing Workforce Development Program (Drexel) (DERISC)	4/1/2021	36
21-20-01	Sinclair Community College Digital Manufacturing Training	11/16/2021	22
21-03-01	Virtual Training Center Platform	11/16/2021	Ongoing
21-08-01	TRACKS-CN	7/1/2021	12
21-22-01	Digital and Cybersecurity Awareness for the Blue Economy/Water Workforce	7/1/2020	36
21-35-01	CyMOT Phase II	7/1/2021	36
22-TBD	Hiring Guide Phase III	1/1/2022	12
22-TBD	CyMOT Phase 1C	1/1/2022	6
22-TBD	Apprenticeship Expansion	1/1/2022	6



APPENDIX B:

Project Concept Portfolio

Strategic Investment Plan

(2022–2024)

Figure 15

Project Concept Portfolio (Potential Future Projects)

THRUST	PROJECT I.D.	PROJECT CONCEPT TITLE	PROJECT CONCEPT DESCRIPTION
Future Factory	PP-004	**AI driven optimization of factory/warehouse layouts**	AI driven solution to optimize the movement of finished goods from the manufacturing line to the holding warehouse or yard and finally to shipping.
Future Factory	PP-005	**Automated weld quality inspection using X-rays**	AI Welding (15-14-03) follow-on which adds automated x-ray testing to determine weld quality/integrity.
Future Factory	PP-007	**Determine "good parts" using sound and vision**	Using visual and/or auditory inputs to identify quality issues. For example, the color of parts during quenching to highlight good parts or the sound of an end fitting crimping.
Future Factory	PP-008	**Digital manifest solution**	Digital manifest tagged to shipping containers to automate loading and unloading of loads at the warehouse, in transit, and at client location.
Future Factory	PP-013	**High-volume, low-cost Item serialization**	Serialization project re-issue, potentially with a broader target. Development of a system that enables individual discrete parts or products to be tagged in order to enable a true digital thread and digital twin benefits.
Future Factory	PP-014	**Low-cost asset tracking in factory environment**	Low-cost solution to provide asset tracking solution for high-interference or high RF noise manufacturing environment where current RFID tags aren't usable and active trackers (e.g., cellular-based) are too expensive for deployment.
Future Factory	PP-015	**Low-cost solution to identify unseen shipping and handling damages**	Low-cost, real-time sensor system to monitor part handling to identify the risk of structural, non-visual damage incurred through handling.
Future Factory	PP-039	**Predictive maintenance in a discrete manufacturing environment**	Creation of a comprehensive playbook for designing and implementing a predictive maintenance solution for discrete Manufacturing equipment.
Future Factory	PP-040	**Reduce barriers to AR adoption**	A large barrier to implementing AR on the factory floor is the vast amount of content creation required to deploy. Any changes to a part, or process, would require updates to AR work instructions. A solution that streamlines or automates AR content creation would solve this problem.
Future Factory	PP-042	**Intelligent welding using digital twin**	Explore how to improve weld quality (manual or robotic welding) using visual, auditory, or other inputs fed into a ML/AI algorithm to provide higher confidence in weld quality without needing to resort to destructive weld testing. Feedback would be provided immediately to avoid costly rework post welding station.
Future Factory	PP-059	**Digital twin of CNC tooling**	Project to explore the creation of a digital twin that would model the cutting tool focused on tool metallurgy, coatings, treatments, and other variables affecting tool wear, accuracy, and breakage.
Future Factory	PP-078	**Wireless process control and automation**	The evolution in wireless technologies has opened the door to a new class of plant automation architecture that offers adopters a significant strategic advantage. The solution concept is a scalable, secure, reliable wireless network infrastructure that automates and controls key elements of a manufacturing process. Preferably these elements would be Class 0 or 1 as per ISA100.
Future Factory	PP-101	**Process automation playbook**	The evolution in wireless technologies has opened the door to a new class of plant automation architecture that offers adopters a significant strategic advantage. The solution concept is a scalable, secure, reliable wireless network infrastructure that automates and controls key elements of a manufacturing process. Preferably these elements would be Class 0 or 1 as per ISA100.

Figure 15 (cont.)

Project Concept Portfolio (Potential Future Projects)

THRUST	PROJECT I.D.	PROJECT CONCEPT TITLE	PROJECT CONCEPT DESCRIPTION
Future Factory	PP-101	**Process automation playbook**	The solution concept is an implementation framework and guide for process automation that is based on uses cases in the PLM and SCM processes. Organizations will use this guide as they identify and plan their process automation.
Future Factory	PP-103	**Digitalization of legacy equipment for OEE**	The solution concept will be the development and validation of turn-key digitalization kits for fundamental manufacturing processes that will enable the monitoring and communication of OEE. The kits will include designs, bill of materials, and installation guides for non-digitalized low-cost production equipment and non- digitalized high-value equipment.
Future Factory	PP-108	**Industrial 5G strategies**	The solution concept will assess gaps in standards for 5G (e.g., ATIS 1000077 and NIST 1800-33A for security, 3GPP releases 15-17 for structure) and determine how and what is applicable from existing wireless standards and guidelines for industrial automation (e.g., ISA100.11a and IEC62591). The solution concept will define key industrial use cases and apply the updated standards/guidelines to the use cases.
Future Factory	PP-122	**Integrated open process automation testbed**	MxD Currently owns two testbeds of interest to participating organizations- 19-04-04 (Digital Twin Testbed for Process Manufacturing) and 19-04-03 (Process Manufacturing Digital Twin - Open Architecture Testbed Framework). While originally intended to be a single testbed, the project was split to accommodate scheduling constraints. This project does the final integration of the two systems to showcase the common strengths of both testbeds. Validating the openness of the two testbeds against recent OPAF (Open Process Automation Forum) standards creates a combined testbed on bleeding edge of manufacturing control technology. The flexible Digital Twin and Open Process Automation testbed showcases the usability of OPA for real processes.
Future Factory	PP-123	**Manufacturing data lake**	Data scarcity, poor data quality, labeling errors, and other deficiencies are challenges in most big data applications, but the problem is especially acute in the manufacturing industry where the proportion of legacy equipment and software is high and thus there are large gaps in available digital information. In other applications such as Natural Language Processing (NLP) and Image Recognition, the availability of large public datasets has been instrumental in the development of ever-improving algorithms and outcomes. However, finding publicly available data which approximates a manufacturer's process and is sufficient to train AI/ML models has historically been so impractical as to prevent its commercial application.

Figure 15 (cont.)

Project Concept Portfolio (Potential Future Projects)

THRUST	PROJECT I.D.	PROJECT CONCEPT TITLE	PROJECT CONCEPT DESCRIPTION
Supply Chain	PP-024	**Value stream mapping for parts inventory**	Value stream mapping for parts inventory to determine where critical asset blocks are and predict future shortages.
Supply Chain	PP-037	**Assess needs and available solutions for supply chain visibility**	Work with Prime Manufacturers and their supply chain to assess what data visibility is needed to implement the Digital Thread with respect to planning, order fulfillment, change management, and more.
Supply Chain	PP-070	**Supply chain visibility/value mapping**	This project would perform a gap analysis on any existing "off the shelf" solution to determine the solution landscape and identify what solutions (if any) would need to be created to close the gaps. The project would leverage previous work on supply chain risk alert and secure supply chain collaboration where needed.
Supply Chain	PP-071	**Supply chain capabilities taxonomy**	Work with industry leaders to define an open taxonomy for manufacturers' capabilities. This will be used by multiple supply chain related projects to help with Supply Chain Visibility, Supply Chain Mapping, Supply Chain Planning, and more. This project could leverage work done in project 15-12-05 to develop a Manufacturing Capability Thesaurus.
Supply Chain	PP-075	**Cross enterprise advanced planning and optimization**	The solution will have the ability to exchange data up and down the supply chain (i.e., across the boundaries of firms) in a secure manner to facilitate the planning and optimization by existing applications.
Supply Chain	PP-100	**Data interoperability for Industry 4.0**	Several reference architecture and standards have emerged to address interoperability for Industry 4.0. DIN's RAMI 4.0, NIST's Big Data Interoperability Framework, Industrial Internet Reference Architecture, IEC 62443, ISO 27000, IEC 62541 OPC UA, and IEEE 1722 are reference models and standards considered for Industry 4.0. The solution concept will address the gaps outline in the reference architecture and standards. It will also demonstrate their application.
Cybersecurity	PP-028	**Networked security architecture**	Build and test a security architecture that will meet the cybersecurity needs of the industrial base including manufacturers that build a mix of classified and unclassified parts. The solution would need to meet DSS compliance for a mixed secure and non-secure manufacturing site.
Cybersecurity	PP-035	**Cybersecurity tools pilot program phase II (Follow-on to 19-12-01)**	Follow-on to the initial Cybersecurity tools assessment project which focused on identifying and assessing low-cost cybersecurity tools to aid small and medium manufacturers to identify and close gaps in their cybersecurity profile and ensure that they are protected from future intrusions. The initial project focused on low-cost solutions specifically focused on smaller manufacturers, while this project will expand the list to include tools focused on mid-sized manufacturers.
Cybersecurity	PP-056	**Predictive and prescriptive AI for securing the factory**	Develop a solution that monitors factory operations and equipment in real-time to identify and address cyber intrusions. The first phase of the project would provide human operators with the issue and how to address it, the second phase would be a completely standalone AI that would neutralize attacks independent of human interaction.

Figure 15 (cont.)

Project Concept Portfolio (Potential Future Projects)

THRUST	PROJECT I.D.	PROJECT CONCEPT TITLE	PROJECT CONCEPT DESCRIPTION
Cybersecurity	PP-057	**Predictive and prescriptive AI for securing the supply chain**	Develop a solution that leverages public and private data sources including social media, GDELT (global news data), cyber command data, and more to predict attacks on the supply chain and proactively mitigate the threat. The first phase would augment the human operator, but a second phase would focus on implementing a completely independent AI
Cybersecurity	PP-058	**From factory to foxhole: RAPTOR/JAMMEX cybersecurity pilot**	Execution of a cybersecurity pilot that performs a gap analysis of an existing capability of platforms for delivering design assets to field operations, such as RAPTOR/JAMMEX, to identify cybersecurity challenges as these platforms are rolled out to the supply chain external from DoD
Cybersecurity	PP-062	**Secure supply chain collaborations**	The Industry 4.0 Digital Thread is built upon the movement of data along the product's lifecycle. For the supply chain to fully participate in this, there must exist a safe and secure way to share data between all the supply chain parts.
Cybersecurity	PP-063	**Digitizing legacy equipment**	Provide secure low-cost tools to allow manufacturers to bring their legacy equipment into Industry 4.0. The project would assess existing "off the shelf" tools vs open-source offerings.
Cybersecurity	PP-065	**Security solutions for the management of legacy equipment**	Assess security risks with legacy equipment (including communication protocols) when used within an I4.0 facility. Determine mitigation plans and provide Playbooks for how manufacturers can identify and mitigate these risks within their facility.
Cybersecurity	PP-072	**SODEX (secure open data exchange)**	The Industry 4.0 Digital Thread is built upon the movement of data along the product's lifecycle. Although some point solutions exist to ensure security and allow for collaboration between different toolsets, no open standard exists. This project would seek to create an open API focused on the secure movement of data.
Cybersecurity	PP-110	**Intrusion detection systems for OT - passive and "ACTIVE"**	The solution concept will demonstrate the application of passive monitoring, profiling, and encryption techniques to identify gaps in technologies, and create an implementation guide.
Cybersecurity	PP-112	**Complex OT asset discovery techniques**	Newer instrument technologies will communicate with resources in the cloud as well as with traditional IT-OT systems. This will increase complexity and cause challenges in visibility across the IT-OT-cloud divides. Future visibility technologies will have to work across a wide gamut of disparate systems that make use of the whole IT/OT Cloud system.
Cybersecurity	PP-115	**Approaches to address OT environment with legacy systems**	Due to the static nature and long lifecycles of equipment in industrial environments, many operational systems may be deemed legacy systems. Legacy components are not restricted to isolated network segments and have been incorporated into the IT operational environment. This project will aim to develop a playbook for modernizing legacy systems for OT integration
Cybersecurity	PP-117	**Approaches to address degradation of OT network architecture**	There is a large distribution of secured network designs across different industries that have resulted in widespread differences in security capabilities. Industrial control systems may consist of isolated skids or components that may be integrated as semi-autonomous portions of the network. These packages may not be as fully integrated into the overall control system, network management tools, or security applications, resulting in potential risk.

APPENDIX C:

Manufacturing x Digital

MxD

Strategic Investment Plan

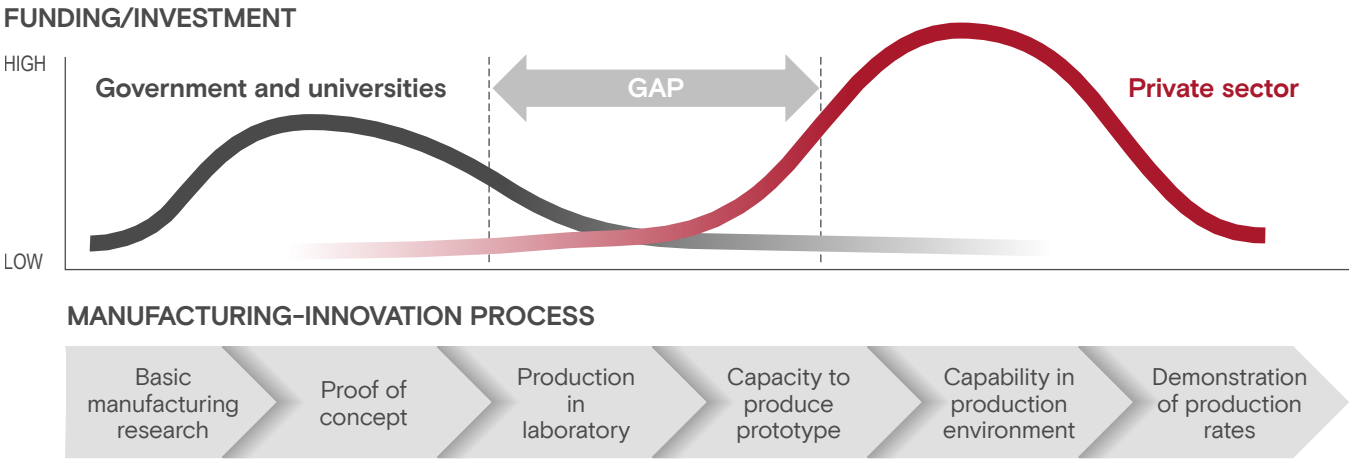
(2022–2024)

MxD's long-term vision is to transform and secure U.S. manufacturing innovation through digital technologies, cybersecurity and an empowered workforce. Since its founding in 2014, MxD has invested more than $230 million in public and private funds in over 85 critical technology element maturation projects to foster the adoption of industrial digital technologies in five key thrusts: Digital Engineering, Future Factory, Supply Chain, Cybersecurity, and Workforce Development. MxD has also established and maintains a 300+ member ecosystem anchored by the U.S. Department of Defense and 20 global manufacturing and technology leaders.

The initial remit from the U.S. Office of the Secretary of Defense for MxD was to focus on maturing digital technologies between Technology and Manufacturing Readiness Levels (TRL/MRL) four and seven.[16] This maturation focus would provide much needed support to technologies emerging from basic research to cross the chasm or "valley of death" naturally occurring in the stages of technology adoption process (See Figure 16). Many emergent technologies languish or become obsolete in the "valley of death" because of low risk-adjusted profitability, need for sizeable investments, or slow knowledge transfer. In 2019, in coordination with the Office of the Secretary of Defense, MxD emphasized further projects already on the cusp of commercialization at TRL-7, defined as a "system prototype demonstration in an operational environment." This expansion of capabilities has created an opportunity to better leverage proven technologies not traditionally used in manufacturing or in specific manufacturing segments and demonstrate their value in representative manufacturing environments. Additionally, in 2019, the U.S. Department of Defense designated MxD as the National Center for Cybersecurity in Manufacturing and awarded $14 million to foster cybesecurity in America's supply chain. MxD has been a beacon of manufacturing innovation with over 12,000 visits annually to its factory floor which demonstrates key digital manufacturing technologies.

Figure 16

Chasm or "valley of death" in stages of technology adoption[17]



16 U.S. Government Accountability Office. (2016). "Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects". **https://acqnotes.com/wp-content/uploads/2014/09/GAO-Technology-Readiness-Assessment-Guide-Aug-2016.pdf**.

17 U.S. Department of Energy, (2021), "Improved Performance Planning Could Strengthen Technology Transfer". **https://www.gao.gov/assets/gao-21-202.pdf**.

MxD's principal reason for existence has intensified overtime with many competitive countries gaining or overtaking the United States' global leadership position in innovation and manufacturing. First, economic models indicate that by 2030 the United States will be $225 billion below baseline GDP forecasts, and the country will leave over 2 million American manufacturing jobs unfilled. The United States cannot retain its global leadership position without an appropriately trained workforce to support it.[18] Second, the United States has played second fiddle to China in total manufacturing value added since 2009, and the widening gap has been staggering (See Figure 17).[19] The European Union continues to be a fierce competitor, neck-to-neck with the United States since 2000. Third, over the last four decades, the United States has diversified its economy to constitute less manufacturing from nearly 30% manufacturing value-added as a percentage of GDP in 1955 to 11% in 2019 (See Figure 18).[20] In contrast, China went from 34% in its heyday of 1990 to 26% in 2020. Although the diversification was a global phenomenon as services and IT became an increasingly larger component of GDP across developed nations, China, Korea, Japan, and many Euro Area countries have retained manufacturing as a major component of their economy. Finally, the United States has been losing ground in manufacturing research and development as a percent of GDP to fierce competitors, such as Austria, China, Denmark, Germany, Israel, Japan, South Korea, Sweden, and Switzerland (See Figure 19).[21] The United States investment remained fairly flat over the last two decades hovering around 2.7% of GDP. In contrast, South Korea grew its investment from 2.1% in 2000 to 4.5% in 2018. Similarly, China had high growth going from 0.9% in 2000 to 2.2% in 2018. Israel had the third largest growth in investment from 3.9% in 2000 to 5% in 2018. It is important to note that at the current growth rates, China will surpass the United Sates in research and development as a percent of GDP by 2027.

Adoption of digital technologies is one factor to strengthen the United States' global manufacturing competitiveness. MxD is charged with hastening the adoption of these technologies. A survey of U.S. manufacturers indicated that most prolific impediment to the adoption of these technologies is an unclear economic benefit (See Figure 20).[22] The second most prolific impediment was a lack of skilled people to manage the new technologies. A close third impediment was the lack of understanding of the impact of these technologies, i.e., use cases. MxD is well-suited to address these impediments, accelerate the adoption of digital manufacturing technologies, and support the strengthening of the United States' manufacturing industry.

18 MxD, (2021), "Managing the Mission".
19 The World Bank. "Data Bank: World Development Indicators". **https://databank.worldbank.org/home.aspx**.
20 Ibid.
21 Ibid.
22 MxD, (2021), "Managing the Mission".

Figure 17

Manufacturing Value Added (Billion USD, Current Value)

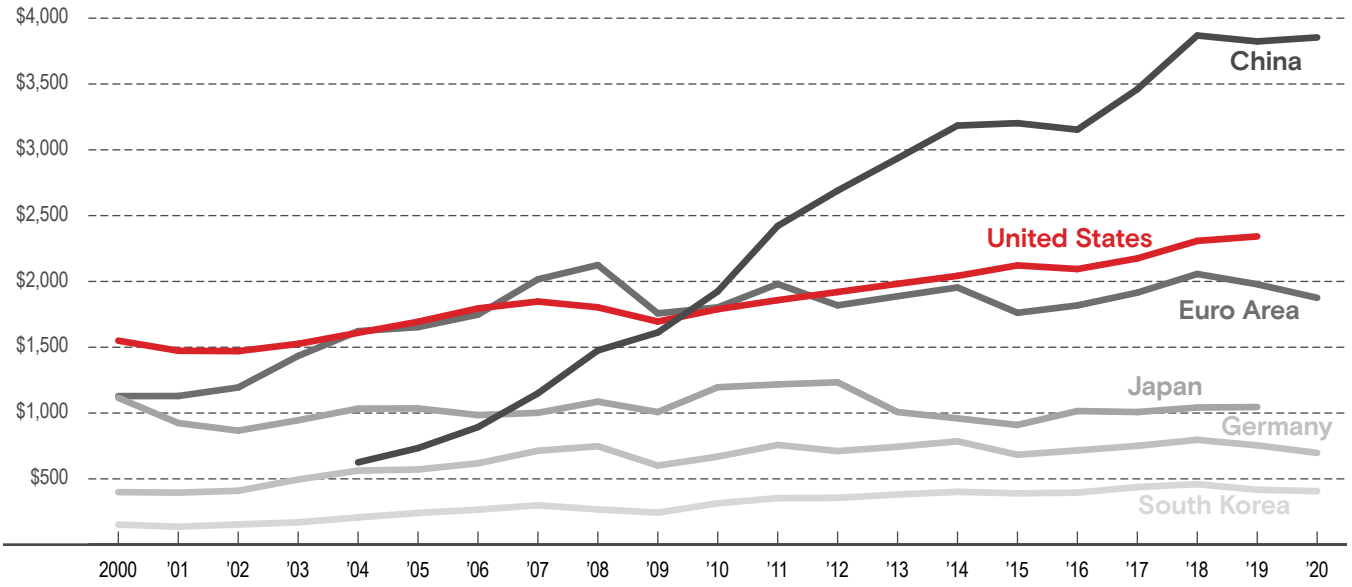


Figure 18

Manufacturing Value Added as % of GDP

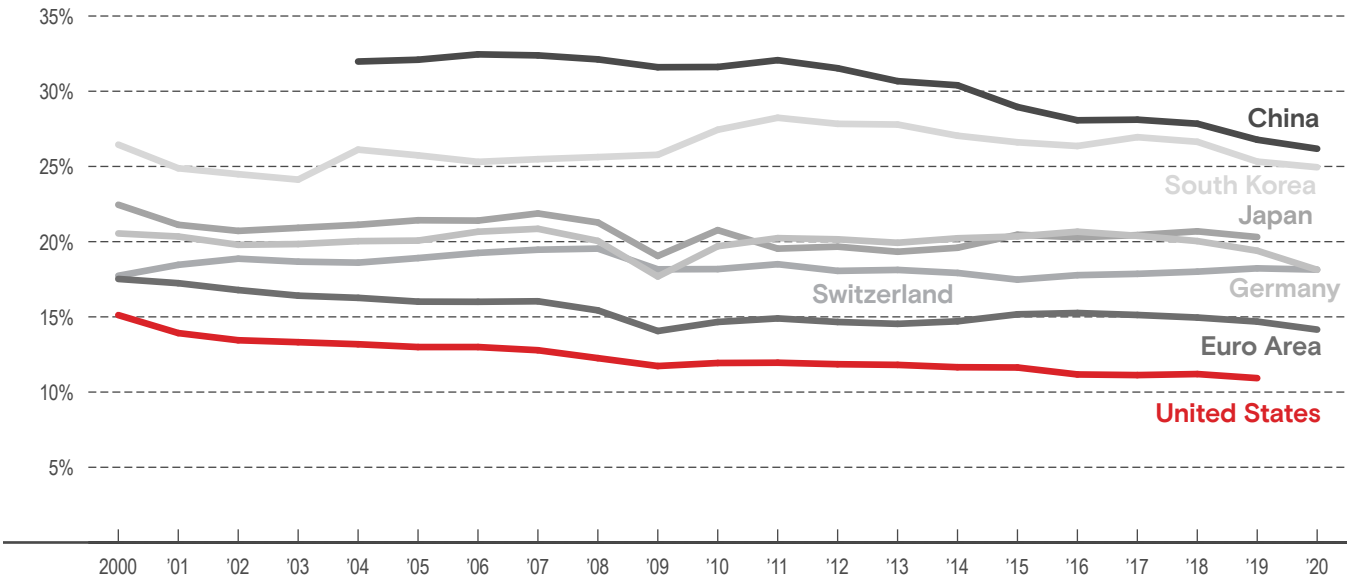


Figure 19

Research & Development Investment as a % of GDP

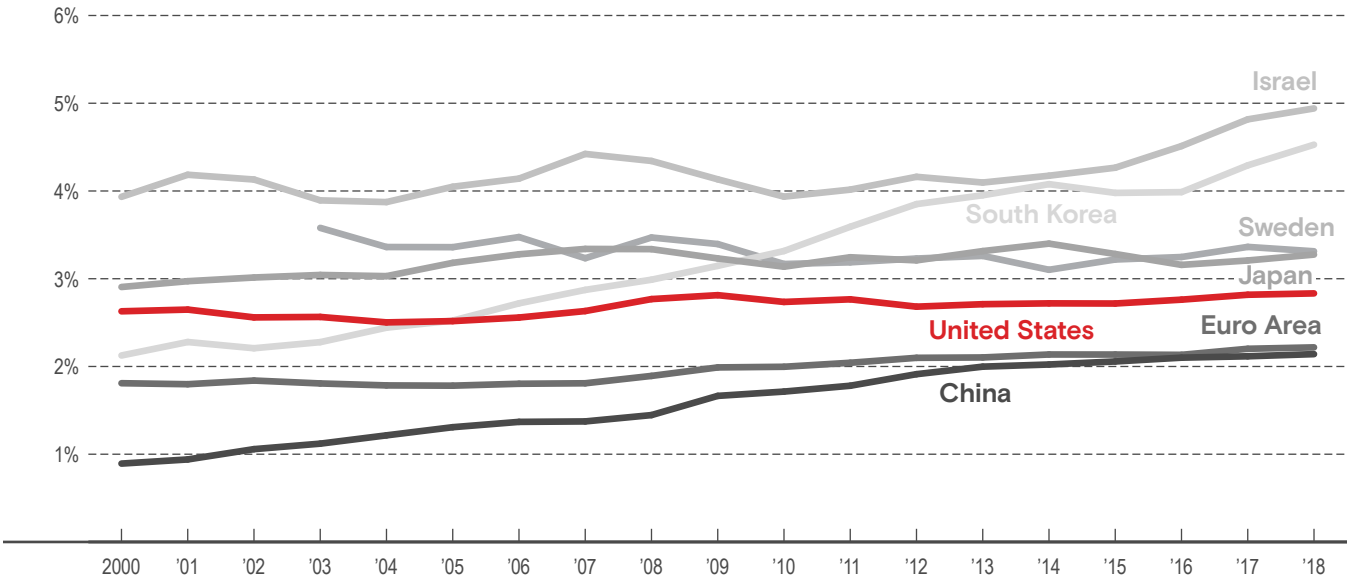
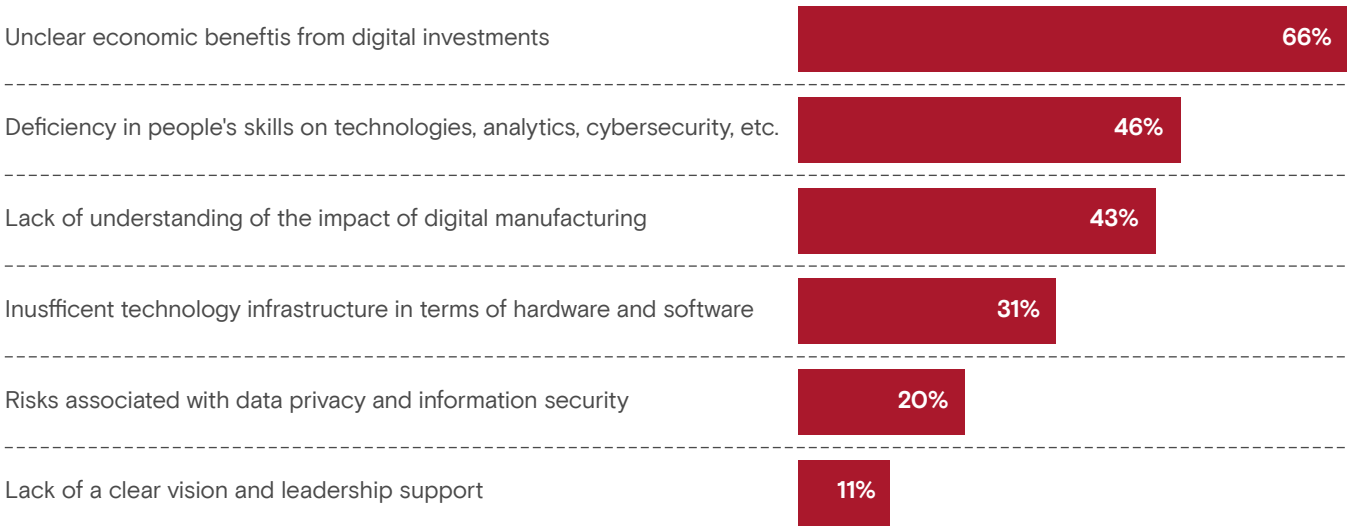


Figure 20

Most Significant Impediments to Adopting Digital Manufacturing Technologies



Technology Strategic Planning Process

MxD defines its time-bounded and time-phased technology development goals and approaches in the Strategic Investment Plan (SIP). The SIP consists of the technology vision, the initiative portfolio, and the initiative execution plan. The vision is the institute's longer-term technological aim for competitive U.S. manufacturing and supply chains. The vision is rooted in the industrial digital fabric that facilitates the exchange of information across enterprises to increase efficiency, reliability, and responsiveness. The current technical strategic thrusts within the vision are digital engineering, future factories, supply chain, cybersecurity, and workforce development. The initiative portfolio consists of activities and support by the institute within the three-year horizon to advanced technologies for U.S. manufacturing and supply chains towards the vision. These activities and support include technology advisory services, factory floor demonstrations, speaking engagements and presentations, authoring journal articles, and participation in industry working groups as subject-matter experts. The initiative execution plan is the sequence of project executions and required resources (e.g., financial, existing, and potential members, and internal staff) that maximizes value for members.

MxD advances technological development for U.S. manufacturers and supply chains in two major phases. It first develops and refreshes the SIP, and then, it carries out the resulting initiative execution plan. The institute develops and refreshes the SIP annually through its strategic planning process, which consists of five major sets of activities:

1. Future State Development and Refresh
2. Technology Strategy Development and Refresh
3. Internal and External Assessments
4. Implications Planning and Portfolio Development
5. Executive Council Approvals and Management into Execution

The institute carries out the initiative execution plan with the Strategy & Engagement group (i.e., External Relations, Engagement, and Business Development) and with the Projects & Engineering group (i.e., R&D Projects, Cybersecurity, Engineering, and Workforce Development). The Projects & Engineering group follows a five-step process for carrying out the initiative execution plan:

1. Scoping
2. Project Down Selection
3. Pre-Award
4. Project Execution
5. Close Out

Vision development and refresh

MxD leads the development and refresh of the technological vision for winning U.S. manufacturing and supply chains. The vision is a longer-term future state of technology-enabled factories and supply chains that are strong, global leaders. The institute uses the vision to define gaps from current state, to define and prioritize strategic thrusts and the necessary technological advancements in each thrust over the planning horizon. The institute refreshes the vision annually, and it makes major updates to the vision when significant technological or industry problem changes occur in the market. MxD and subgroups formed from the Technical Advisory Committee execute activities to develop and refresh the vision. These activities include but are not limited to primary and secondary research, identification of external sources of information, and synthesis of data and information. The Technical Advisory Committee convenes for a workshop in the first calendar quarter to review and integrate the findings of the subgroups. The outcome of these activities is a clear and defensible definition of globally leading manufacturers and supply chains in the future and the digital technology advancements needed.

Strategy development and refresh

MxD also spearheads the development and refresh of the technology strategy for realizing the vision. MxD and subgroups from the Technical Advisory Committee validate, prioritize, and select the technological advancements across the strategic thrusts to realize the vision. The group defines the types of intervention and support initiatives by the institute for the advancements. The group then selects the initiatives that maximize value to members and that the institute will pursue over the planning horizon. Strategies are the sets of initiatives that maximize value, and they change more frequently than the vision when technologies evolve, industry problems change, market conditions change, when project findings warrant shifts, or when funding changes. The Technical Advisory Committee convenes in the second calendar quarter to review and integrate the findings of the subgroups. The outcome of these activities is strategies for the strategic thrusts defined and selected in the technology vision.

Internal and external assessments

Internal and External Assessment is MxD's approach for collecting and synthesizing information for Vision and Strategy Development and Refresh. The sources of information are internal and external to the institute's ecosystem, and the information may be associated with internal and external capabilities, problems, and needs. MxD and subgroups from the Technical Advisory Committee carry out these assessments and the tasks include but are not limited to primary and secondary research, identification of external sources of information, and synthesis for data and information to update the vision or strategies. Recent examples of these tasks are one-on-one meetings with Tier 1 and Tier 2 members to ensure alignment with industry's specific priorities, member ideation sessions and workshops, Request for Information (RFI) seeking information on emerging technologies, and engagements with industry groups and organizations outside of MxD's ecosystem. The engagements with external organizations help provide supplemental information and a comprehensive view of the digital technology developments for manufacturing and supply chain, thus it prevents the institute and its members from developing perspectives that may thwart the mission. These engagements are also excellent ways to identify leads for membership and to accelerate their acquisition. When MxD engages with organizations outside ecosystem to obtain information, the Business Development group is tapped to continue discussing membership. Further, some industry groups are prime sources of information for the vision and strategy and have complimentary missions and infrastructure. The institute collaborates closely with them to execute on the strategic initiatives while bringing them on or maintaining them as members.

Implications planning and portfolio development

MxD and subgroups from the Technical Advisory Committee define the preliminary requirements for the strategic initiatives emerging from Strategy Development and Refresh. First, the group refines the definition of the strategic initiatives. This entails defining clear objectives, scope, expected period of performance, desired dates for the release of request for proposals, success criteria, and potential metrics to gauge the success of the technology. Second, the group roughly estimates the benefits of the technology developed in the initiative and the costs for developing and implementing it. Third, the group defines the resources required to execute the initiative. This involves identifying resources from the institute, from members, and from outside the MxD ecosystem. MxD's Business Development group creates recruitment plans for the external resources, when required. Finally, the group defines risks to the development initiative and to the implementation of the technology. The group also creates plans to manage those risks.

MxD and subgroups from the Technical Advisory Committee maximize the expected value of the initiative. The value maximization is constrained by the expected funding over the planning horizon to cover development and execution costs. Since some of the maximization constraints and initiative characteristic are known with uncertainties, the outcome of the maximization is several potential scenarios for the initiative portfolio and initiative execution plan. The Technical Advisory Committee convenes for a workshop in the third calendar quarter to review, synthesize, and integrate findings.

Executive council approval and management into execution

MxD's Internal Review Board consists of the President and CTO, Vice President of Projects and Engineering, Vice President of Strategy and Engagement, Technical Fellow, and Director of Technology Strategy. This board reviews and modifies the initiative portfolio and initiative execution plan during the third calendar quarter. The Director of Technology Strategy is responsible for facilitating the meetings and the President and CTO is accountable for the updated portfolio and execution plan. The updated portfolio and plan become the preliminary SIP, and it is presented to the Executive Council for approval during their fourth calendar quarter meeting. Once approved, the SIP becomes the governing plan for initiatives and development projects for the following year.