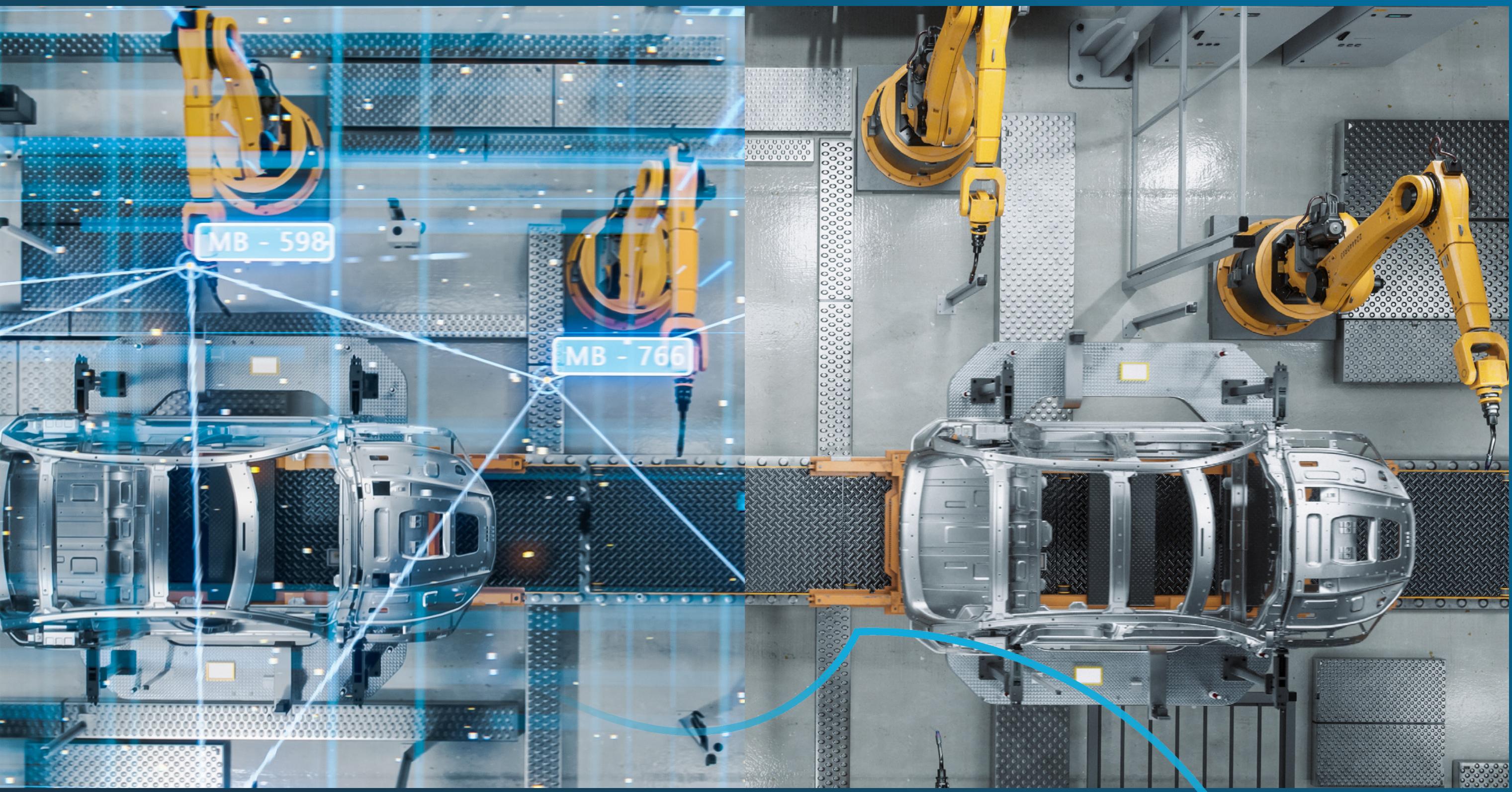


Making brownfield factories smarter and greener

A business case for digital manufacturing in brownfield factories

Capgemini

Foreword

The journey towards smarter and greener manufacturing sites is not without its challenges. This is particularly true for Brownfield sites, whose legacy infrastructure and ingrained processes can seem like formidable obstacles to change. Yet, it is precisely in these environments the potential for transformation is most profound. Digital technology can breathe new life into aging facilities, optimizing operations, minimizing waste, and reducing environmental impact.

There are plentiful digital manufacturing success stories, with companies saving millions of dollars from reduced energy bills, more efficient communications between teams, visual inspection systems, optimized supply chain management, and reductions in CO_2e emissions. However, these stories are often about exploratory pilot projects, and there are far fewer stories about the full-scale adoption of digital manufacturing. Why is this when full-scale digital transformation holds such potential for substantial financial rewards and carbon savings? There are many sound reasons: for example, the investment case for physical production assets may be more attractive, or there may be concerns about the impact of digital technology obsolescence on OT stability.

So, how can you make progress toward wholesale transformation of manufacturing? I've long believed that technology, when harnessed responsibly and creatively, can serve as a force for tremendous good. In the following pages of this Everest Group report, supported and endorsed by Capgemini, you'll discover insights, case studies, and expert perspectives to help you build your business case and navigate your route to maximum value from your digital manufacturing initiatives for brownfield sites.

I hope you'll find inspiration from this paper and join us in harnessing the power of technology to build a smarter, greener, and more sustainable world for generations to come.

Nicolas Rousseau
EVP, Chief Digital Engineering & Manufacturing Officer
Capgemini Engineering

Everest Group®

April 2024

Making Brownfield Factories Smarter and Greener

A Business Case for Digital Manufacturing in Brownfield Factories

Contents

Introduction

Traditionally, manufacturers have focused on refining their processes to enhance efficiencies, improve the quality of finished products, and control expenses. In recent times, they have had to find new ways to pursue efficiencies and excellence with the advent of digital manufacturing, which augments manufacturing with technologies such as data analytics, AI/ML, augmented reality, industrial IoT, additive manufacturing, digital twins, simulation, blockchain, robotics, connectivity, edge computing, and cybersecurity – perhaps there are more to the list.

These technologies are being increasingly used amid the dynamic nature of business environments, stringent regulatory standards, newer and more collaborative ways of working such as remote and technology-led operations, and the need for operational resilience in the face of recent and contemporary sociopolitical events.

Additionally, depleting natural resources and increasing greenhouse gas emissions have made (tech-led) sustainability a prime focus area for enterprises. Manufacturing enterprises, along with firms from the energy and utilities and metals and mining sectors, are particularly under pressure to prioritize sustainability efforts, given that they pose the highest environmental risk.

Digital manufacturing technologies help address the challenges that these companies pose by facilitating process optimization and supply chain management, controlling raw material and energy consumption, and tracking carbon emissions. Further, leveraging digital manufacturing to enhance efficiency and streamline processes is closely intertwined with sustainability objectives, often resulting in more eco-friendly processes.

Notably, while it is easier to strategize and implement digital transformation initiatives when a factory is being built ground up, manufacturers are also actively assessing and driving the adoption of such initiatives in their legacy operations or, more particularly, brownfield factories.

However, bringing these factories on board the digital manufacturing train is not an easy proposition, given their complexity and risks to ongoing operations. Factors such as the integration of modern technologies across legacy systems, the risk of de-stabilizing current operations and interdependencies of processes, longer time frames of value realization, and the inherent resistance to change necessitate that enterprises do their due diligence to assess the costs and benefits before infusing capital into such initiatives. We believe that a solid business case exists for implementing digital manufacturing capabilities in brownfield factories, and, in fact, the benefits of such initiatives – if implemented thoughtfully – can far outweigh the risks and expenses of bringing about the change.

In this viewpoint, we:

- Explore the current state of digital manufacturing adoption in brownfield factories
- Examine the technology enablers
- Discuss the key use cases
- Consider the challenges that enterprises face in modernizing their factories
- Propose a business case for digital manufacturing in brownfield factories to make such factories not only more efficient, but also more sustainable

Digital manufacturing in brownfield factories

Digital manufacturing involves the use of automated and computer-aided technologies that enhance traditional manufacturing processes, leading to greater efficiency, accuracy, and sustainability. It helps break manufacturing siloes by connecting manufacturing processes and business function across the organization, facilitating thorough decision-making and consistency across processes.

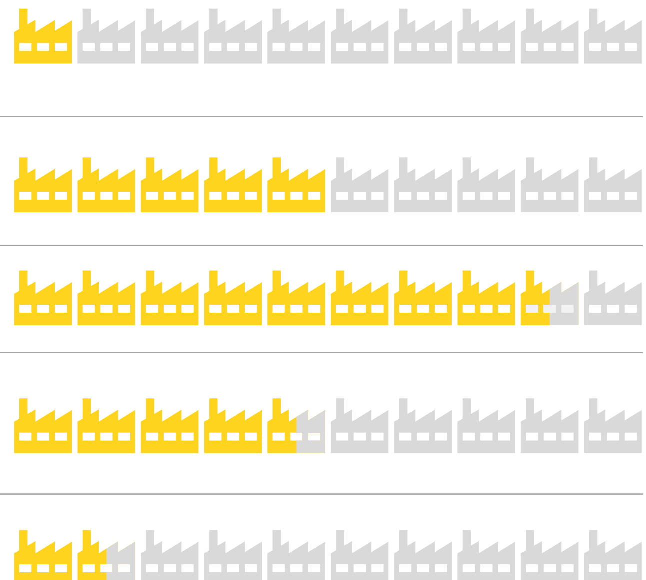
Consequently, enterprises are increasingly adopting digital manufacturing across the globe. Notably, enterprise spending on digital manufacturing in brownfields has consistently increased over the years, reaching close to US$110 billion in 2023. This growth represents a nearly 15% increase between 2022 and 2023 and can be attributed to the areas of IoT, cloud, analytics, and connected platforms.

However, as Exhibit 1 depicts, our research for Everest Group’s Industry 4.0 PEAK Matrix Assessments reveals that while enterprises are actively exploring pilot projects, large-scale adoption has been scarce (and scattered). While almost 46% of surveyed enterprises are exploring pilot projects to assess the value addition, they are only moving use cases with the highest potential toward industrial deployments. Enterprises are cautious in terms of full-scale adoption of digital manufacturing due to the macroeconomic environment, longer time frames of value realization, and inherent resistance to upgrading a process that works well.

Exhibit 1: Digital manufacturing: enterprise adoption levels

Source: Everest Group (2024)

Scaled and mature digital manufacturing adoption across the enterprise	5%
Implemented in parts of the organization (siloed operations)	25%
Invested in pilot projects	46%
Early stages of adoption / exploring the potential of digital manufacturing	18%
Not thinking of adopting any digital manufacturing initiative	6%



Case in point: JSW Steel

JSW Steel has been consistently implementing digital initiatives in its plant operations since 2017, with a focus on increasing productivity from existing assets in more cost-efficient ways, ensuring safety, improving customer and supplier experience, and transforming key support functions. The firm invested INR890 million in digital adoption in 2021-22 and claims to have saved INR4.27 billion in the same year through these initiatives. Cumulatively, the firm has saved INR11 billion so far.

Enterprise spending on digital manufacturing varies across industries, with allocations ranging between 15% and 25% of the total asset base – representative of moderate adoption – on average. Enterprises from the aerospace and defense, industrial products, and automotive industries are the prominent spenders, though use cases vary across verticals. Aerospace and defense firms spend on precision manufacturing, waste reduction, predictive maintenance, and supply chain optimization, while automotive and industrial products enterprises leverage digital technologies such as additive manufacturing, advanced robotics, digital twins, IoT, and data analytics to achieve the same objectives – enhance operational efficiency and worker safety.

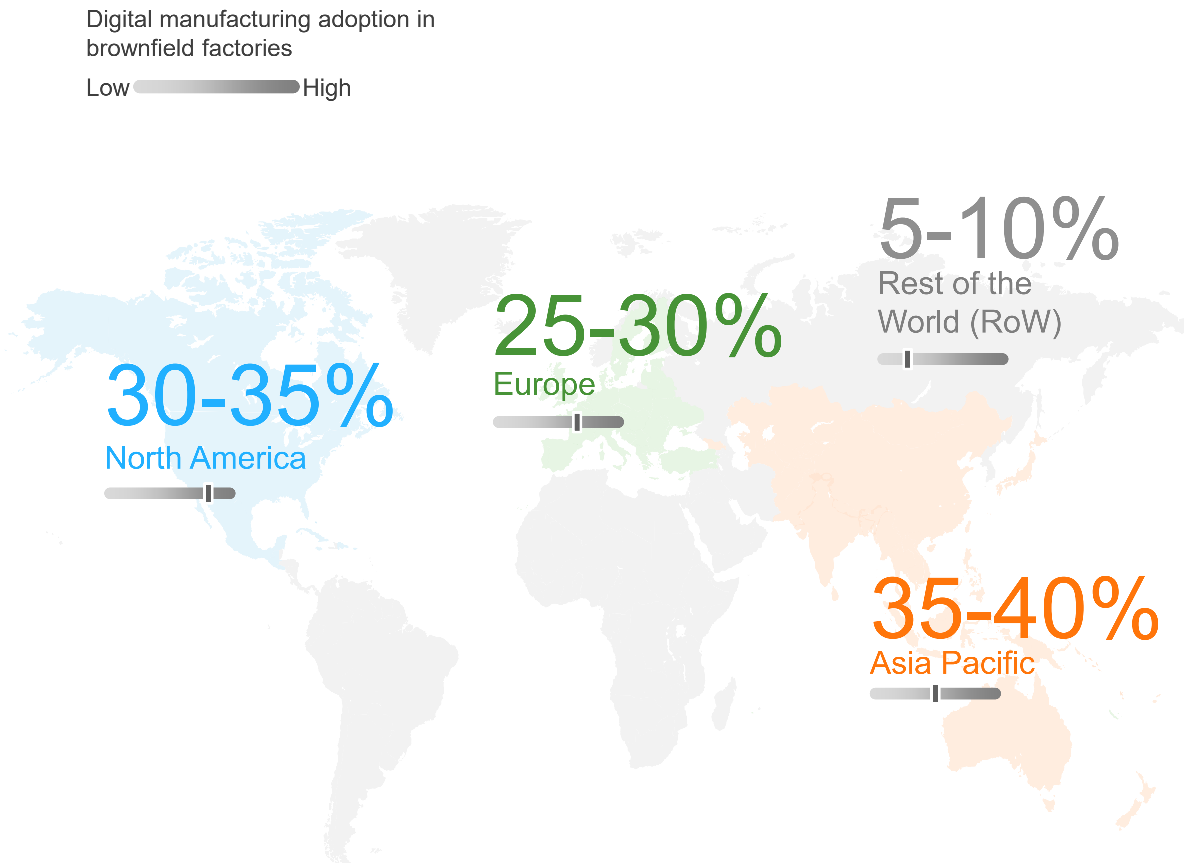
Globally, Asia Pacific leads in manufacturing investments due to the significant presence of manufacturing hubs such as China, Japan, South Korea, and India, and technology advances across other East and Southeast Asian countries. China alone accounts for almost 30% of global manufacturing annually.

North America comes second, with a mature manufacturing ecosystem driving investments in digital manufacturing, while automotive and industrial firms largely drive spending in Europe. Notably, manufacturing initiatives in Europe and Asia Pacific remained resilient, while those in North America slowed down amid the global recessionary sentiments across late 2022-23.

Exhibit 2 shows that while Asia Pacific dominates overall manufacturing spending, North America and Europe come out tops in terms of digital manufacturing adoption in brownfield factories. This gap is also attributed to the fact that enterprises in Asia Pacific have historically had a steady stream of labor, which has resulted in delays in adopting automation and other digital technologies. A majority of enterprises, therefore, are setting up the building blocks of connected factories by investing in data and process automation solutions. In contrast, factories in North America and Europe that have invested early in digital technologies possess a more mature infrastructure and are, therefore, better prepared to adopt large-scale digital manufacturing initiatives.

Exhibit 2: Enterprise spending on manufacturing in brownfield engagements by geography

Source: Everest Group (2024)



What is driving the growth of digital manufacturing?

Digital manufacturing can augment existing factory equipment and machinery, legacy software systems and operational networks, the workforce, and standard operating procedures in brownfield setups, as Exhibit 3 depicts.

Exhibit 3: The role of digital manufacturing in brownfield factories across equipment, software infrastructure, and processes

Source: Everest Group (2024)

Category	Role of digital manufacturing in brownfield factories
Equipment	• Upgrade equipment with sensors and controllers • Introduce IoT-enabled devices in the manufacturing process • Adopt workforce assistant robots and handheld devices
Software and connectivity infrastructure	• Establish a secure connectivity network across the factory • Adopt data centers, cloud infrastructure, and data platforms to store, manage, and access operations data • Converge operational data into leadership systems • Upgrade Programmable Logic Controllers (PLCs) to facilitate connectivity and remote operations • Adopt Manufacturing Execution Systems (MES), Product Lifecycle Management (PLM) solutions, and other IoT platforms • Adopt digital twins in tandem with Supervisory Control and Data Acquisition (SCADA) systems
Process	• Optimize the shop floor • Optimize the supply chain

Enterprises are using a diverse set of technologies – including data analytics, AI/ML, sensors, IoT equipment and platforms, AR/VR, digital twins, connectivity, cloud and edge computing, 3D modeling, digital twins, robotics, additive manufacturing, and Automated Guided Vehicles (AGVs) – to equip factories with digital capabilities. The successful adoption of digital manufacturing is predicated on the overlapping or simultaneous use of these technologies.

Generative AI in manufacturing

Generative AI is also expected to have a significant impact on brownfield factory operations. Although the technology is still in its nascent stages, with enterprises exploring PoCs and pilots, it has the potential to accelerate digital manufacturing initiatives and augment capabilities with improved decision-making, optimized production lines, and stricter quality controls. Key applications of generative AI are likely to include automatic modeling of digital twins, data management, simulations based on real-time data, process optimization based on parameters and requirements, predictive maintenance, and supply chain optimization complemented by virtual assistants to the workforce. These assistants streamline operations by analyzing SoPs, providing guided maintenance and easing the transition to advanced technologies. Enterprises can also use gen AI to augment technical publications that underpin the operations and maintenance of equipment and factories, enhancing traditional processes, while showcasing the value of emerging technologies in manufacturing.

Use cases driving the adoption of digital manufacturing in brownfield factories

Traditionally, manufacturers have leveraged process improvement approaches such as Lean Six Sigma, total quality management, and production systems to minimize wastage and improve efficiencies. However, while these processes are relevant, they are not enough to make factories future-ready.

Consequently, enterprises are increasingly turning to digital manufacturing, especially as it assists with use case families such as:

- **Asset monitoring and management:** Establishing a factory operation requires substantial capital expenditures for equipment procurement, as well as consistent maintenance and timely upgrades to ensure uninterrupted and prolonged production runs. Poorly maintained equipment results in costly repairs and creates bottlenecks in the manufacturing process. Through digital-led asset monitoring, enterprises can monitor the end-to-end status of all fixed and mobile assets in factories, right from installation to operations, maintenance, and disposal
- **Process tracking and optimization:** It is crucial for enterprises to track manufacturing processes to optimize the workflow, minimize wastage, maintain product inventory. Additionally, tracking helps to optimize the supply chain, which is essential given the volatile geopolitical scenario and frequent supply chain disruptions
- **Workforce augmentation:** Factors such as the shortage of skilled labor and a generational shift (with older, more experienced people retiring and newer generations entering the workforce) are spurring the adoption of digital technologies in manufacturing. These factors are leading to the prioritization of workplace safety, digital nativeness, mechanized assistance, and simpler Human-Machine Interface (HMI)

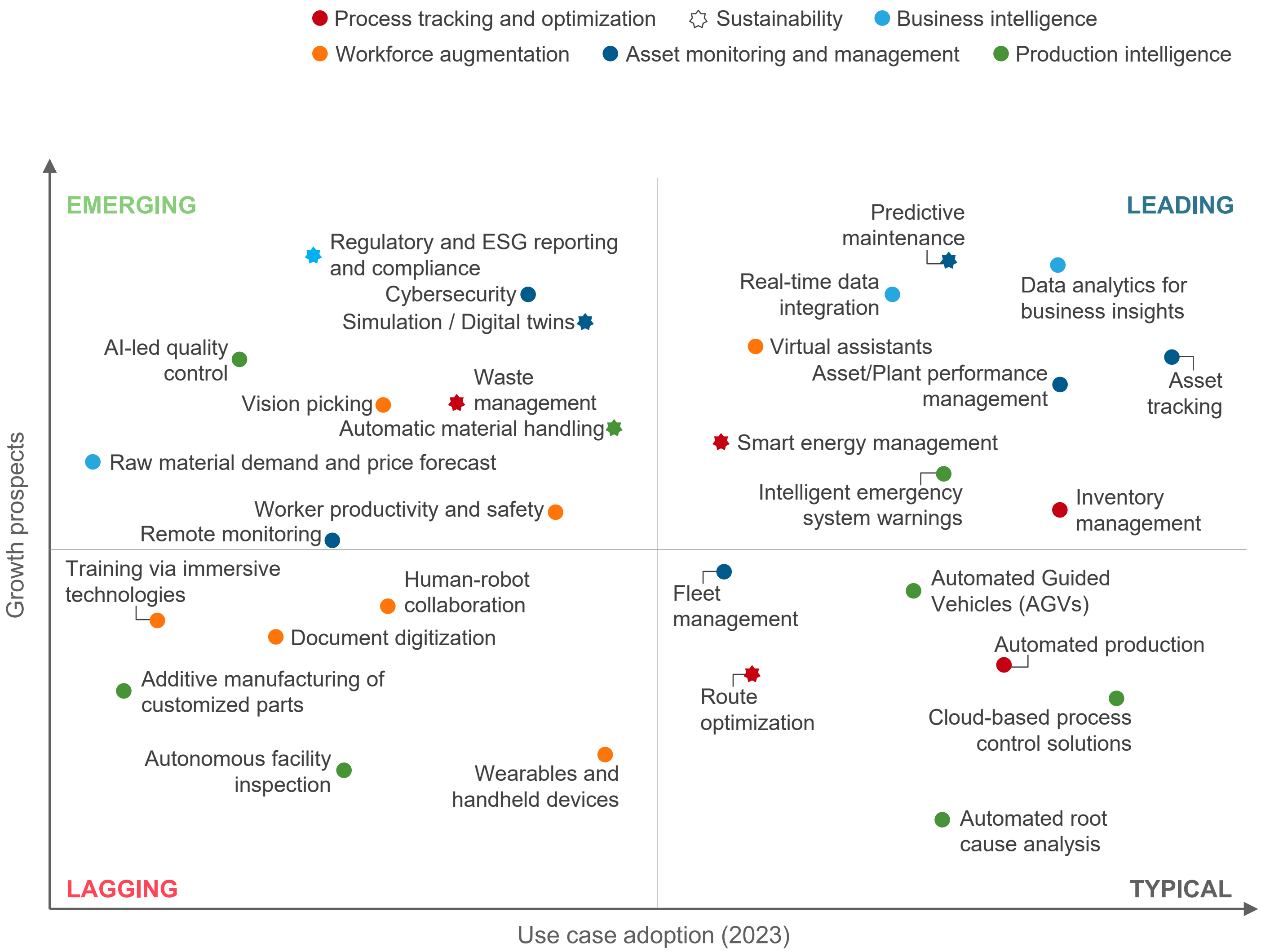
- **Production intelligence:** Even for a brownfield factory operating at its fullest capacity, it is a challenge to meet diverse customer requirements and accelerate time-to-market. Consequently, enterprises are adopting production intelligence solutions to enhance efficiencies, minimize human efforts, implement stringent quality controls, and build customized products
- **Business intelligence:** Business environments have become extremely volatile in recent times, and, consequently, the senior leadership's involvement and cross-functional collaboration have increased in factory operations. Digital technologies makes the specificities of factory operations accessible to the leadership and other firm functions to facilitate enhanced collaboration and top-down decision-making on products and processes
- **Sustainability:** While enterprises across industries are prioritizing sustainability due to rising carbon emissions and depleting resources, manufacturing enterprises are more under pressure to go green since they pose higher climate risks. Digital manufacturing helps enterprises monitor their energy consumption and carbon emissions across their value chains, formulate efficient waste disposal strategies, optimize resource utilization, prolong the life cycle of equipment, and meet their sustainability goals

It is worth noting that the technology families listed in Exhibit 3 serve as the foundational pillars supporting these families of use cases. Investments in asset monitoring and management for manufacturing operations are supported by upgrading equipment with sensors and controllers and introducing IoT-enabled devices into the manufacturing process, all falling under the "equipment" category.

Process tracking and optimization, which is crucial for operational efficiency, benefits from similar equipment upgrades and investments in software such as IoT and cloud-based platforms and connectivity infrastructure such as private 5G and Wi-Fi networks. Additionally, shop floor and supply chain optimizations improve production optimization. Adopting workforce assistant robots and handheld devices helps augment the workforce, while investments in software, connectivity infrastructure, and data platforms bolster process and business intelligence. The comprehensive integration of technology underscores the technology foundation supporting diverse use cases in manufacturing operations. Exhibit 4 illustrates the adoption and growth potential of these use cases.

Exhibit 4: Digital manufacturing use case adoption and growth potential in brownfield factories

Source: Everest Group (2024)



Given today's macro environment, use cases that are likely to have an immediate impact on a company's business and operations are the most implemented and are likely to remain a priority in the future. Such use cases are primarily based on sensor-powered visibility and data analytics.

Emerging use cases aim to enhance product quality and increase operational efficiency; however, their widespread adoption is anticipated to occur gradually over an extended period of time. Adopting these technologies will also require technology and other capabilities beyond sensors and data analytics to include computer vision, simulation, secure connected networks, and major physical overhauls. Various sustainability-oriented use cases also fall into this category of emerging use cases.

The focus on sustainability

The shift toward sustainability encompasses a wide range of initiatives, with a particular emphasis on enhancing process efficiency and optimization. Consequently, enterprises benefit from the fact that most digital manufacturing initiatives end up making their processes more sustainable. As Exhibit 4 shows, several use cases drive the sustainability goals of an organization. These include:

- Integrating sustainability policies and reporting standards into the operating software
- Reducing waste generation by timely maintenance of equipment to avoid major repairs and replacement and adopting digital twins and simulations in testing
- Optimizing the movement of raw materials for lower energy consumption using data analytics
- Monitoring and managing energy consumption across the factory through energy management solutions such as energy profiles and intelligent HVAC operations
- Improving process efficiency through automated handling

Case in point: BMW

With a focus on innovation and sustainability, BMW is transforming its Munich plant, operational since 1922, into an advanced manufacturing facility. In its paint shops, BMW is using robotic arms for an integrated paint process, which has helped BMW reduce natural gas consumption and CO2 emissions by 50% and electricity consumption by 25%.

Though enterprises are under pressure to reduce emissions and resource consumption, demands on manufacturing's production output are only likely to increase. Therefore, brownfield enterprises must transform their business processes, not just target efficiency, making digital manufacturing an imperative from a sustainability perspective.

One such transformative approach is the circular economy. As enterprises aim to increase the influx of recycled raw materials into their supply chains, they should evaluate their current manufacturing value chains and upgrade them to accommodate more recycled input. Technologies such as digital twins and data analytics help simulate and study these scenarios before actual upgrades are implemented. Digital manufacturing capabilities can also help validate the quality of recycled materials that go back into the value chain to maintain the final output's quality.

Sustainability is taking center stage in enterprises' future goals, as they are increasingly acknowledging sustainability as an opportunity center rather than a cost center. With the sustainability ecosystem maturing, the criteria of evaluation and sustainability reporting and compliance are becoming stricter, requiring more efficient data capture and analysis. Regulatory bodies are trying to minimize the scope for green-washing and penalizing unsustainable manufacturing processes with heavy fines. Consequently, enterprises are exploring how they can control Scope 2 and 3 emissions, along with implementing efforts to trace and curb Scope 1 emissions.

Manufacturers are also leveraging digital capabilities to address compliance issues. A maze of regulations governs them, with the costs of non-compliance far surpassing hefty fines and resulting in shoddy products, time-consuming lawsuits, loss of investor value, business disruptions, and trust and reputation erosion. To comply, manufacturers are adopting technology measures including AI-led quality control systems, real-time monitoring devices to flag non-compliance, and AI-powered analysis of the high data volumes generated to address the root cause of non-compliance.

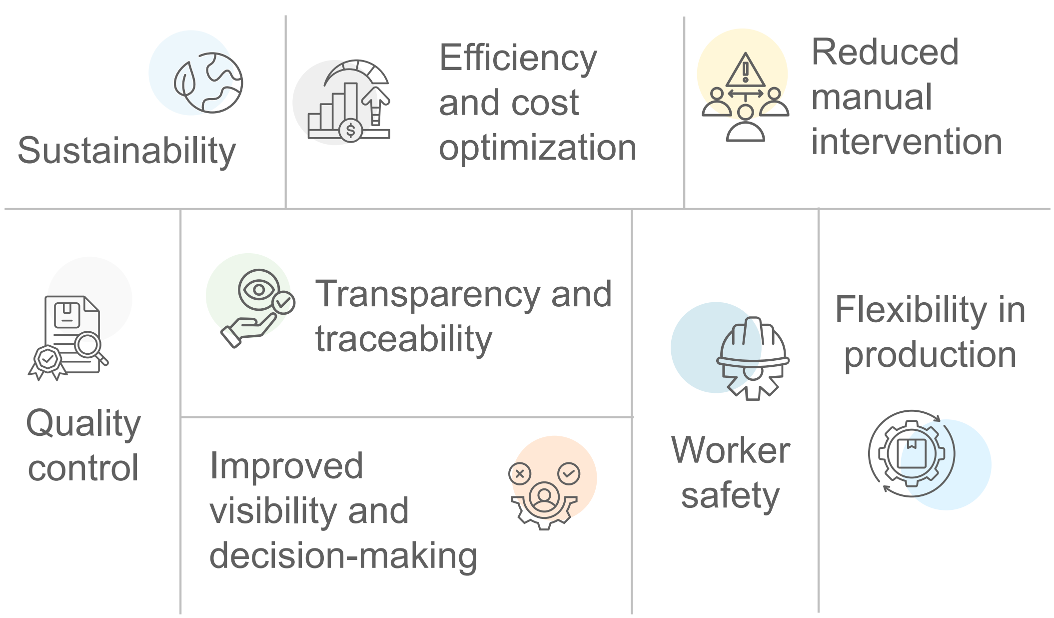
Factory of the future: a business case

The benefits of adopting digital manufacturing in brownfield factories

Enterprises' focus on identifying digital manufacturing adoption opportunities in brownfield factories is driven by the transformative benefits these technologies unlock, as Exhibit 5 depicts.

Exhibit 5: Benefits of adopting digital manufacturing in brownfield factories

Source: Everest Group (2024)



We take a closer look at these benefits below.

- **Improved visibility and decision-making:** By leveraging sensors and IoT devices, operators and supervisors obtain real-time data and insights on their operations, such as equipment health and performance, raw material flow, and labor utilization, allowing them to make more accurate decisions and respond to issues such as human error and production bottlenecks quickly and remotely. With greater visibility into manufacturing processes, the leadership and corporate functions can collaborate better and align manufacturing processes with broader business goals and strategies, facilitating agile and strategic decision-making, accurate risk management, and a more precise future roadmap

Case in point: Johnson and Johnson

During the pandemic, Johnson and Johnson extensively leveraged digital technologies to minimize business disruption. The firm optimized the manufacturing process to increase Tylenol production to meet market demands. It also prepared contingency plans on operating factories with a reduced workforce and amid supply chain disruptions. Engineers were able to monitor and manage production facilities remotely through Google Glasses. The firm also deployed track-and-trace solutions throughout the supply chain to ensure that products reached customers on time and in a fit-for-use state.

- **Transparency and traceability:** Sensors, data platforms, and blockchain-based traceability solutions allow enterprises to be more transparent about their manufacturing process, which builds trust among external stakeholders and value-conscious consumers. By educating consumers about manufacturing and supply chain practices and allowing them to trace the products to their origins, enterprises will be able to gain more consumer mind space, implement their feedback sooner in processes and product portfolios, and increase consumers' willingness to pay

Case in point: BASF

BASF is exploring digital solutions to make consumers a key stakeholder in its product development process, right from ideation to market insights and traceability. The company is experimenting with a blockchain-based traceability solution to open up the supply chain to consumers, allowing them to trace products back to their exact origins.

- **Efficiency and cost optimization:** Data analytics and AI/ML algorithms help make the manufacturing process more efficient, improving cost controls. Guided manufacturing operations and virtual assistants help improve the efficiency of operators and get them get it right every time. Predictive equipment maintenance helps avoid major repair or upgrade expenses, while technologies such as digital twins help control ideation and testing costs by leveraging simulations before investing in a pilot

Case in point: P&G

P&G's 150-year-old plant in Rakona, Czech Republic, aimed to ramp up production and use digital manufacturing capabilities to drive this expansion. The firm identified use cases such as direction setting, universal packing system, in-process quality control, supply chain synchronization, and modeling and simulation. Using digital manufacturing techniques, the Rakona plant was able to improve productivity by almost 160%, reduce full plant costs by roughly 20%, and reduce inventory by close to 43% between 2014 to 2016.

- **Flexibility in production:** Enterprises are using robots, data analytics, and computer vision to deploy flexible manufacturing systems that allow them to manufacture different products or variants of the same product on the same production line. Automating these activities helps minimize the downtime between changing the settings before different products come on the assembly line

Case in point: MTU Aero Engines

MTU Aero Engines has implemented an automated production process for airfoil components, as part of which operators only load the racks with blank parts. The rest of the process is automated. Robots pick up the blanks, secure them into the clamping device, and feed it into one of the tooling devices (by product type) for manufacturing. The robot also configures the settings for the next part that is to be manufactured. The solution can run without manual intervention for days at a time and has pre-built predictive maintenance and autonomous correction functions to ensure process stability. It has helped to reduce the downtime associated with retooling from 7-8 hours to nearly 15 minutes.

- **Quality control:** IoT- and AI-led solutions such as video analytics and digital twins improve adherence to quality standards, reducing defects and the wastage of resources

Case in point: Orange

Orange uses a digital twin platform to improve product quality and delivery time. It is a graph-based platform that creates the product's model by connecting each component's digital twin, which considers their definition, operating parameters, and internal relationships. The platform sends out notifications to operators, highlighting each component's availability, tracking whether all the available components are connected at their required positions, and providing next assembly steps in real time. Once the product is completely assembled, the platform does a final quality inspection and creates a record of the assembly workflow for further analysis and process improvement.

- **Reduced manual intervention:** Sensorization has reduced manual intervention in data capture, creating a more accurate data pool. Similarly, automated operations minimize the reliance on manual labor, aligning more closely with the concept of "dark factories," which function with minimal to no human interaction

Case in point: Ford

In the automotive industry, the installation of torque converters into transmission cases involves an intricate assembly process that demands substantial manual labor, potentially exposing workers to safety hazards. Keeping this in mind, Ford automated the process about a decade ago. However, the process still required considerable human involvement as the procedure had strict clearance criteria and the automation was a static solution that had to be updated each time a new vehicle model came on the assembly line. Ford upgraded this process at its Livonia, Michigan, plant by adopting an AI-powered platform that analyzes previous operations based on the data collected, and automatically configures robots on how the assembly should be carried out when the next transmission begins. It also analyzes historical data to identify quickest routes to assemble the torque converter. Ford was able to improve throughput by close to 15% by adopting this solution.

- **Worker safety:** Automating hazardous operations, deploying robots to collaborate with human workers, and implementing workforce augmentation solutions such as SoP guides, virtual assistants, and wearable technologies contribute to creating a safer and more optimal working environment for employees in manufacturing plants

Case in point: Rolls Royce

Rolls Royce is adopting digital manufacturing capabilities to improve worker safety as part of its Zero Harm initiative. The firm is adopting 3D visualization solutions to familiarize the workforce with the plant surroundings and the threats they are exposed to. It has also adopted ML-based solutions for Personal Protective Equipment (PPE) to adhere to quality standards and deployed robots in hazardous environments such as furnace operations.

- **Sustainability:** Use cases such as energy management, additive manufacturing, waste management, and automatic material handling help optimize raw material and energy consumption and reduce CO2 emissions

Case in point: Boliden

Swedish mining firm Boliden has been using digital manufacturing solutions to make mining and extraction a more responsible and sustainable process. The firm has adopted automation across the value chain, reducing fuel consumption by about 10%. The firm is also setting 5G communication networks to facilitate the deployment and maintenance of AGVs, which can improve safety and efficiency while cutting down emissions. The company is deploying multiple automation-powered solutions to conserve energy; for example, smart ventilation systems are helping save almost 25% energy over traditional ventilation systems.

Besides the tangible benefits that drive the adoption of digital manufacturing, companies are also attracted to its convenience and speed in increasing production capabilities in factories. Digital technologies enable enterprises to rapidly respond to market dynamics, roll out new initiatives across different plants faster, and integrate new capabilities into production capabilities, all the while monitoring quality standards, regulatory compliance, and efficiency.

Below, we present a case study on how enterprises are adopting digital manufacturing technologies to enhance their quality controls and make their processes more efficient.

Case study: because flawless packaging is “worth it”: L'Oréal deploys AI to enhance packaging quality

Background and business objectives L'Oréal is the world’s largest cosmetics company, making EUR41 billion in revenue in 2023. The firm has been proactively exploring opportunities to adopt digital manufacturing solutions to achieve its manufacturing action plans that cut across sustainability, quality, efficiency, and people. People remain central to the firm’s digital manufacturing initiatives, with a focus on how technology can empower operators to deliver quality and align with the firm’s broader goals. L'Oréal has developed several applications in-house to reduce paperwork, improve the quality of data that is captured, and simplify process changeover settings to augment worker experience.

Challenge The cosmetics giant was facing a challenge in its shower gel packaging processes, leading to recurring production stops. Some of the shower gel bottles sourced from suppliers did not meet L'Oréal's quality standards. While some bottles had manufacturing defects, others were getting damaged during transit. These defective bottles impacted production, as the line had to be stopped multiple times to remove them. Additionally, operators had to spend hours cleaning the equipment each time there was an overflow of shower gel from the defective bottles. It also caused errors in the later stages of the process, such as the misplacement of labels on the bottles. L'Oréal, therefore, sought a partner that could help address this issue through digital technologies.

Solution and approach L'Oréal chose Capgemini Engineering as its partner to address this challenge. Capgemini Engineering deployed a custom-built quality control device that used the combined capabilities of computer vision and AI to identify and remove defective bottles in the packaging line without impacting the production process.

- The provider owned the end-to-end responsibility of project management, from ideation to solution delivery, ensuring timelines and quality standards
- Capgemini Engineering augmented L'Oréal’s team with a team of subject matter experts in digital technologies such as data analytics and ML who helped co-create the solution
- While both teams brainstormed on ideating the solution, Capgemini Engineering led the technical deployment
- Capgemini Engineering deployed a custom-built quality control device that used the combined capabilities of computer vision and AI to identify and remove the faulty bottles in the packaging line, without impacting the production process

Outcomes L'Oréal observed a significant improvement in quality controls for bottles and process efficiency following the deployment.

- The equipment was able to investigate 60 bottles per minute and took less than 0.5 seconds from detection to decision-making (on removing a bottle from the packaging process)
- For every defective bottle that was removed, the operators saved nearly one hour of cleaning effort

The solution also mitigated issues that occurred later in the packaging process, such as the misalignment of labels on the bottles. L'Oréal has also adopted other simpler computer vision-based use cases across multiple production lines. With people being central to the operations, L'Oréal believes that along with KPIs and commercial returns, the success of a solution should also reflect how well it addresses the pain points of workers on the shopfloor and the level of acceptance it finds among users. The solution has fared well on these parameters as well, with wider operator acceptance and the utility of the solution reflecting in worker happiness.

Challenges in adopting digital manufacturing in brownfield factories

While adopting digital manufacturing initiatives in brownfield operations promises to make processes more efficient, accurate, and sustainable, it’s not an exactly easy task to accomplish. If not executed carefully, digital manufacturing can lead to the wastage of millions of dollars getting wasted and also create the additional challenge of fixing a broken process, a process that was working simply fine without digital capabilities.

The challenges that enterprises face with digital manufacturing can be categorized as:

Process-centric challenges

- In the absence of a concrete digital manufacturing definition and strategy, the broad scope of digital manufacturing makes it difficult for factories to clarify what it means in the context of the firms’ operations and align all stakeholders on these investments. Insights gathered from conversations with enterprises during Everest Group’s Industry 4.0 PEAK Matrix Assessment reveal that factory stakeholders themselves recognize the absence of a digital manufacturing strategy as one of the most critical roadblocks in the adoption of these technologies – this also leads to enterprises simply prioritizing the adoption of best-in-class technologies over a process-first approach that can identify the best use cases
- Similarly, without a data engineering strategy in place, a firm gets overflooded with all kinds of data captured by IoT devices and sensors but finds it difficult to store and manage this data or draw actionable insights from it
- Scalability of solutions is a challenge, since most existing software systems that have been adopted across plants operate in a siloed manner, with their own tech stack
- Finally, when it comes to real-world adoption, enterprises are realizing that real-life implementations are vastly different from the PoCs due to process interdependencies or changes in environmental conditions

People-centric challenges

- Enterprises often cite resistance to change from the leadership and the shopfloor as the prime challenge for successfully implementing digital manufacturing. While corporate functions do not show interest due to lower perceived value add (with existing processes working fine without digital capabilities), shopfloor employees resist the change because of additional operational steps, the need for technical knowledge, and fear of losing their jobs to machines
- If solutions are designed without taking people into consideration, they result in poor human-machine collaboration, including subpar ergonomic designs or robots not aligned with workers' needs
- Shortage of a digitally ready talent pool is another significant roadblock in adopting digital manufacturing solutions. Enterprises are having to make significant investments in hiring and training employees to get them ready for digital manufacturing processes

Technology-centric challenges

- Given that most equipment across brownfield plants was not designed with IoT and connectivity in the picture, enterprises see retrofitting such equipment with sensors and connectivity devices as a major technology roadblock. Retrofitting also poses challenges related to interference with existing Programmable Logic Controllers (PLC) and interdependencies across systems, IT-OT integrations, and interoperability
- Enterprises are learning the hard way that improvements in digital manufacturing are a continuous process, with initiatives requiring periodic assessments and upgrades instead of being one-time investments
- Connectivity network establishment, cybersecurity threats, and regulatory compliance are other challenges given the complexity of a digital manufacturing plant's operations. Security, in particular, is a major enterprise pain point, as even a minor disruption can bring processes to a complete halt and cause significant reputational and operational damage. Additionally, it is difficult to ensure security standards across technologies given the complexities, multiple third-party solutions, and customized tech stacks

"If you go onto the shop floor of a smart factory … people looking at those digital products, digital dashboards, using the technology – it's about them."

– Rashitha Jayasekara, Chief of Digital Manufacturing, Rolls Royce

Parameters that define the success of digital manufacturing initiatives

The challenges associated with digital manufacturing tell us that multiple factors are at play in defining the success of a digital manufacturing initiative: technology understanding, availability of resources, capital expenses, commercial viability, environmental impact, alignment with people, and business impact. A successful digital manufacturing initiative typically checks all the boxes against the following parameters:

- **Alignment with the firm’s vision and goals:** alignment of digital manufacturing initiatives with the firm’s vision and goals such as improving margins, revenue growth, and compliance with SDGs
- **Technical requirements:** ease of retrofitting technologies (both software and hardware) without adversely impacting existing operations, and effectiveness of connectivity networks, cybersecurity, and data storage and management
- **Resource and capital requirements:** optimal use of capital and talent; cost controls become all the more important for projects initiated amid a slow macroeconomic environment
- **Feasibility:** ease of transitioning use cases from PoCs to pilots to real-world implementation and deployment
- **Risk management and governance:** effective governance frameworks and contingency plans to monitor and adjust, as needed
- **Culture and collaboration:** alignment across stakeholders and an efficient change management process to ease employee experience
- **Realized impact:** planned versus realized impact on parameters such as quality, time-to-market, energy consumption, workplace safety, speed of decision-making, and visibility/transparency
- **Scalability:** ease of standardization and interoperability for greater scalability

Exhibit 6 provides an overview of these parameters and their accompanying KPIs to assess the success of digital manufacturing initiatives in brownfield factories.

Exhibit 6: KPIs to assess the success of digital manufacturing initiatives

Source: Everest Group (2024)

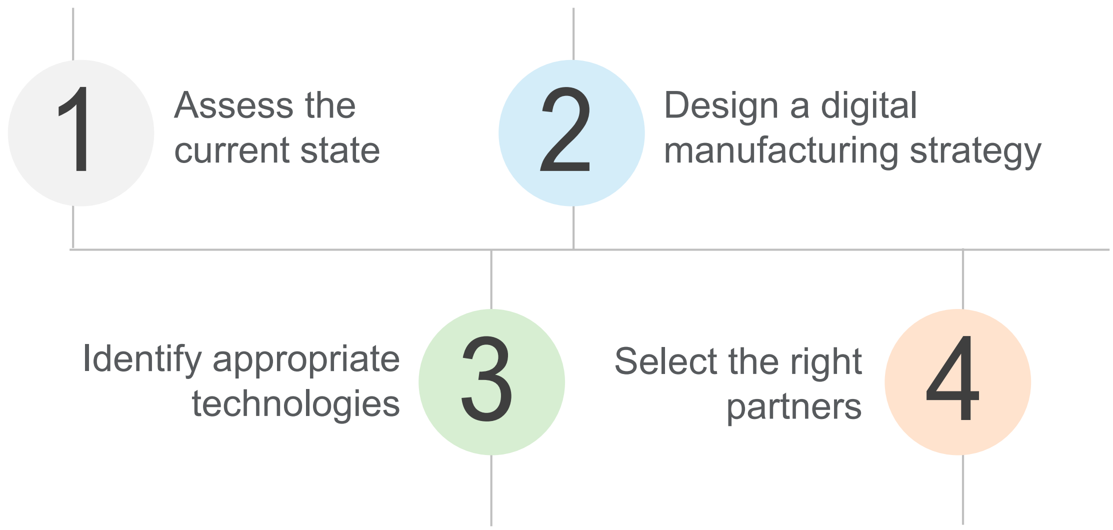
Parameter	Sub-parameters (indicative)	KPIs (indicative)
Alignment with the firm's vision and goals	Contribution to company's broader goals	Growth in revenue and margin, number of SDGs addressed, increment in asset NPV
	Pace of digital manufacturing adoption	Percentage growth in digital solutions across manufacturing processes
Technical requirements	Ease of retrofitting	Compatibility score, integration time, number of modifications done, level of complexity
	Additional technical capability needed	Security benchmarks, increase in network traffic and bandwidth utilization, reduction in network latency, data capture timelines, data cleanliness, data recovery plans in place
Resource and capital requirements	Capital utilization	Budget allocations, actual cost of the initiative, cost distribution over the project period
	Resource utilization	Number of skilled FTEs available, number of FTEs needed, value delivered per FTE
Feasibility	Ease of execution	Percentage of PoCs moving to production, percentage of successful adoptions, number of iterations needed
Risk management and governance	Security and compliance	Number of policies that the initiative complies with, number of security or policy breaches
	Contingency plans	Time taken to switch to traditional processes, number of disaster mitigation plans in place, percentage change in efficiency during contingency processes
Culture and collaboration	Change management	Number of learning and training sessions and their effectiveness, shopfloor experience scores, employee engagement in the entire value chain
	Cross-functional collaboration	Number of cross-functional stakeholders and digital threads, information transparency levels
Realized impact	Business	Percentage increase in revenues, percentage reduction in costs, change in the time-to-market, improvement in quality standards, process visibility, time taken to adopt supervisory inputs, reaction time to alerts
	Environmental	Reduction in energy consumption and CO2 emissions, waste reduction, improved efficiency
Scalability	Ease of scaling across multiple use cases	Number of use cases that can be implemented through minor modifications, level of standardization and interoperability, impact on performance due to standardization

While we recommend the KPIs above to measure success, we also realize that brownfield factories have multiple issues to address in their digital manufacturing journeys. For one, they already have well-established software and hardware in place and integrating newer capabilities is never a straightforward process. Similarly, arriving at a balance between the best technologies, cost, and impact on operations also requires tradeoffs, as does the decision to adopt the most appropriate tools and technologies versus maintaining a high degree of standardization.

To overcome these issues, enterprises should follow a value-driven approach to digital manufacturing initiatives, as we recommend in Exhibit 7.

Exhibit 7: Value-driven approach of digital manufacturing initiatives

Source: Everest Group (2024)



We take a closer look below.

1. **Assess the current state:** Start with a detailed study of the current state of operations to:
   - Identify any gaps that digital manufacturing solutions can plug
   - Understand the current state of automation and level of human involvement
   - Select the issues that digital initiatives need to address – selection can be based on criticality, scalability, workforce augmentation, and potential impact, among other factors
   - Determine the KPIs that need to be tracked, the data that needs to be captured, and how the workflow of digital capabilities should be designed to maximize value

   Based on the current state and benchmarking studies, the firm should define the future state of operations that it aims to achieve using digital manufacturing, thereby setting concrete objectives for such initiatives.

2. **Design a digital manufacturing strategy:** Defining a concrete digital manufacturing strategy is paramount to the success of such an initiative, since it aligns all stakeholders on the goals, breaks siloes in processes, and plans out the execution roadmap.

   Enterprises should consider the following factors when defining their digital manufacturing strategies:

   - Define the initiative's objective(s): productivity, time-to-market, sustainability, or cost reduction
   - Facilitate cross-functional collaboration right from brainstorming to execution workflows
   - Educate and train employees and encourage ideas from the employee community to ensure greater acceptance
   - Strike a balance between best-suited technologies in one factory versus a standardized approach across the board
   - Lay out appropriate cybersecurity protocols to ensure data privacy and the safety of machinery against cyberattacks, as connectivity increases the surface area of security breaches

   Define a framework that will assist in future upgrades and can adapt to changes. The framework should consider balancing between human-machine collaboration, planning periodic assessments and upgrades, and contingency plans to limit disruption to production.

3. **Identify appropriate technologies:** Next, enterprises should identify the relevant technologies that they need to adopt to enable their digital manufacturing initiatives. When selecting the technologies, an enterprise must consider the following factors:

   - Relevance of the technology for the use case
   - Pricing and commercial structure
   - Compatibility across existing systems
   - Preparation needed to integrate a technology or device
   - Ease of adoption and operation
   - Support for multiple use cases and scope for scalability
   - Energy consumption and cost of operations
   - Skills and capabilities needed internally

4. **Select the right partners:** Due to the complexities of brownfield operations and the vast scope of digital manufacturing initiatives, it becomes an overwhelming task for a single enterprise to execute alone. Furthermore, building all the necessary capabilities in-house is challenging and time-consuming. Finding the right partner becomes crucial for success, as a strategic partner or competent service provider can accelerate transformation while sharing the associated risks. The benefits that partners offer to enterprises in digital manufacturing initiatives include:

- **Subject matter expertise:** While most enterprises carry deep domain expertise within their industry, partners can bring in an equal depth of understanding of digital technologies, such as data analytics, IoT, and AR/VR
- **Talent availability:** Partners augment enterprises' talent pools with digitally skilled workers who are distributed across the globe, thereby offering both location proximity and lower talent costs
- **Cost and risk management:** Co-creating with partners helps share the risks associated with the development of new solutions as well as lower the cost of development by bringing in pre-built accelerators
- **An ecosystem of partners:** Partners also bring with them the expertise of their ecosystem partners, which can further simplify implementation, improve efficiencies, and maximize value for enterprises
- **Employee training:** A firm can collaborate with the academia to host formal training programs for employees, helping to develop the talent pool of the future through focused curriculum, extensive R&D collaborations, and hands-on training programs
- **System integration:** System integration partners can accelerate digital manufacturing since they understand the process intricacies and provide managed maintenance and support services for operational technologies

As connectivity, sensors, and IoT devices, as well as manufacturing platforms, form the building blocks of smart factories, telecommunication service and equipment providers, PLM firms, IoT and edge device providers, and system integrators become the primary partners that enterprises collaborate with to deploy digital manufacturing solutions. Enterprises are also collaborating with industrial technology firms to ideate and deploy use case-specific solutions and promote R&D in areas such as AI, robotics, and haptics.

Over the past decade, the relevance of hyperscalers as partners in digital manufacturing initiatives has also grown to the point where they massively influence the initiative's success. Hyperscalers help to rapidly deploy solutions through the cloud, as well as store, manage, and analyze high data volumes. IT-oriented players with OT-specific offerings are also entering the partner ecosystem, while semiconductor firms are emerging as valuable partners with offerings such as integrated IoT solutions.

Conclusion

Several use case families unlocked by digitalization – including asset monitoring and management, process tracking and optimization, workforce augmentation, production intelligence, business intelligence, and sustainability – are driving the strategic shift toward digital manufacturing in brownfield factories.

At the same time, it is crucial to define a comprehensive set of assessment parameters to gauge the success of such initiatives. These parameters include alignment with the company's broader vision and goals, technical and resource requirements, feasibility, risk management and governance, culture and collaboration, impact, and scalability.

Additionally, we believe that enterprises should follow a value-driven approach – encompassing the current state of operations, quantifiable objectives, a thoughtful digital manufacturing strategy, the right set of technologies and tools, and suitable strategic partners – to succeed in their digital manufacturing initiatives. A strong ecosystem is paramount to the success of such initiatives, as partners, including third-party service providers, help accelerate the transformation process, provide their own expertise, mitigate risks, control expenses, and augment enterprises' talent pools to achieve desired outcomes.

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This study was funded, in part, by
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