WHITE PAPER

Modernize your manufacturing with a digital thread

Link your data from design to distribution

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The evolution of industrialization has seen significant shifts fueled by technological advancements, culminating in Industry 4.0, also known as the Fourth Industrial Revolution. This era sees automation, data exchange and artificial intelligence (AI) converging to revolutionize manufacturing processes, resulting in “smart factories“ capable of autonomous decision-making and adaptive production. Industry 5.0 is emerging as a visionary concept, building upon Industry 4.0. Industry 5.0 emphasizes human-robot collaboration and socio-technical systems integration. Unlike its predecessors, Industry 5.0 prioritizes human creativity, emotional intelligence and problem-solving skills, aiming to harmonize human and machine capabilities for enhanced productivity and sustainable development. The transition from Industry 4.0 to Industry 5.0 is not about replacement but coexistence and evolution.

In contemporary manufacturing, embracing industrial automation is crucial for competitiveness and is seen as a strategic imperative. Enterprises prioritize automation initiatives driven by the transformative potential of digitization, automation and data-driven decision-making. Despite challenges posed by diverse equipment, manufacturers increasingly optimize operations with connected devices, leveraging advancements in big data and predictive analytics. Integration technologies such as cloud computing, IIoT, smart devices and edge computing facilitate connectivity and are reshaping manufacturing paradigms toward a unified vision of automation.

While the concept of industrial automation isn’t novel, the pace of technological advancement and the breadth of its implications continue to evolve rapidly, challenging companies to adapt.

TABLE 1:

Challenges companies face in adapting to Industry 5.0

Technology challenges

Inadequate or legacy equipment: Outdated machinery in manufacturing hampers digital integration, limits real-time visibility and complicates data-driven decision-making. Retrofitting to meet modern standards is expensive and time-consuming, delaying technology adoption.

Lack of interoperability among commercially available solutions: Fragmented manufacturing solutions lead to communication issues between hardware and software, requiring manual intervention for data analysis and fostering vendor lock-in, complicating upgrades.

Insufficient network infrastructure: Manufacturing modernization depends on smooth data flow between shop floor and enterprise systems, utilizing diverse communication protocols like Modbus, OPC and MQTT. However, outdated network infrastructure can impede real-time data transmission, causing delays and inaccuracies.

Separation of IT and OT: In the digital age, merging information technology (IT) and operational technology (OT) is crucial for unified data exchange and connectivity in manufacturing. Without integration, data silos, communication barriers and compliance issues obstruct the holistic utilization of shop floor data for digital thread implementation.

Data challenges

Disparate systems and data sources: Integrating data across manufacturing systems leads to fragmented views and inconsistent insights, hindering comprehensive analysis and decision-making due to lack of proper integration.

Inadequate data quality: Raw data from diverse shop floor systems requires manual processing for usability, consuming time and resources, while risking errors due to the absence of a robust data architecture deployment.

Data security concerns: As manufacturing processes digitize and devices interconnect, the shop floor faces heightened cyber threats due to sensitive data exposure. Integrating legacy systems into digital ecosystems can further compound vulnerabilities, necessitating robust protection measures.

Increasing complexity of data compliance and regulations: Compliance with manufacturing data regulations demands meticulous attention, substantial investment in infrastructure and the ongoing adaptation to evolving requirements, complicating the landscape.

Historical data retention for knowledge base and compliance: Companies must retain sensor data for regulatory compliance and leverage it for knowledge creation, aiming for golden batch and process optimization. However, managing long-term data poses challenges in scalability, cost, integrity and regulatory compliance, demanding robust governance and advanced management capabilities amidst evolving technologies and legacy system compatibility concerns.

Business challenges

Resistance to change: Adopting new technologies often requires changes in workflows, job roles and even the organizational structure. Introducing technological principles and ways of working can clash with existing cultural norms, leading to resistance and friction.

Lack of digital skills: Demand for skilled professionals in data analytics, cybersecurity and automation grows as manufacturing relies more on technology. However, a shortage of such individuals impedes effective digital thread implementation, potentially hindering operational optimization, insights identification and innovation.

Lack of cross-collaboration: Digital technology integration in manufacturing requires collaborative efforts among IT, operations, engineering and business units. Yet, siloed structures and communication barriers hinder insights sharing and strategic alignment, potentially limiting comprehensive shop floor data utilization and impeding process optimization, innovation and competitiveness.

The digital thread is pivotal in modern manufacturing, linking data from design to distribution. However, diverse equipment creates interoperability challenges between OT and IT. Bridging this gap with digital thread deployment is essential for streamlining operations and real-time monitoring. As IT integrates with shop floor operations, the convergence of OT and IT drives digital thread adoption. Despite this, data analytics faces hurdles due to diverse sources and formats. Addressing these complexities demands sophisticated frameworks to ensure data accuracy, reliability and security while enhancing operational efficiency and decision-making capabilities by managing the generated data volume better.

FIGURE 1:

Traditional factory setup (ideal state)

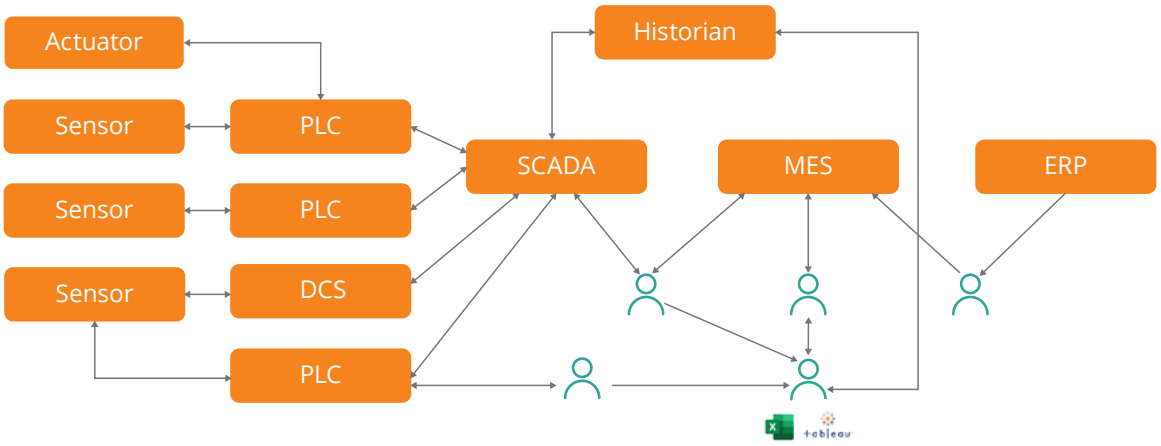
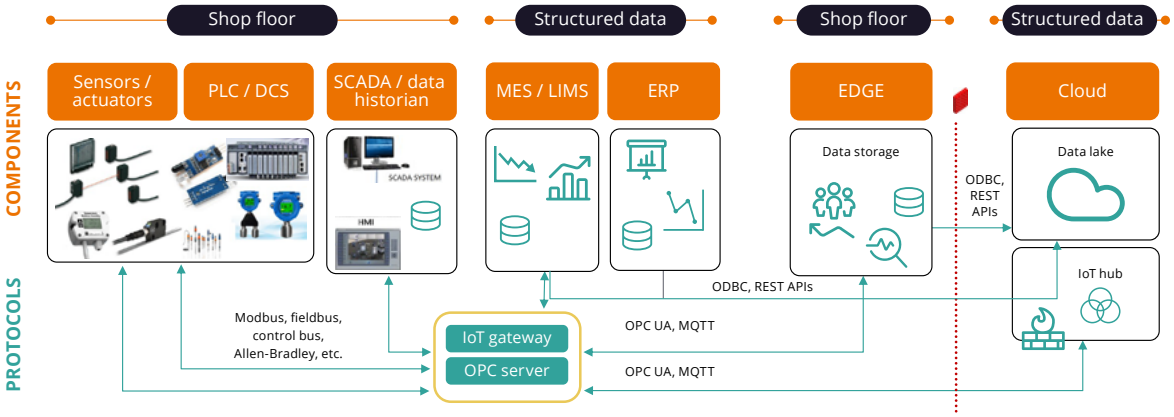


FIGURE 2:

Modern interconnected factory



In shop floor environments, diverse hardware and software systems serve various functions, requiring tailored integration methods. Each component follows specific protocols, complicating scaling and integration, which can be costly. Data is scattered across multiple points, forming intricate pathways for collection and aggregation. This data complexity and the need to integrate edge and cloud computing create hurdles for establishing a digital thread. Overcoming these challenges is crucial for streamlining operations and harnessing the full potential of shop floor technologies.

The building blocks of the digital thread

The digital thread consists of four fundamental building blocks that enable its seamless integration and operation throughout the product life cycle. These building blocks serve as the foundation for the interconnected flow of digital information.

Infrastructure readiness

Fact: Currently, 50% of manufacturers rely on manual tools like spreadsheets or internally developed solutions, which impose significant IT burdens and pose a risk of obsolescence. Nonetheless, an overwhelming 97% of manufacturers have intentions to adopt and utilize smart manufacturing technology in the foreseeable future.

A robust infrastructure forms the backbone for a successful digital thread implementation on the shop floor. It ensures that the necessary hardware, software and network capabilities are in place in a compliant and secured way, and it establishes the foundation for seamless data flow between disparate systems and devices on the shop floor. Shop floor infrastructure must be well equipped enough that it enables real-time data capture from shop floor devices like sensors and PLCs. This continuous flow of information allows for immediate insights into production processes, equipment performance and product quality. Infrastructure readiness also entails scalability and interoperability that can accommodate future growth and the integration of new technologies by leveraging open communication standards and protocols without significant infrastructure overhauls.

TABLE 2:

Infrastructure requirements across multiple levels of the shop floor

Levels	Hardware and software	Communication protocols	Connectivity requirements
Level 1	Sensors, actuators, control devices, motor control centers and HMI	Modbus, Profinet, Ethernet/IP, Profibus, DeviceNet	Robust wired infrastructure, IoT-enabled sensors, actuators, IoT gateways
Level 2	SCADA systems, historian	Modbus TCP/IP, Ethernet/IP, OPC UA, MQTT	Robust wired infrastructure, wireless connectivity solutions
Level 3	MES, QMS, advanced analytics tools	OPC UA, ODBC/JDBC, APIs, MQTT, AMQP, DDS	Edge computing infrastructure, MES connectivity over IT protocols and ethernet networks
Level 4	ERP, PLM software, BI and analytics tools, SCM solutions	OPC UA, SOAP, REST APIs, XML, HTTPS	ERP connectivity over IT protocols and networks
Level 5	Cloud-based solutions, digital twin	HTTPS, SOAP, RESTful APIs, MQTT, AMQP, OPC UA	Cloud computing infrastructure, robust cybersecurity measures, edge/IoT analytics enabled on the cloud

Achieving seamless integration across shop floor environments faces persistent challenges despite vast protocols and standards availability. In greenfield settings, integrating smart instrumentation is straightforward, but brownfield environments with legacy systems pose complexities like space constraints and compatibility issues. Retrofitting infrastructure with smart sensors often demands costly upgrades, disrupting production. Standardization efforts aim to enhance interoperability, yet compatibility issues persist among equipment and software from different vendors. Change management hurdles arise from employee resistance to new technologies, necessitating careful planning to minimize disruptions. Overcoming these challenges requires concerted efforts to align on interoperability standards and invest in modernization initiatives. Solutions include cloud-agnostic logical architecture, configurable connectors (database, OPC, MQTT, AMQP) and ISA-88- and ISA-95-compliant data models. Such integration across multiple levels is necessary for the successful deployment and sustainability of the digital thread.

Data readiness

Fact: The progression of data utilization in manufacturing is expected to yield a 5% enhancement in global GDP and a 20% increase in manufacturing EBITDA.

The digital thread hinges on quality, accessible data from the shop floor. However, 40% of manufacturers express a deficiency in leveraging data for decision-making purposes. Data readiness ensures effective capture, structuring and management, vital for utilization. It entails industry standards, robust governance, standardized models for consistency and ontologies for contextual meaning, enabling seamless integration and accurate interpretation, crucial for its integrity.

ISA standards, crucial in industrial automation, ensure system interoperability, reliability and security. Compliance ensures adherence to recognized protocols, reducing risks and ensuring data integrity. Common standards, like ISA-95, facilitate enterprise-control system integration, while ISA-88 guides batch control system design. Integrating both standards

enables comprehensive data modeling, supporting seamless interoperability. ISA-88 manages batch processes, complemented by ISA-95's data granularity definitions. Despite challenges, these standards remain vital for manufacturing IT strategies, forming the industry's backbone.

Adopting standardized data architecture principles enables scalability and accelerates business value realization. Establishing a central repository for raw data from shop floors and enterprise systems across multiple sites ensures consistency and compatibility in ingestion methods. Utilizing streaming data enhances real-time analytics, facilitating prompt decision-making. Contextualizing raw data with tagging and metadata enhances interpretation and interoperability, unveiling actionable insights. Data transformation into a common data model aligns with standards, facilitating integration and eliminating complexities. Centralized access to both real-time and historical data enables efficient analytics. Aligning data with business rules creates analytics-ready data products, expediting analysis and insights-driven decision-making. In industries like manufacturing and pharmaceuticals, this approach optimizes processes, reduces downtime, ensures regulatory compliance and enhances efficiency across multiple sites.

Manufacturers can optimize shop floor data readiness through data quality standards, governance practices and data migration. To address data challenges, organizations can turn to solutions like advanced data quality tools for cleansing and enrichment, robust governance frameworks and investments in data architecture, like data lakes. Compliance management solutions aid regulatory adherence, while collaboration with agencies and technology deployment facilitates record-keeping. Cloud-based data lakes and archival systems maximize historical data management alongside life-cycle strategies, ensuring compliance. AI and machine learning integration extracts insights from historical data, enhancing overall efficiency.

By embracing data readiness principles and leveraging industry standards such as ISA-88 and ISA-95, organizations can overcome challenges related to data integration, quality and compliance. The combination of standardized data models, robust governance practices and advanced analytics capabilities empowers manufacturers to unlock the full potential of their shop floor data.

Analytics readiness

Fact: Enhancing data analytics utilization is the primary approach manufacturers intend to employ to achieve positive business outcomes in the next five years.

To unlock the full potential of the digital thread, analytics readiness on the shop floor is crucial for manufacturers. The digital thread generates extensive data from shop floor sources, and analytics readiness ensures that the infrastructure is in place to convert this data into actionable insights. With advanced analytics techniques, manufacturers can uncover trends, anticipate equipment failures, streamline production processes and enhance decision-making for continuous improvement. Without analytics readiness, the digital thread merely acts as a data repository, concealing valuable insights and impeding process optimization and informed decision-making. By leveraging analytics, manufacturers can establish a continuous flow of information, connecting every aspect of the production life cycle and empowering data-driven decision-making at every level.

Building an analytics-ready shop floor involves two essential components. First, integrating industry-standard analytics tools and platforms is crucial for visualizing data, conducting statistical analysis and employing machine learning algorithms to derive insights from shop floor data. Second, understanding the diverse needs of stakeholders is paramount. Tailoring analytical features to meet the requirements of floor operators, as well as upper management, ensures accessibility to pertinent insights. Offering a spectrum of tools, ranging from simple dashboards for operational staff to advanced platforms for managers, enhances accessibility to relevant information. Customized interfaces based on skill levels facilitate comprehension of analytics. Ultimately, adaptability to address specific stakeholder needs is critical for effective decision-making in a smart factory setting.

Despite challenges, analytics on digital shop floors significantly enhance efficiency, decision-making and competitiveness in manufacturing. As of now, 79% of manufacturers have made significant progress in implementing advanced data analytics, including predictive and prescriptive analytics. Establishing persona-driven pathways of data consumption, often through edge devices or packaged software, is essential. Employing tools for descriptive, predictive and innovative analytics fosters innovation. Companies should enable pre-built analytical apps such as OEE, AI and machine learning algorithms like predictive maintenance and applications like digital twin at various levels to maximize the benefits of analytics in manufacturing.

Cybersecurity readiness

Fact: Among manufacturers, cybersecurity emerges as the most critical technology use case, with 92% considering it paramount, while 88% of organizations are already implementing it.

The digital thread in manufacturing demands stringent cybersecurity measures on the shop floor to safeguard sensitive data and intellectual property from cyber threats. Standards like ISO 27001 and protocols such as OPC UA and MQTT ensure resilient cybersecurity frameworks with encrypted data transmission. Cloud technology offers scalability but requires robust security controls. Challenges persist, including legacy system vulnerabilities and insider threats. Solutions entail data protection strategies, encryption and continuous threat monitoring. Compliance with regulations like FDA and network segmentation are crucial, alongside separating OT networks from IT networks to prevent unauthorized access and malware.

Fact: For implementing a digital thread, you need a structured approach

Implementing a digital thread on the shop floor presents complex challenges, including integrating hardware and software systems, managing diverse data sources and addressing legacy equipment limitations and data security concerns. Companies must invest in robust infrastructure, data management, analytics and cybersecurity measures to overcome these obstacles and unlock transformative potential. Embracing IoT, AI, advanced analytics and cloud computing enables real-time decision-making and enhances efficiency in operations. A structured approach, encompassing process mapping, infrastructure assessment, cybersecurity requirements design preparation and user training, is needed to establish a robust digital thread framework for seamless connectivity and data flow across systems.

About the authors

Dharmesh A. Ved has over 25 years of industry experience in healthcare and pharma, specializing in Industry 4.0 smart manufacturing. His strategic focus lies in integrating vertical and horizontal systems to drive end-to-end value creation across industries. With deep expertise in plant automation, he designs solutions for real-time productivity and quality monitoring and has developed an ideal plant and cloud enterprise architecture. Additionally, Dharmesh collaborates with solution providers to create reporting and analytics solutions for manufacturing across diverse industries.

Anoop Garg brings over 20 years of experience in leading large-scale tech transformation engagements. He specializes in cloud-based big data solutions, advanced data and analytics platforms and strategic IT roadmap planning. Since 2014, Anoop has led various tech strategy engagements for life sciences-based clients and contributes to capability development at ZS, where he is the lead for tech capabilities and offerings in manufacturing.

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Joyeeta Chatterjee is an associate in ZS's New Delhi office and is part of the supply chain and manufacturing. She is a core member of the team, delivering research on subjects related to the factory floor, data contextualization, analytics and associated topics. Joyeeta holds a bachelor's degree in economics from Symbiosis College of Arts and Commerce and an MBA from Nirma University. Her background and analytical skills have been instrumental in her contributions to the supply chain and manufacturing research initiatives at ZS.

About ZS

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