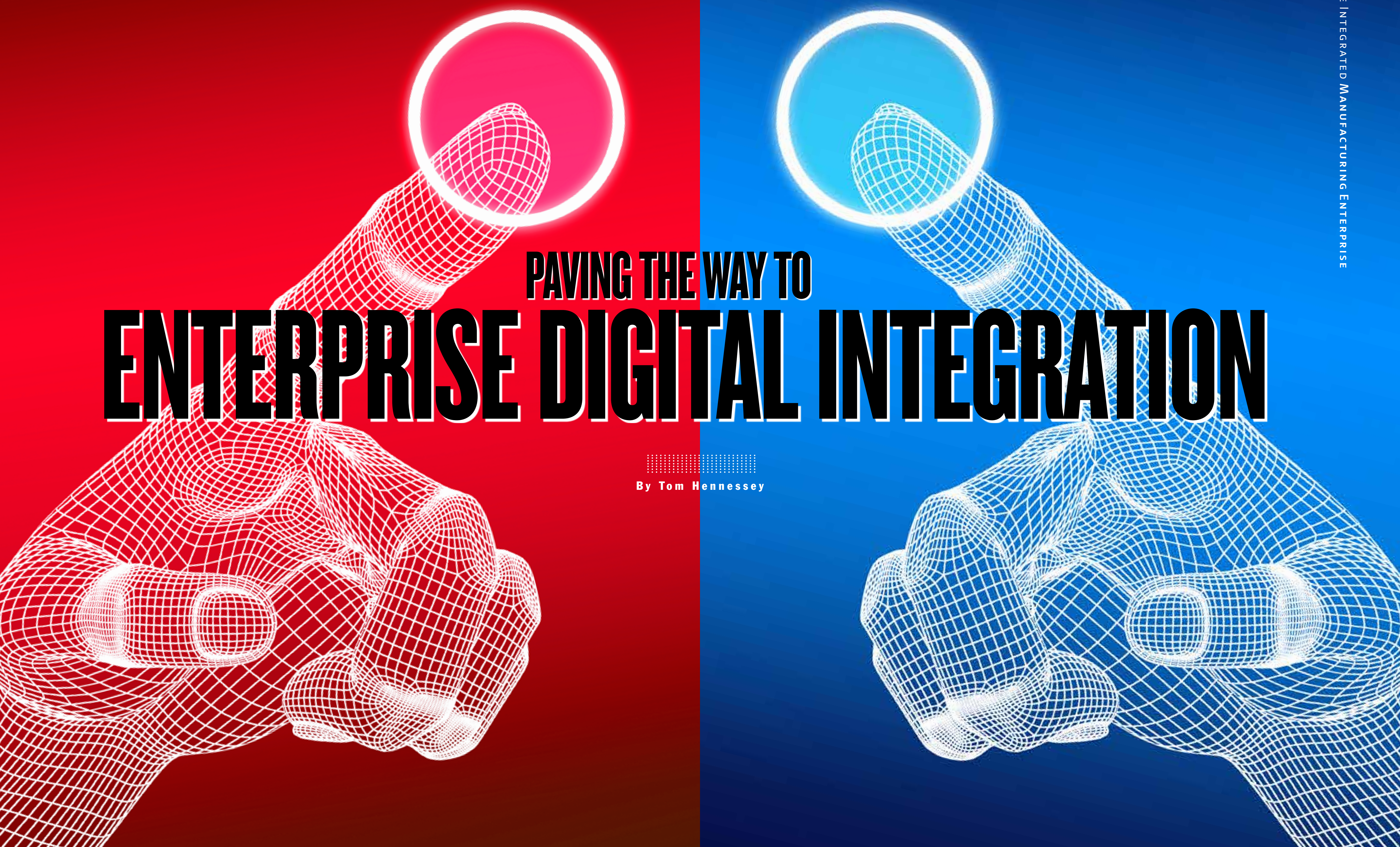
Based on the dual concepts of digital twin and digital thread, the Model-Based Enterprise approach can provide true competitive advantages to manufacturers of highly engineered products.

PAVING THE WAY TO ENTERPRISE DIGITAL INTEGRATION

By Tom Hennessey



THE POTENTIAL BENEFITS OF TRUE ENTERPRISE-WIDE digital integration have heretofore been largely theoretical and experimental, and implemented primarily in military environments. As supporting technologies mature and innovations converge, the conceptual visions of leading smart manufacturers are rapidly shaping practice and process on the shop floor. The Model-Based Enterprise (MBE) approach, centered around the dual concepts of digital twin and digital thread, is being realized through harmonized implementations of robotics and automation, augmented reality, 3D modeling and printing, advanced analytics, and Internet of Things (IoT) diagnostics.

The definition of the MBE, as developed by the National Institute of Science and Technology (NIST), a leading proponent of smart manufacturing advancement, is "an integrated and collaborative environment, founded on 3D product definition shared across the enterprise, enabling rapid, seamless, and affordable deployment of products from concept to disposal."

This is a critical vision for the manufacturing sector, which is the sixth largest employer in the U.S., accounts for at least 12 percent of U.S. GDP, and fuels innovations in science, technology, and engineering on a global scale. Manufacturing accounts for 75 percent of private sector R&D and the majority of issued patents, employing 60 percent of U.S. R&D employees. As a sector, it is growing faster than the economy at large. Moreover, advancements in manufacturing technology and business operations pave a path to innovation and optimization in government, utilities, communications, and more.

Studies and leading edge initiatives in the aerospace and defense (A&D) industry have shown that an MBE approach can drastically reduce design-manufacturing-inspection cycle times and confer competitive advantage (cost savings, time to market, agility, and quality) to manufacturers implementing the core practices of Model Based Definition (MBD), which leverages annotated 3D models as digital masters. Toyota and Boeing, for example, have claimed 50 percent reduction in costs when using 3D models embedded with product and manufacturing information (PMI) along with related MBE practices like smart automation and IoT-driven analytics.

Securing sizable gains in manufacturing capabilities and operating efficiencies is especially vital to manufacturers of highly engineered products such as aircraft, satellites, ships, industrial equipment, and medical devices. In complex discrete manufacturing industries, products have longer cycle times, multiple levels of subassemblies, global supply chains, and customized specifications. The production of each unit (e.g., single airplane) must be fully documented, tracked, and analyzed from design to obsolescence.

In the absence of enterprise-wide digital integration, fundamental activities like documentation, change management, and compliance are laborious, time-intensive, and prone to error and waste. Forging stronger digital connections between phases of the product cycle—all the way from design, engineering, and production through inspection and maintenance—and leveraging data created by systems and processes are now requisite for advanced manufacturers. The more complete, seamless, and automated the integration across the lifecycle and enterprise, the greater the rewards: cost savings, productivity step changes, near-zero defect rates, greater visibility, and insights to fuel innovation.

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Innovation in Motion: Aviation MRO

While many industry sectors face these challenges, the urgency and promise of implementing the MBE approach are perhaps most easily illustrated by the convergence of smart manufacturing technologies in the airline industry. Deloitte's 2017 report on the A&D sector notes that backlogged orders for commercial aircraft are at an all-time high; at current rates, it will take nearly 10 years to produce the 13,500 aircraft on order. Global demand for air travel is robust and growing, compelling airlines and manufacturers to increase capacity by building new planes faster and making the most efficient possible use of their existing fleets. Maintenance, repair, and overhaul (MRO) operations play a crucial role in a business where safety, reliability, and uptime are paramount. MBE-oriented technologies are essential to optimizing the efficiency and accuracy of aircraft inspection and maintenance.

Aircraft technicians must refer to a huge collection of documentation and process specifications from various sources, interacting with multiple systems to complete maintenance cycles such as flight status/scheduling, MRO, electronic manuals, parts ordering, and records and archiving. The inherent complexity leads to errors on the maintenance floor when information or procedures are outdated or misapplied. A 2012 FAA report found that more than a third of violations by mechanics were related to not using proper documentation.

Full implementation of the MBE approach, including the concepts of digital thread and digital twin, will integrate and enhance the documentation, sensor data, diagnostics, schematics, and MRO histories that service technicians require to perform compliant inspections and repairs. MRO enterprises are using MBE-enabling technologies to automate inspections, optimize maintenance routines, guide repairs, and create spare parts on demand. The supporting technologies include IoT diagnostics and advanced analytics, robotics, augmented reality, and 3D printing.

Digital Thread and Digital Twin

The dual concepts of digital thread and digital twin were conceived in the military aircraft industry, which sought to dramatically improve outcomes and control costs by analyzing data captured digitally from end-to-end throughout a product's lifecycle. As data from smart manufacturing systems, embedded sensors, and inspection records (to name just a few) comes streaming in across connected platforms, there is a clear need for comprehensive, harmonized, authoritative digital records and models. Intelli-

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gence from all that data can be leveraged to minimize downtime, streamline regulatory compliance, and achieve operational excellence in many industries.

The digital thread is the core communication framework that enables connected data flow throughout the lifecycle and across traditionally segmented functions such as design, engineering, production, and inspection, ensuring an integrated, authoritative, up-to-the-minute view of manufacturing lifecycle data. The digital thread enables unprecedented analysis, collaboration, traceability, and change management.

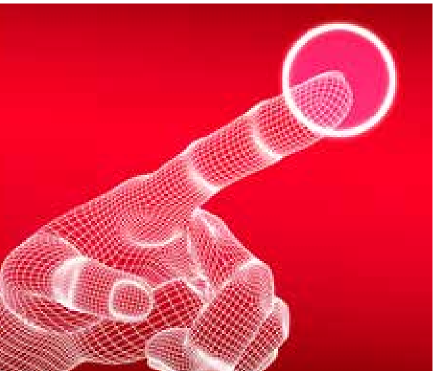
The digital twin is the digital model of a particular asset (product) that includes design specifications and engineering models describing its geometry, materials, components, and behavior. Most importantly, it includes the as-built and operational data unique to that specific physical asset (for aircraft, the "tail number"). The digital twin includes engineering changes made during production and deviations from original design, as well as inspection, operation, and MRO data.

Robotics and UAVs

Unmanned Aerial Vehicles (UAVs, or drones) are being used to perform safer, faster, and more accurate inspections of aircraft in MRO hangars. Airbus has demonstrated that using drones equipped with 3D camera technology cuts inspection time from two hours to 15 minutes. The Air Force found that UAV inspection consistently produced the same results as traditional methods, which require personnel in safety harnesses to move over aircraft as tall as multi-story buildings looking for minute cracks.

In addition to sophisticated cameras that capture and transmit high-quality photos and video, drones can also be equipped with specialty lighting, laser navigation systems (better for indoor use), and semi-autonomous capabilities. In the near future, airlines hope to deploy fully automated systems (preprogrammed with airplane model-specific inspection paths) with scanning technology that can detect and measure damage at sub-millimeter levels, effectively exceeding the physical capabilities of human inspectors. This technology is quickly being harnessed for similar uses inspecting pipelines, power lines, wind turbines, bridges, nuclear facilities, and much more.

Robotics are fairly commonplace in modern manufacturing facilities, but advances in collaborative robotics will be especially useful in complex discrete manufacturing, where highly skilled human operators are essential but in short supply. These robots are designed to be lighter, safer and easier to interact with. They feature AI and machine learning capabilities, advanced camera and sensor systems, and adaptive behavior and components (e.g., grippers) that allow for multiple uses and non-expert control. Their sensors can capture and record human and machine performance for inclusion in the digital thread and performance analyses.



At the enterprise level, digital transformation will require profound cultural shifts. Many will find it hard to switch from traditional methods to digital processes.

Augmented Reality and Advanced Guidance

Related developments in augmented reality are also bringing greater precision and efficiency to inspection and repair work in MRO hangars. Augmented and virtual reality tools—systems that layer digital 3D images and virtual schematics over real-world images or devices—are also helping to bridge the gap in skilled technicians through advanced training and guidance systems. By some estimates, global growth in air travel will create a need for nearly 700,000 new maintenance technicians over the next 20 years. Any technology that streamlines the work of MRO specialists, or helps train new and existing workers, will help manufacturers and airlines keep up with demand. Furthermore, these systems can ease collaboration between remote workers, an increasingly essential capability in global supply chains.

Wearable devices such as smart glasses, supplemented by AR software and natural language interfaces, are already in use in production and repair processes. As they are integrated with automated inspection methods (UAVs, sensor data) and digital models, they evolve into a key interface between human operators and the cyber-physical systems underpinning the MBE. Service information can be consumed visually and contextually in real time, eliminating the confusion caused by disparate systems and documentation sources.

As natural language capabilities mature, voice-driven interaction with smart glasses and tablets will create a hands-free interface and the ability to "chat" with the device in a more natural manner. These advanced guidance systems have the potential to reduce errors, lower labor costs, and significantly improve MRO metrics including Mean Time to Repair (MTTR), First Time Fix Rate, and Aircraft-On-Ground (AOG) time.

Additive Manufacturing

One of the major challenges faced by MRO shops is spare parts management. Without efficient access to needed parts, unscheduled groundings quickly add up to significant losses. Yet, predicting when and where a part will be needed, or maintaining a complete inventory of parts, is impractical and expensive.

Additive manufacturing (AM), or 3D printing, is already revolutionizing prototyping and production in many industries, from consumer goods to medical devices. In fact, Boeing reports that 50,000 3D printed parts are already flying on their products.

In the MRO enterprise, AM has the potential to transform spare parts practices. Manufacturers of spare parts and MRO hubs will store the digital data necessary to print parts and components in CAD software instead of storing physical parts on shelves, with obvious benefits to storage and distribution costs, inventory turnover, MTTR, and fleet uptime. 3D printing can also be an efficient solution to procuring hard-to-find or discontinued spare parts.

The global market for aerospace AM is projected to grow at a CAGR of 56% until 2020; 3D printing for the early-adopting A&D sector already accounts for 12% of total global AM revenue. As advanced AM production techniques continue to emerge, the impacts on aircraft supply chains and MRO shops could be transformative. The reliability of 3D printing technology is sure to benefit from the strict safety and quality requirements for aircraft components, once again resulting in benefits to industries beyond A&D.

Augmented and virtual reality tools are helping to bridge the gap in skilled maintenance technicians.

Big Data, Analytics, and IoT

The big story of the MBE and the digital transformation of MRO is Big Data. To come into enterprise-wide practice across the value chain, the digital thread and digital twin concepts require comprehensive, real-time, properly managed data streams from myriad sources. Diagnostic connectivity via the Industrial IoT and advanced analytics are among the most fundamental technological developments enabling the MBE. As capabilities advance, the synergy between human expertise and machine learning (AI) has the potential to vastly improve the functionality, safety, and sustainability of many highly engineered products.

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The success of digital integration depends in large part on an enterprise's ability to collate, store, manage, and analyze data from all parts of the manufacturing lifecycle, from business operations to production to MRO. Early adopters will be rewarded with significant boosts to productivity, problem solving, and innovation.

Microcomputers (sensors) are now embedded in many devices and assets and are able to connect to and exchange data with other systems and centralized data repositories (IoT). By analyzing exceptions and aggregate performance data against the 3D model (digital twin or MBD), engineers predict and diagnose issues as well as enhance future designs. By relying on sensor and usage statistics, repair and maintenance processes can be streamlined and performed with greater precision.

Many industries, including aerospace, have zero tolerance for safety and reliability issues. The ability to avoid disasters and expensive groundings by building performance-based models and predictive/prescriptive maintenance protocols becomes even more critical as the number of flights and aircraft continues to rise alongside consumer demands for affordable and convenient travel.

IoT and analytics are enabling development and experimental adoption of Aircraft Health Monitoring System (AHMS) checks and condition-based (as opposed to scheduled-based) maintenance. While not yet approved as a replacement for traditional visual inspections, AHMS and other sensor-based checks are reducing inspection time and increasing accuracy and insight. For example, sensor data are superior to visual inspections when determining if a composite structure has been compromised. Another obvious advantage of sensor monitoring is that the data flow is continuous. Visual inspection data is only as current as the most recent inspection; sensor data is up-to-the-minute.

IoT data from asset or machine components becomes even more powerful when combined with additional data sets, including environmental readings, fuel usage metrics, historical records, configuration settings, and much more. Today, most maintenance activities are planned based on a combination of elapsed time and asset usage frequency, which leads to both over- and under-servicing of assets.

Predictive and prescriptive analytics could radically improve MRO planning. Predictive analytics can be used to forecast when components will need to be replaced or repaired. Prescriptive analytics can go further, analyzing multiple parameters, possible scenarios and available solutions to identify the optimal choice.

Increasingly sophisticated use of the data collected by sensors in manufacturing equipment, products, and enterprise management systems will drive progress toward the MBE vision.

Challenges Ahead

As leading MRO and manufacturing enterprises in the A&D sector and beyond work to digitally integrate disparate systems and introduce automated technologies and processes, there will be many challenges to overcome. The costly and involved process of upgrading technology infrastructure to accommodate and integrate enterprise management systems, IoT and Big Data programs, robotics, and additive manufacturing is daunting, especially for smaller entities in the supply chain. Finding the skilled talent to develop, implement, and maintain the technologies underpinning the MBE is another thorny issue, one that will require the cooperation of government and educational institutions on a national, even global scale.

At the enterprise level, digital transformation will require profound cultural shifts. Workers may resist automation and retraining, executives may resist the required capital investments, and everyone will inevitably resist change and find it hard to switch from traditional methods to digital processes. Particularly key is learning to trust the digital master (e.g., MBD or digital thread) as the authoritative source for all design, engineering, production, and inspection activities.

For U.S. manufacturers, global competition—for customers, workers, suppliers, resources, and intellectual property—continues to intensify. Likewise, regulatory scrutiny at home and abroad shows no signs of easing, especially not for complex discrete manufacturers in highly sensitive industries like A&D, medicine, and energy. Regulations and standards always lag behind technological innovation, and are likely to frustrate, even hinder, automation and integration initiatives in the near to mid term. Industry leaders and associations should continue to work together on standards (IIoT, CAD/CAM, etc.) to ensure interoperability, a hallmark of successful digital thread implementations. Last but not least, cyber security remains a vexing and relentless battle against organized crime, state-sponsored operatives, and political hacktivists.

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Next Steps

The pressures of global competition, skills shortages, and customer demand leave little time for timid starts and half measures. It's time for manufacturing and MRO enterprises to take a hard, clear look at the maturity of their digital capabilities. NIST and related organizations are developing and promoting enterprise capability assessment tools, test beds, standards, and partnerships to support companies as they build smart manufacturing platforms and adopt an MBE approach.

In addition to readiness assessments, there are many first steps to take on the MBE journey: benchmarking and goal-setting, experimenting with pilot projects, training in MBE essentials, and cultivating data management expertise are but a few. As the A&D sector has exemplified through MRO innovations, digital integration and automation have real potential to transform massive, complex industries. What once was a conceptual vision for the future is rapidly materializing into tomorrow's standard of excellence. M