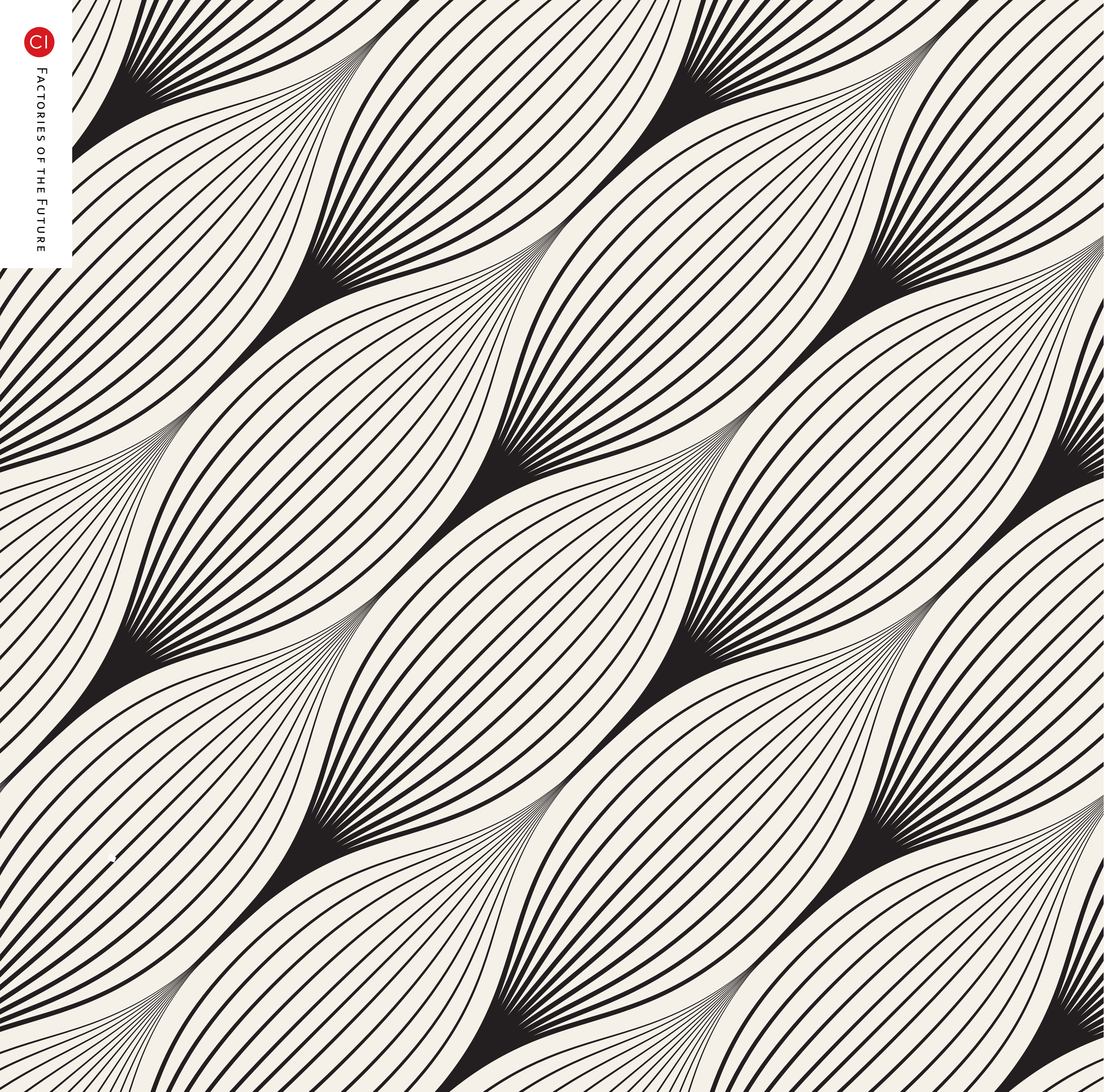

MANUFACTURING LEADERSHIP JOURNAL

FOLLOWING THE DIGITAL THREAD INTO THE FUTURE

The concept of the digital thread holds the promise of integrating the manufacturing enterprise in a way never before achieved. But manufacturers must understand the challenges as well as the rewards of this transformative paradigm shift.

By Tom Hennessey

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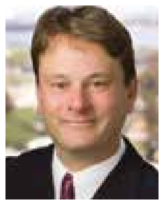
OPTIMISTIC DESCRIPTIONS OF FACTORIES OF THE FUTURE may sound like science fiction. Yet, the promise of end-to-end digital integration in manufacturing, from initial design to maintenance and overhaul, is emerging through advances like the Industrial Internet of Things (IIoT), smart manufacturing, and automation. One of the primary visions driving the transformation of manufacturing is the concept of the digital thread. The digital thread links systems used to execute and track design, engineering, manufacturing, and MRO (maintenance, repair, and overhaul), establishing a seamless flow of information from product conception to delivery and beyond. This type of closed loop integration employs data and analytics across the entire product lifecycle, optimizing efficiency, operations, and maintenance.



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The concept of the digital thread was spearheaded by the military aircraft industry, from its desire to improve the performance of future programs by applying lessons learned. The concept has quickly taken hold beyond the aerospace and defense industry, powered by advances in digital and cyber-physical manufacturing systems, predictive analytics, automation, and the IIoT. Manufacturers—especially those producing complex, highly engineered products in the aerospace, electronics, medical device, nuclear, and industrial equipment industries—are striving to leverage these advances to transform the way they orchestrate and optimize business, digital, and physical processes. The digital thread will link and enhance those processes horizontally across smart factories and vertically throughout the value chain.

The digital thread is the communication framework that enables a seamless, connected data flow and integrated view of a product or asset throughout its lifecycle. Connecting and integrating across traditionally siloed functions (e.g., design, engineering, production) supports better decision-making at all levels, more effective collaboration throughout the supply chain, and powerful, real-time business insights. In complex manufacturing, delivering the right information to the right place at the right time is essential to every core process, including change management, quality, compliance, and supply chain visibility and control. The digital thread should provide a formal system for controlled interplay of authoritative technical and as-built data, with the ability to access, integrate, transform and analyze data from disparate systems into actionable information. Product lifecycle data should be tracked and analyzed from design, procurement, testing, production, field operation, and sustainment services.

For those with "boots on the ground," achieving this level of machine and data integration may seem daunting—not to mention the human factor. There are certainly many inherent difficulties and obstacles in such a transformative endeavor. Yet, the digital thread concept is not being developed and adopted in a vacuum. It has arisen from a powerful convergence of enabling technologies: big data analytics, the IIoT and sensors, 3D printing and visualization, augmented and virtual reality, cloud computing, robotics, and digital manufacturing platforms like Manufacturing Execution Systems (MES), Manufacturing Operations Management (MOM), and Product Lifecycle Execution (PLE).

Building on this momentum, the National Institute of Standards and Technology (NIST) recently launched a Smart Manufacturing Systems (SMS) Test Bed, a model factory that will facilitate and test digital thread implementations and enabling technologies. The test bed includes: a computer-aided technologies laboratory running software tools to control design, fabrication, inspection, data, verification and testing; a real-world manufacturing facility equipped with CNC machine tools and precision inspection devices; and online data streaming, collection, storage, and publications services. Participants can experiment with the digital manufacturing process, search a repository of SMS Test Bed data, and even try replicating model products previously fabricated via digital threads in their own facilities.

Enabling the Digital Thread

All the components required to begin developing a digital thread framework are readily available. Data storage and cloud computing are affordable and flexible. Advanced analytics and machine learning help us draw valuable insights, predictive models, and simulations from massive amounts of data. Precise, real-time, contextual data is generated by sensors on products and equipment, consumed by cyber-physical and control systems, and fed into algorithms and analytics solutions to create models, simulations, and forecasts. Accenture has projected that the IoT ecosystem will expand rapidly over the next four years: 212 billion sensors, 50 billion connected devices, and 2.5 billion connections to wireless networks.

Manufacturers are using advanced 3-D printers to produce prototypes and intricate components, including some that would otherwise be impossible to produce. This additive manufacturing approach enables powerful design flexibility, speeds time to market, and controls costs for custom products; medical device makers are leveraging this approach to create breakthrough products. 3-D design and visualization solutions enable the creation of digital twins, virtual copies of a manufacturer's product that are referenced throughout the product lifecycle. Digital twins are repositories of data from all stages of manufacturing, from design to inspection and maintenance, and as such are essential components of the digital thread. These standardized digital 3-D

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models streamline the interpretation and transmission of product-specific data throughout the product lifecycle, dramatically reducing the time and error-prone human interaction required by 2-D systems. NIST researchers estimate that moving from 2-D, paper-based methods (still used by 90% of small manufacturers) to 3-D digital manufacturing can cut production time by as much as 75 percent.

In similar fashion, augmented and virtual reality solutions are helping designers, engineers, and factory technicians work with machines and execute complex processes with deeper access to visual schematics and models. These advanced solutions create next level interfaces to simplify human-machine interaction, deliver real-time, contextual data about machine performance, streamline maintenance and repair, and virtually test the impact of changes. Robotics and automation likewise ease the burden on humans, creating safer and more ergonomic operating conditions, speeding production, increasing precision and quality, and reducing errors and downtime. Robotic components and automated processes produce digital records of configurations, calibrations, diagnostics, and performance—all of which loop back into the digital thread.

The Model-based Manufacturing Enterprise

Cloud computing may not be as new and exciting as robotics and virtual reality, but it is one of the primary drivers of the digital thread framework, and smart manufacturing in general. On-demand, scalable information technology services can be quickly deployed, easily managed, and connected via APIs and open standards to machines, data stores, and enterprise integration platforms. These platforms lie at the heart of the digital thread: performing data aggregation and analysis, triggering controls, recording operations and performance, and automating workflows across the shop floor and throughout the value chain. As the various functional types of manufacturing systems become more closely integrated, the digital thread becomes more fully realized.

Enterprise Resource Planning (ERP) and Product Lifecycle Management (PLM) systems are considered fundamental for model-based manufacturing enterprises, but a genuine digital thread cannot exist without a PLE platform. To develop, describe, manage, and communicate information about their products from conception to end-of-life, manufacturers use PLM.

PLM architecture is object-oriented and structured around products, product relationships, and configuration management functions. To manage resources for production, manufacturers use ERP. ERP architecture is transaction-based and organized around production resources. While the ERP system utilizes product data and process plans contained in the PLM system, the architectures of ERP and PLM are fundamentally different. PLM provides "the what": modeling, BOM management, process planning, process simulation, and engineering change management. ERP provides "the when, where, and how much": scheduling, financials, and inventory. But to have a fully functioning digital thread manufacturers also need "the how". That's what PLE provides through process execution, process control, quality assurance, traceability, and deviation handling.

Improving interoperability across industries and vendors, cybersecurity, and standards and open platforms are keys to the success of the digital thread.

A Number of Integration Challenges

As solution providers improve the integration of these types of enterprise systems with each other and with the other enabling technologies discussed, the seemingly futuristic prospect of the digital thread coalesces into real digital transformation of the product lifecycle and supply chain. There are equally real challenges and obstacles to address along the way, cyber security and other fundamental technical difficulties chief among them. Securing sensors, machines, data, networks, and cyber-physical systems is paramount to the sustainability of the whole endeavor.

Manufacturers of highly engineered products in defense, aerospace, medical devices, and energy are acutely sensitive to security concerns, for obvious reasons. Connections between machines (including legacy equipment), machines and computing systems, and machines and operators have to be established, tested, and secured. Improving interoperability across industries and vendors should be a top priority; government and industry organizations will have to step up and lead the way to unified standards, alliances, and open platforms.

Balancing Risks and Rewards

Forging ahead with the required investments can be a financial and cultural challenge for manufacturers who have spent decades optimizing and fine-tuning traditional systems. Measuring ROI in new paradigms is inherently tricky, but such extensive transformations require top down buy-in from executives and boards. Those leading the way will have to prove that digital integration won't break the factory or value chain—or break the bank.

The risk involved in any type of digital transformation is significant. In complex industries, it can downright painful. Workforce issues loom large—there aren't enough appropriately skilled workers, and retraining requires time and resources. The continuous Big Data collection and analysis that underpins the digital thread requires data science, cybersecurity, and IT skills that are in high demand across all types of businesses and public agencies. The already beleaguered manufacturing workforce has been resistant to automation, justifiably fearing job losses. Extending the digital thread into the supply chain will require overcoming myriad obstacles, including basic supplier readiness. SMEs, including smaller manufacturers that deliver components and subassemblies to larger enterprises, lack the resources to retrain, retool, and implement advanced systems. On a grander scale, global crises,

Forging ahead with the required investments can be a financial and cultural challenge for many manufacturers.

economic trends, and political upheavals send ripple effects through multinational supply chains. All of this, of course, has to be managed under intense market pressure and regulatory oversight.

Yet, progress marches on. As with the broader digital transformation in commerce and communication, those who wait on the sidelines for an easier time to join the march may be left out entirely. The potential benefits, both near- and long-term, are undeniable and compelling. Quality, control, and risk can be precisely managed in real-time across the enterprise. Business, production, and compliance problems are solved faster, better, and cheaper. Decision support becomes more granular, and is harmonized across the factory and throughout the supply chain. The digital thread brings customers, vendors, and suppliers closer, tying them into holistic feedback and evaluation loops. People, machines, and other resources are put to more efficient use, with optimization driven by better metrics and predictive performance analytics that flag pending issues before they cause outages or quality defects.

The biggest value with the digital thread lies in the remarkably improved capacity to manage product configurations.

For complex manufacturers, many of which are digital thread pioneers, the biggest value lies in the remarkably improved capacity to manage product configurations and change management across the entire value chain and product life cycle. These capabilities allow companies to ensure faster time-to-market, more successful new product introductions, and flexible reactions to customer needs. Closing the loop on engineering changes promotes conformance to customer specifications and regulations, assuring that as-built configurations precisely match as-designed. It also ensures that knowledge and documentation of changes are communicated upstream and downstream, preserving integrity with optimal efficiency. From the shop floor to the C-suite, the digital thread framework enables visibility, consistent practices, continuous products and process improvement, and efficient compliance with exacting quality and compliance standards (e.g., ISO 9001, AS9011, and FDA's 21 CRF Part 11 and Part 820).

Connecting Quality and Compliance

Quality management is a key feature of the digital thread. In complex discrete manufacturing, especially, the tolerance for faulty parts and products is near zero, for obvious life-and-death reasons. Closely managing quality throughout the entire manufacturing process using integrated systems that embed proofing and inspection practices and verify the certifications of personnel, tools, and machines saves time, reduces waste, and protects enterprise reputation.

High-profile quality failures like the Takata airbag recall have prompted Gartner, ISO, and others to issue urgent calls for greater focus on supply chain visibility and quality control. Likewise, regulatory compliance is an ongoing headache for many industries. Within the digital thread framework, quality and compliance activities are more closely linked. Related data collected and analyzed at key points can be used to predict, prevent, and detect errors. Corrective actions can be automated, documented, and propagated through the supply chain to avoid repetitive or cascading errors. The tracking and traceability of these inspection and remediation processes improves audit readiness and streamlines callbacks when necessary.

The Journey to Digital Manufacturing Maturity

Diving in to paradigm change requires strategy and planning. In the case of digital transformation, it also requires infrastructure readiness. Initial steps on the journey to realizing the digital thread include implementing enterprise systems (integrated MES suites), maturing IIoT capabilities, and evolving supply chain infrastructure. Build foundational value by focusing on leveraging the data generated by design, engineering, production, quality, compliance, and MRO processes. In a recent Capgemini survey, 61% of executives and senior decision makers acknowledged that data is now a driver of revenues, and becoming as valuable to their business as their existing product and service lines.

Start by evaluating readiness factors: infrastructure, finances, risk profile, and workforce skills. Examine both assets and weak points thoroughly, and develop strategies to leverage or remediate these factors in the context of digitizing operations. Develop specific milestones and strategies for reaching them. Look for expert help from established consultancies, IT vendors, and cloud service providers.

Use pilot projects to prove concepts and demonstrate ROI, to cement top floor buy-in, and to focus on low-hanging fruit that has a high probability of visible success. For example, many enterprises started their journey with optimizing logistics, using sensors to provide contextual, real-time information about supplies and shipments.

On a broader scope, participate in the development of industry standards working towards interoperability and open platforms (e.g., DMDII, MESA, NNMI, the Industrial Internet Consortium). Learn from the NIST SMS Test Bed and similar projects. Get involved in workforce pipeline development and retraining initiatives.

Manufacturers cannot afford to ignore the swelling tide of opportunity and disruption created by the power of digital transformation and integration. Around the world, concerted efforts are underway to revolutionize design, production, and extended services. Germany's Industrie 4.0 and China's Made in China 2025 initiatives are turning up the pressure on the U.S. and other manufacturing centers. The global manufacturing sector is a $10 trillion dollar behemoth. The digital industrial revolution will unleash tremendous value and innovation over the next 10 years. Jumping in now, with a focus on bringing the digital thread to fruition, will ensure competitiveness and resilience for years, even decades, into the future. M

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