Global Machinery & Equipment Report 2024

BAIN & COMPANY

Acknowledgments

This report was prepared by Michael Staebe, leader of Bain & Company's Global Machinery & Equipment practice, and a team led by Practice Director Catherine Safaya-James and Practice Consultant Francesca Manfredi.

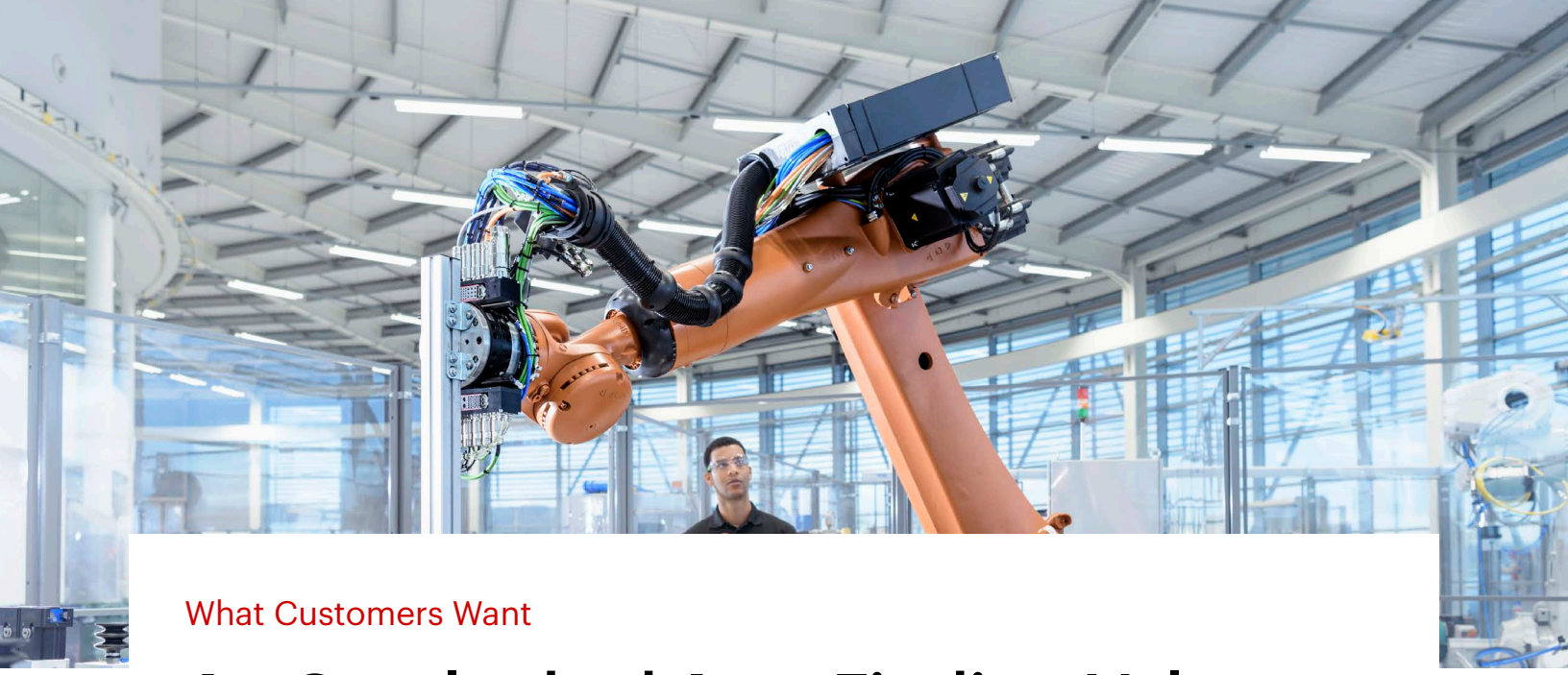
The chapters of this report were written by Bain Partners Adrien Bron, Neil Malik, Numan Waheed, Mike Coxon, Helen Liu, Michael Staebe, Josh Hinkel, Tessa Bysong, Leon Lu, Bodo Koerber, Bill Radzevych, Benjamin Grant, Caperton Flood, Andy Capanyola, Fumihiko Nishiwaki, Jörg Gnamm, and Michael DuVall; Expert Partners Patrick Hui, Guido Vetter, Thomas Frost, Xavier Houot, and Sehoon Min; Associate Partner Lisa Kabus; Expert Associate Partners Prashanth Parthasarathy and Leonides De Ocampo; Expert Senior Manager Stefan Silberstein; and External Advisor Dennis Kuesters.

The authors would like to express thanks for their contributions to the chapters to Bain Partners Hernan Saenz, Mary Stroncek, Prashant Iyer, and Thomas Kwasniok; Expert Partners Frank Lesmeister and Lokesh Payik; Expert Associate Partner Brian Kiefer; Associate Director Marian Zoll; Practice Director Simone Doms; and Practice Senior Manager Christian Ruehl.

The authors wish to thank Bain Partners Thomas Lustgarten, Hugo Parkinson, Prashant Sarin, and Greg Gerstenhaber; Bain Practice Executive Vice President Martin Nilvall; Leila Kunstmann-Seik and Anna Civilini for their planning and marketing support; and Gail Edmondson, Aili McConnon, and Paul Judge for their editorial support.

Contents

What Customers Want



What Customers Want

An Overlooked Ace: Finding Value in Your Installed Base

Digital models of installed machinery can improve product performance and predict necessary maintenance.

By Leonides De Ocampo, Bodo Koerber, Andy Capanyola, and Fumihiko Nishiwaki

At a Glance

- Leading machinery companies are using installed base management to move closer to a software-defined system that separates the life cycle of hardware from its functionality.
- New remote monitoring and diagnostics technologies such as digital twins will be key to creating new services and generating revenue.
- The market for digital twins is expected to increase tenfold, to $110 billion, by 2028.

“Installed base management” is not a term that dominates business news headlines. But this often-overlooked process to manage product life cycles more efficiently offers significant untapped value to machinery and equipment companies.

Leading companies have already started using new digital technologies that enable remote monitoring and diagnostics of their equipment. Those that use digital twins—namely, virtual representations of machinery and equipment—are gaining a competitive edge. The overall market for digital twins is

predicted to increase tenfold, from $10 billion in 2023 to $110 billion in 2028, according to Research and Markets. Developing twins for predictive maintenance of machinery is expected to be the most widely used application of the digital twin.

Managing an installed base remotely typically requires customers to keep their machines connected at all times. Tiered features allow customers to control which data is shared. The more data they share, the more services they can access, such as root cause analysis, which pinpoints the root cause of machinery problems.

Emerging leaders in installed base management are creating a centralized industrial cloud platform, enriching their digital twins with additional data, and using advanced analytics to derive commercial benefits from the data collected and analyzed throughout the product life cycle.

The opportunity

Traditional approaches to product management often focus on the sourcing of raw materials and the production phase, and they fail to address installed base management. Digital twins deliver the most value when they receive a continuous flow of data from the installed base, which requires that machinery is online continuously, not just for periodic updates.

Installed base management, which is also referred to as connected asset management, starts with customers tracking the usage and performance of specific machines or equipment in the field. Machinery and equipment producers can collect data in real time during maintenance or upon product return. With this data, they can create digital twins of specific machines (as opposed to a generic digital model), which can be used to optimize their service offerings, improve product performance, and predict necessary product maintenance.

Many machinery executives believe that installed base management will generate significant value by adding new revenue streams.

Many machinery executives believe that installed base management will generate significant value by adding new revenue streams. Semiconductor company ASML, for example, expects its installed base revenue to grow at a compound annual rate of about 12% and generate more than €6 billion in 2025, up from slightly less than €4 billion in 2020.

Some companies such as GEA, a leading European machinery company, have started using remote monitoring to better manage their installed base. The company's customers connect with GEA technicians via mobile phones. Remote eyewear allows the service technician to see what the customer

is seeing. Using these tools, the technicians can remotely conduct repairs or plant inspections, significantly reducing response times and minimizing the need for travel.

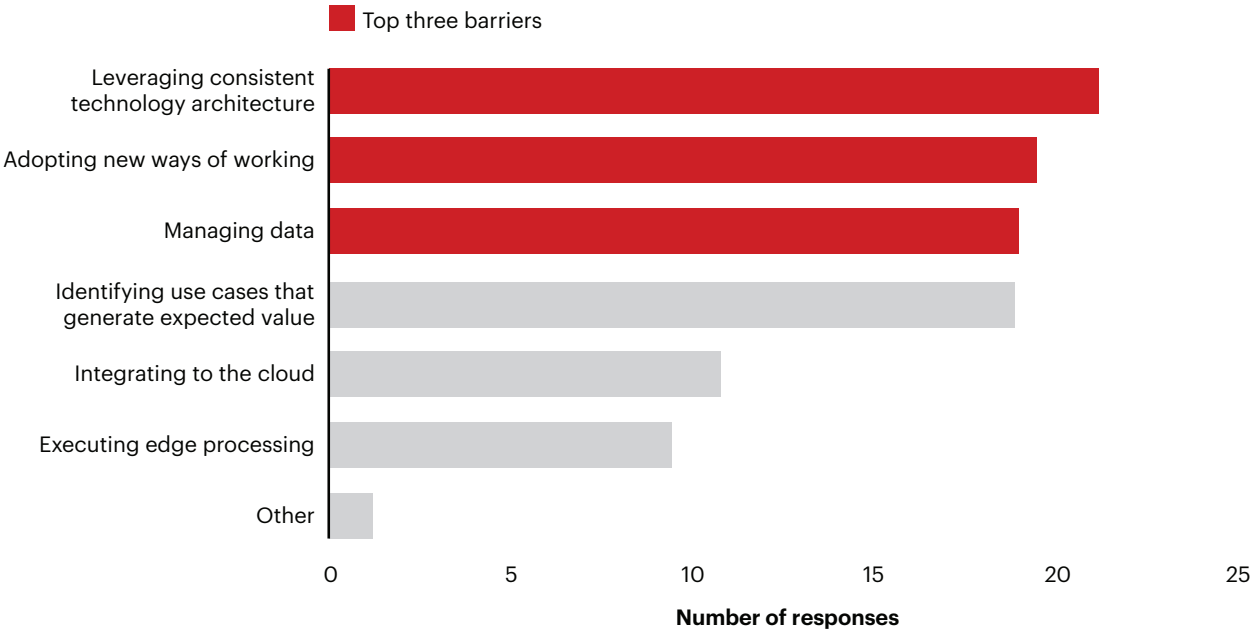
The importance of data

Continuous data flow is essential to creating value from installed base management. Successful companies analyze data from across the product life cycle. This data not only provides valuable insights but also powers the various digital twin representations that inform decision making.

The first major challenge is creating a centralized infrastructure capable of hosting all data spanning the product life cycle *(see Figure 1)*. This infrastructure, often housed in the cloud, collects, stores, and analyzes data. The system scales as the installed base grows, and consequently, it is built to accommodate increasing data volumes and complexity. Hyperscalers—namely, large data centers with massive computing resources such as Amazon Web Services, Google, or Microsoft Azure—dominate the market for storage infrastructure with services focused on cloud solutions.

One leading provider for processing and packaging technology in the pharmaceutical and food industries has harnessed the power of installed base management to create new value-added services for customers. Using software, the company analyzes usage and demand patterns observed across the machinery's transaction data. The software integrates with installed base management tools

Figure 1: Technology architecture is the top barrier to scaling installed base management



Note: Installed base management is a subset of Industry 4.0
Source: Bain Factory of the Future Survey, 2022 (n=80)

and extracts and maps the data. This helps create visual representations of specific markets that might present opportunities to offer new products and services or enhance existing services.

Investing in digital twin technology

Once the data and computing infrastructure are in place, the next step is creating a digital twin strategy, including the type of twin and how it relates to the real machine or equipment. A holistic strategy includes data from across the product life cycle, and vertical data flows from equipment, for instance, up to the cloud.

Continuous data flow is essential to creating value from installed base management. Successful companies analyze data from across the product life cycle.

Some customers have concerns about revealing internal data to third parties. Successful machinery companies communicate the advantages of installed base management and digital twins, and they explain why continuous data is the lifeblood of these tools. They also underscore how digital twins safeguard privacy.

Mechanical engineering company Krones, for instance, offers a fully connected digital twin of production lines for packaged beverages. The company offers remote diagnosis through augmented reality support and a VPN connection to the machines. This connected line helps customers reduce downtimes, plan reliable maintenance, decrease resource consumption, and improve material management. Other companies prefer a platform connection to the cloud rather than a point-to-point connection.

Caterpillar has created digital twins of its next-generation excavators to improve their performance. These virtual simulations visualize the flow and temperature of air through the machine's coolers while varying fan speeds to simulate performance in different customer applications. The digital twin optimizes machine cooling and monitors performance over the life cycle of the machine while optimizing energy use.

Moving to a software-defined approach to derive commercial value

By adopting installed base management, companies move closer to a software-defined system that separates the life cycle of the hardware from its functionality. In software-defined systems, companies can make remote technology updates without affecting the production line. They can also use virtualization techniques, portable control, and open application programming interfaces to build

reconfigurable, modular production lines vs. rigid, linear ones. This enables on-the-spot changes and accommodates future transformations. Hardware components no longer limit the system lifetime.

Top-performing companies use advanced analytics and machine learning to derive insights from the vast amounts of data contained in digital twins. These insights can guide decisions across the product life cycle, from design enhancements to predictive maintenance. To successfully build a service sales pipeline, leaders use the gathered data to identify a customer's service needs, tailor service offerings, and create targeted client outreach such as sales campaigns or client calls *(see Figure 2)*.

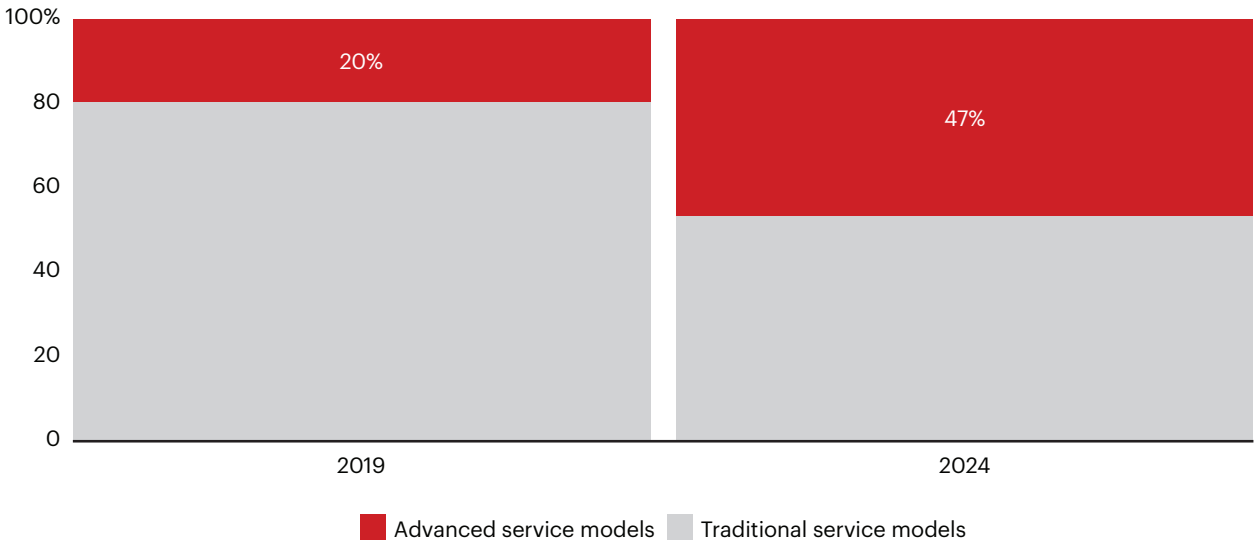
GE has smart machines, for example, that run advanced machine applications and can function autonomously or connect to other machines in a synchronized fashion. Sensors put intelligence and computing power directly onto these GE machines, which, in turn, connect to a cloud-centric, distributed environment. These smart machines can be found in a variety of cases from jet engines to medical imaging devices.

Leaders using installed base management follow three key principles

Integration: Ensure seamless integration of your digital twin technology with existing systems and processes. This integration enables a comprehensive view of the installed base and eliminates silos that can hinder data flow and collaboration.

Figure 2: Advanced service models, including those enabled by installed base management, are expected to be a significant and growing part of service revenue in 2024 and beyond

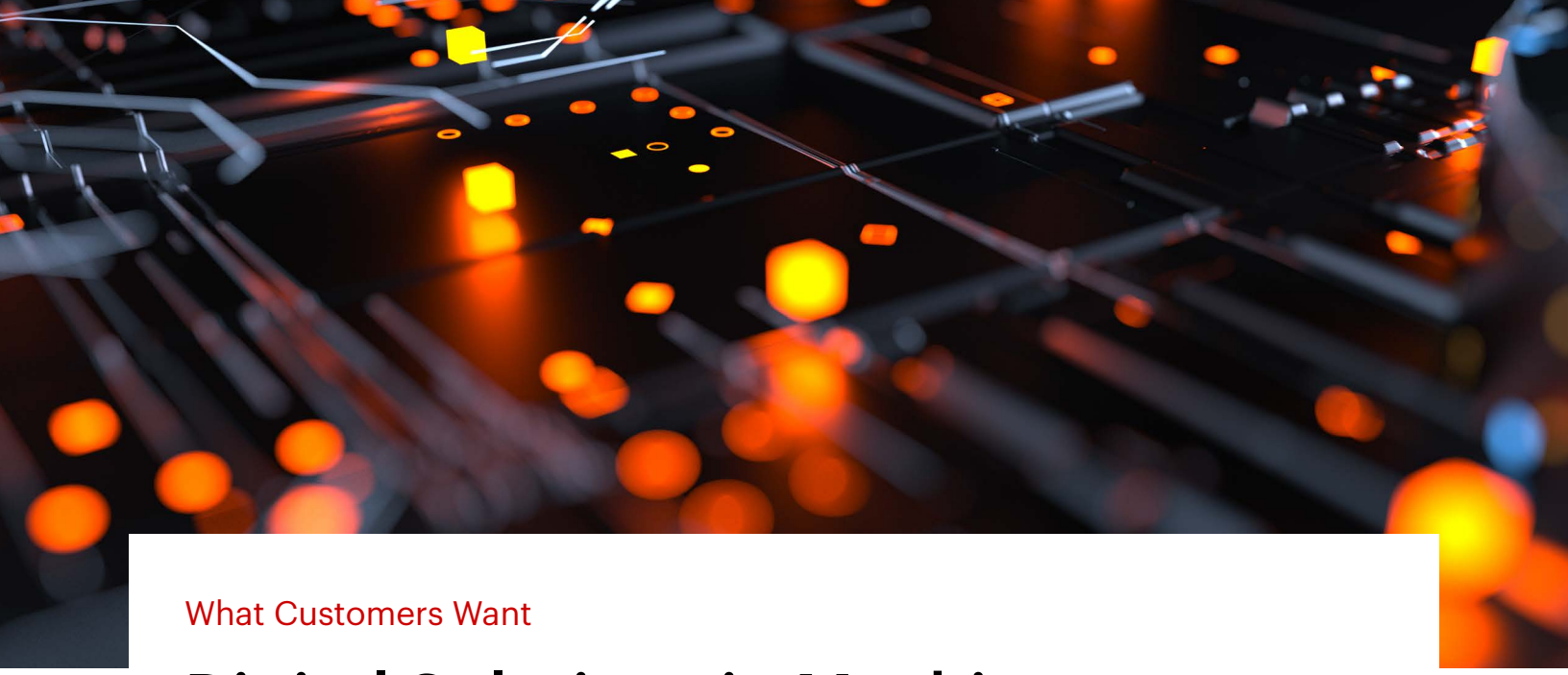
Percentage share of service revenue



Source: Bain Service Circle Survey, 2019 (n=19)

Continuous learning: Customer needs and technology evolve rapidly in the machinery industry. Commit to continuous learning and adaptation. This includes updating monitoring and diagnostics technologies and incorporating customer feedback into product improvements.

Data sovereignty: Many new initiatives are creating and using smart services that share data while also ensuring the digital sovereignty of data owners. The Industrial Data Space, for instance, is a virtual data space using standards and common governance models to allow for the secure exchange and easy linkage of data in business ecosystems.



What Customers Want

Digital Solutions in Machinery: Don’t Be Left Behind

The industry has reached a turning point in the shift from products to solutions.

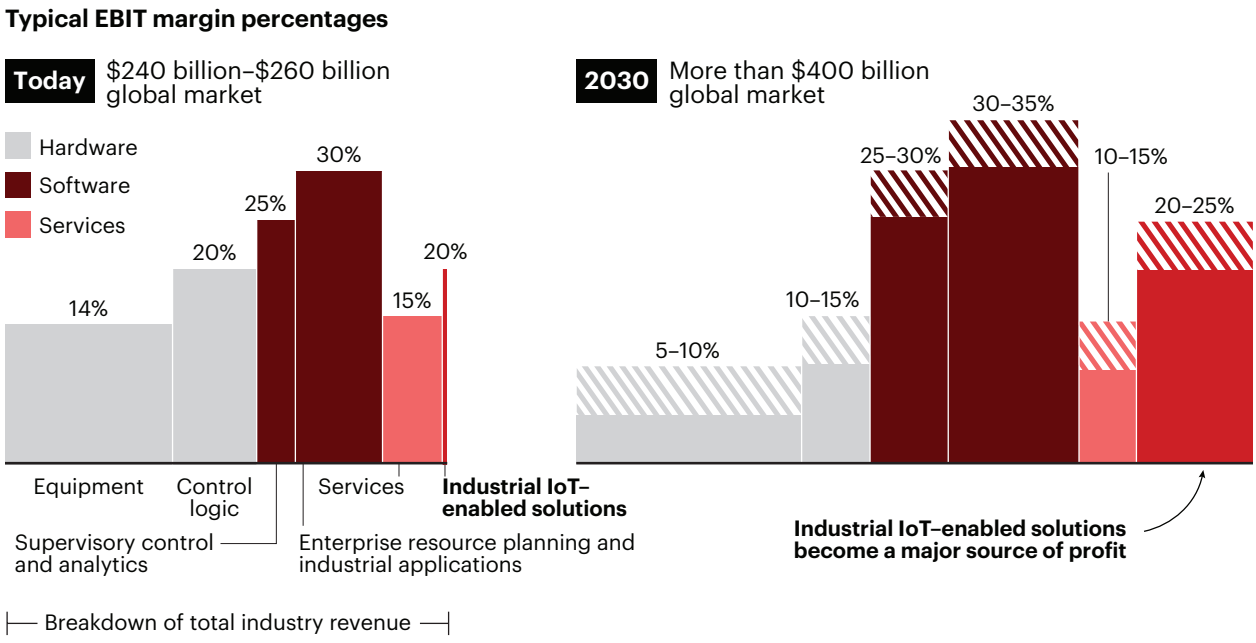
By Adrian Bron, Neil Malik, Numan Waheed, Mike Coxon, and Helen Liu

At a Glance

- Industry is now a bigger consumer of chips and Internet of Things technology than any other sector.
- Successful machinery companies design digital solutions for customer segments in which they are a leading supplier.
- Emerging leaders in digital solutions for machinery outperform the industry on total shareholder return by 100%.

It’s the moment of digital truth for machinery and equipment makers. Though digital solutions in industry have taken longer to mature than anticipated 10 years ago, change is now accelerating at a pace that risks leaving some companies unable to catch up. As digital solutions proliferate, they are creating seismic shifts in machinery and equipment profit pools and market dynamics *(see Figure 1)*.

Figure 1: Technology will significantly shift industry profit pools toward software and digital solutions



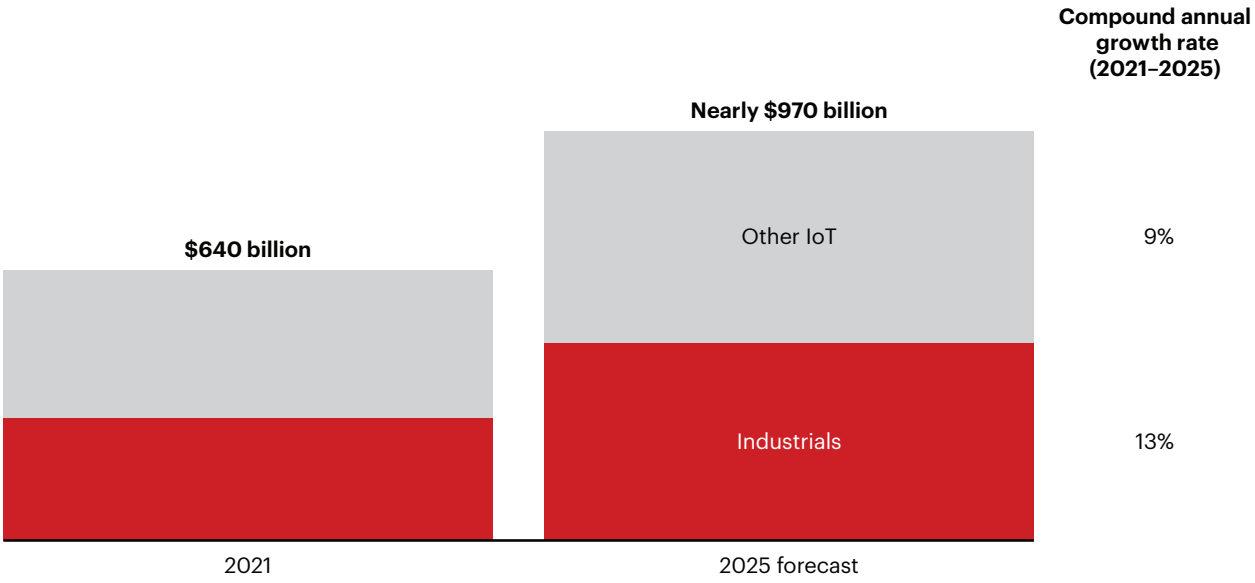
Note: IoT stands for Internet of Things
Source: Bain analysis

A key indicator of the pace of change is the industry's voracious consumption of semiconductor chips and Internet of Things (IoT) technology. The industrial sector is now a bigger consumer of chips and IoT technology than any other sector. And industrial companies' spending on IoT is growing at a higher rate than that of any other sector *(see Figure 2)*.

The push to develop solutions has prompted leading machinery companies to redefine their markets. Instead of producing standard products for a global market, many are developing customer solutions tailored to specific industries. That pivot means focusing on a smaller number of customers in specific vertical industry segments, but it increases the scope of what these leaders can offer those customers—it also means less fragmented supply chains.

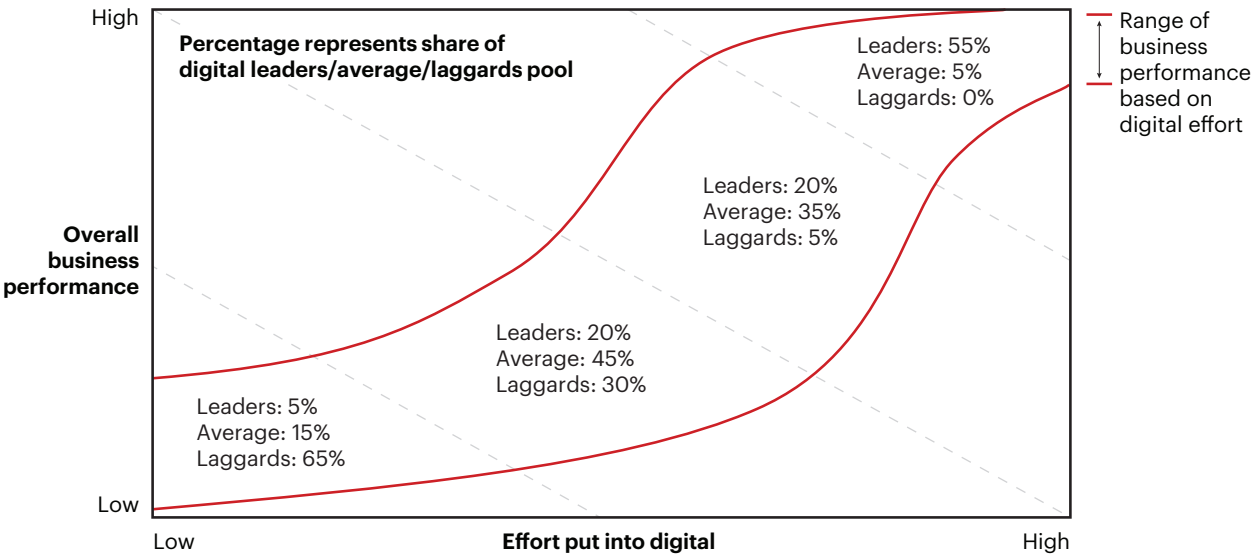
The shift to digital solutions is the most sweeping change to the industry in a lifetime for many machinery executives. But for those that get it right, the payoff is huge. Digital solutions leaders already outperform the industry on total shareholder return by 100%. Customers are seeking these solutions as part of their strategic evolution. Machinery companies that are among the first to meet that demand will generate higher revenue, bigger margins, improved customer loyalty, and software-like valuation multiples *(see Figure 3)*.

Figure 2: Industrial companies are fueling strong revenue growth in Internet of Things and analytics



Sources: Gartner; IDC; MarketLine; Bain analysis

Figure 3: Industrial digital leaders have higher sales and margin growth



Notes: The word "effort" represents combined investments in digital programs, including financial, human capital, and others; overall business performance is measured as relative sales and margin growth vs. peers
Source: Bain Digital Insights Survey 2019 (N=205 for all industrial companies; leaders n=33, average n=141, laggards n=31)

The pitfalls

In our experience, three common pitfalls often hinder machinery companies' efforts to develop digital solutions. The first is failure to clarify the company's ambition in digital solutions. In short, why invest? As they rush to join the race, many engineer digital products and services to sell more hardware and equipment instead of conceiving new offerings for unsolved customer needs. As a result, their solutions are less competitive and produce disappointing results. Worse, these companies continue to focus on traditional product markets while rivals reshape the competitive landscape. That approach risks leaving these companies lagging the pack.

The second pitfall is lack of focus on selected customer groups. Narrowing a firm's focus on a few target markets is one of the biggest challenges leadership teams face in the transition to digital solutions. Companies that engineer software products and solutions without targeting a few industry verticals will be overwhelmed by the heterogenous demands of multiple industries. To compete, they will be forced to redesign or reengineer solutions from one company to the next. These companies won't be able to scale their solutions. As a result, they won't be profitable.

It's understandable that machinery companies have a reflex to build solutions broadly for all industries. Until now, many have sold standard equipment globally to a heterogenous base of customers. But that's the reason these companies lack, with few exceptions, enough domain and application competence to develop digital solutions for every industry. A leading producer of robots, for example, won't necessarily understand what it requires for its robots to work optimally in different industrial environments such as an automotive assembly line, medical lab, or food processing plant.

Emerging digital leaders are targeting customer segments in which they have the greatest domain know-how. Some machinery and equipment companies have significant domain know-how. Others, such as ABB, build motors or robots used in a variety of industries. Machinery makers that sell to multiple industries have the greatest challenge building domain know-how.

Emerging digital leaders are targeting customer segments in which they have the greatest domain know-how. Some machinery and equipment companies have significant domain know-how.

The third common pitfall is failing to figure out how to build a digital solutions business that can become a robust second engine for the company—a technology-based engine as opposed to a product engine. Often companies start by pursuing ventures or experiments in digital solutions outside the

organization. Such ventures, disconnected from the main business, typically prove impossible to scale because the solutions are not integrated into the business.

The customer mindset

Most machinery original equipment manufacturers (OEMs) today have some digital solutions in their offering. But scaling them successfully requires significant investments, a multiyear transformation, and a customer mindset. Leaders start by answering two vital questions: For which customers are we among the most relevant suppliers, and what solutions would solve the problems these customers face? Software companies excel at this customer-centric market approach; indeed, it has propelled their success over the past 20 years. Machinery companies that lead the digital solutions shift will do the same over the next two decades.

John Deere, for example, has invested billions of dollars over the past decade to pivot from tractor manufacturer to a provider of solutions for precision agriculture, including machines combined with digital technology that make farming more efficient. In 2022, the company introduced self-driving tractors and sprayers that can distinguish weeds from crops. The company is now planning to connect 1.5 million machines in service and use its cloud-based operations center to store crop data, hoping to sell farmers subscriptions to software that will help yield higher profit margins.

Similarly, Hilti is transforming itself from a maker of power tools to a digitalization partner for midmarket contractors. To build its digital muscle, the company made two large acquisitions, including one for more than $300 million. It also has invested several hundred million dollars in its own R&D and go-to-market capabilities, adding solution consultants and systems integration capabilities.

In our experience, machinery companies that have built successful digital solutions follow five guidelines:

- **Target a few customer segments.** Leaders in digital solutions address customer pain points in select vertical markets. Thermostat maker Danfoss provides solutions to food supermarkets that depend on reliable refrigeration. In addition to selling systems that monitor the temperature of refrigerated storage areas and shelves, the company's connected thermostats also offer solutions for energy management, usage analytics, and predictive maintenance.

- **Become a digitalization partner.** Digital solutions, such as software, change the way a company works. Software companies use teams of expert advisers to help customers adapt their ways of working and ensure that they get the full benefits of the technology they install. Machinery companies offering digital solutions also need to provide presales consultation to help customers understand how digital solutions will change their operations. Leaders offer success management services to ensure that customers are getting the most out of installed solutions. Hilti, known for its red drilling tools, has expanded its direct salesforce model to include software consultants in order to offer IoT and technology solutions.

- **Embrace customer unit economics.** Machinery and equipment companies build business plans based on product unit economics, ensuring that the price of a machine covers the costs of building it. Digital solutions, such as software, require a different approach as the biggest cost is not building the product but acquiring customers. Leading machinery companies create a business case for digital solutions based on customer unit economics, including the cost of acquiring customers and customer lifetime value. That ensures the business case is sound. (The bad news: It's not a fast payback).

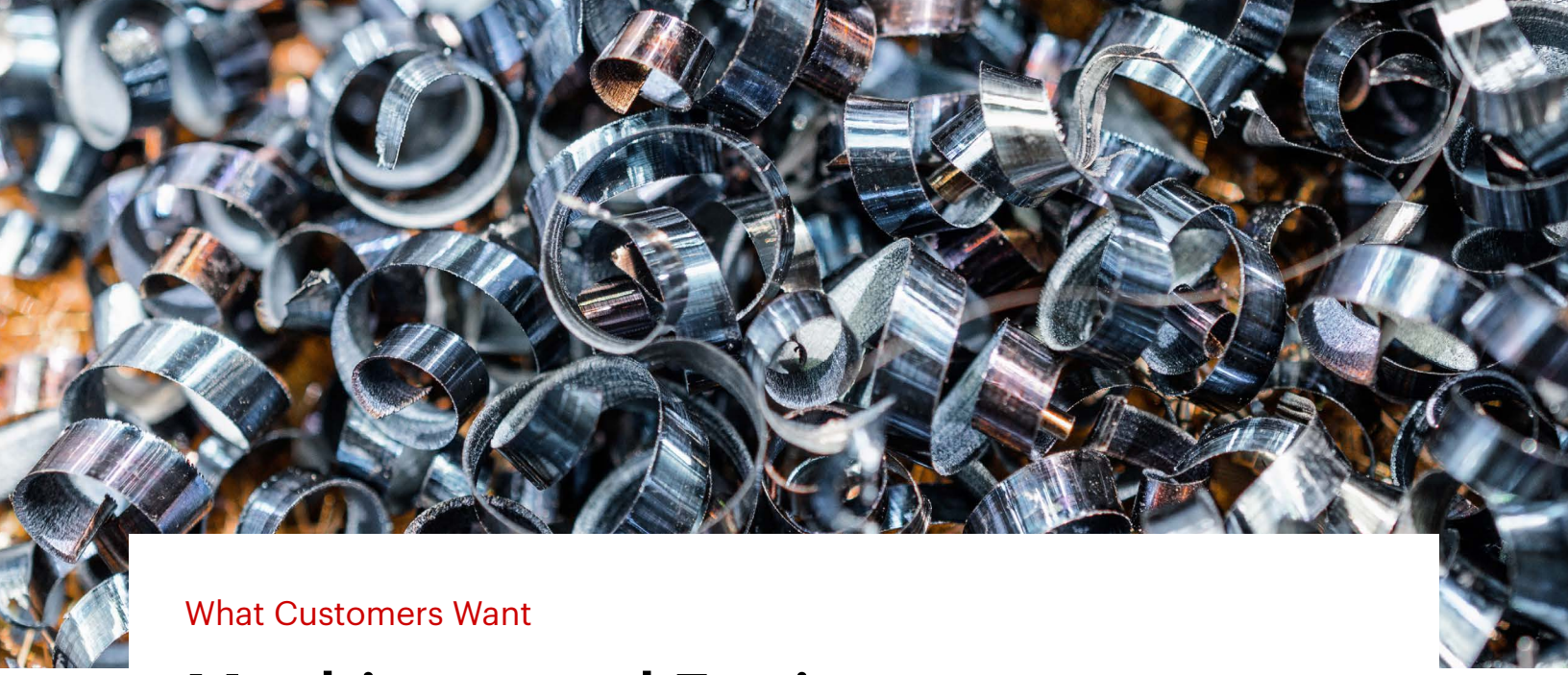
  Take the case of electric vehicle maker Tesla, which has pioneered a new business model for automotive OEMs. In addition to selling cars, Tesla offers drivers additional digital solutions throughout the product life cycle, including an extensive charging network, entertainment services, and autonomous driving packages. These solutions help Tesla maintain an electric vehicle market share of greater than 50% in its core US market.

- **Invest in an Engine 2 business.** Successful machinery companies use both organic investments and acquisitions to build a substantial technology-based business that can complement hardware sales. Partnerships offer the greatest value in back-end operations with solution development and delivery. Leaders, including John Deere, avoid outsourcing customer-facing parts of the business. The reason is clear: Sector-specific knowledge and customer relations play a key role in winning sales and retaining core customers.

- **Use open technology architecture.** Digital solutions that are built on flexible technology architecture have a big advantage in the market—seamless integration and interoperability with leading IT systems and operations technology (OT). Open technology architecture also complies with security standards.

  Schneider Electric recently acquired Aveva, a leader in software for engineering and operations, including the creation of digital twins of industrial machinery. Aveva's software integrated smoothly with Schneider's market-leading IT/OT open architecture and EcoStruxure platform, which connects data and applications from the shop floor to the C-suite. To provide tailored solutions to industry verticals or customers, Schneider has made additional acquisitions (e.g., ETAP) and developed customer solutions for specific use cases on top of its EcoStruxure platform.

The digital transformation of machinery is well underway. Leading OEMs are forging deeper relationships with their best industrial customers and developing solutions for the industry segments in which they are a leader. Future winners will scale solutions that can be used repeatedly in the same sector with minor adaptations from one customer to the next. As that process accelerates, it will change the competitive boundaries of the industry: Future markets will be defined by customer segments, not products. In this new era, machinery companies that have scaled digital solutions for a targeted set of customers will have a competitive advantage that is difficult to challenge.



What Customers Want

Machinery and Equipment: The Circular Path to Value

Leaders use circular strategies to develop new sources of value and competitive advantage.

By Michael Staebe, Joshua Hinkel, Xavier Houot, Tessa Bysong, and Leon Lu

At a Glance

- Bain research shows that 47% of large machinery companies have circularity commitments, but most remain narrow in scope.
- Circular strategies will lead to new business models and reshape profit pools.
- Most machinery executives believe that circular practices will deliver significant cost savings.

By 2030, circularity will change the way large sectors of the machinery and equipment sector operate. Profit pools will shift as companies embrace business models that preserve materials and extend the life span of machinery. Circular operating models will reconfigure value chains. And as companies begin to decouple their growth from resource consumption, a new set of winners and losers will emerge.

A recent Bain study shows that 47% of large machinery companies have made circularity commitments. But so far, most initiatives remain narrow in scope—focused on recycling, reduction of inputs, and waste reduction. Many leadership teams view circularity as a recycling or sustainability topic—one linked to regulation. Few have begun to think about it as a value creation opportunity—one that can

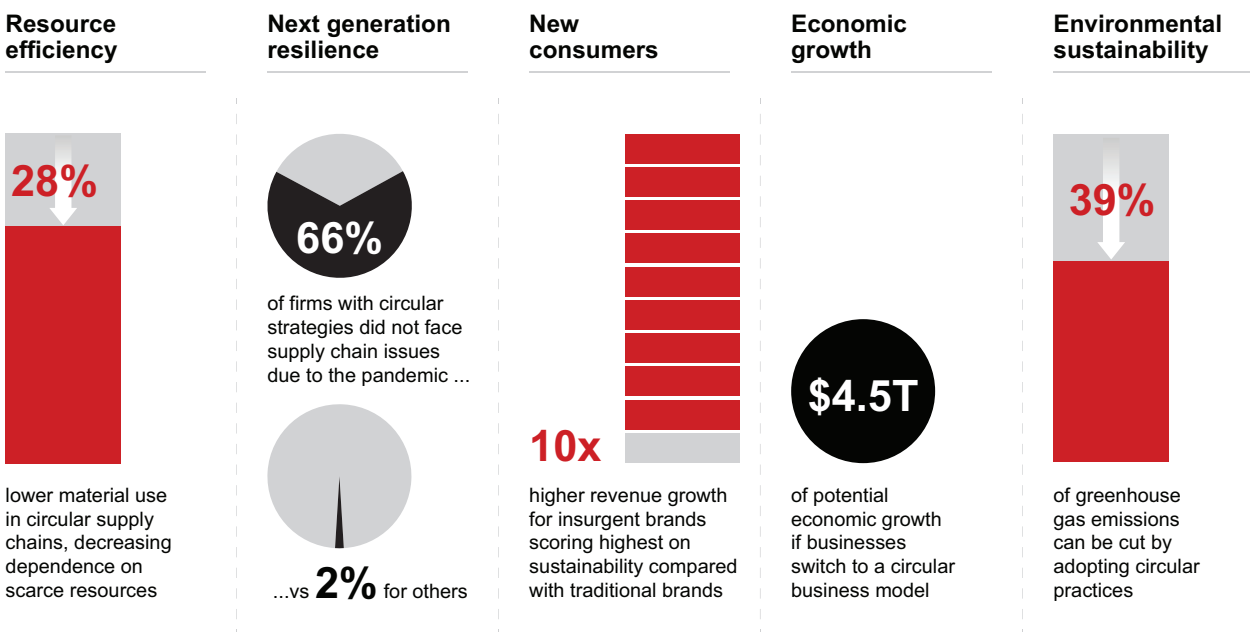
provide new revenue streams, supply chain resilience, enhanced customer intimacy, and access to new customer groups over the next 20 years *(see Figure 1)*.

Nearly 60% of machinery executives see their industry's future as circular, according to Bain research. These leaders are convinced that circular business models will be table stakes for competing in a new era. A majority believe that circular practices will improve their operational capabilities, significantly reduce costs, and enhance customer loyalty.

Emerging leaders with circular operations and Internet of Things (IoT) capabilities generate strong gains in efficiency and sustainability. The IoT data they gather creates vast opportunities to preserve assets at their maximum value for the longest possible time, improving energy efficiency and reducing the need for resource extraction. Data without a circular strategy and supply chain to extend the life span of machines and retrofit them is far less effective. Circular business models, in turn, depend on connected machines and data to reduce the use of raw materials.

A growing number of industry executives see a win-win opportunity in which circularity lowers the cost of equipment ownership for clients and promotes closer, long-term customer relationships for machinery makers. These companies are starting to apply a circular approach to parts of the value chain, equipment portfolio, and customer segments that can benefit most from the shift. Companies that anticipate shifting profit pools will be well positioned to identify new opportunities ahead of the competition and reimagine products and services for a circular future.

Figure 1: Circular business models can deliver economic benefits



Sources: Circle Economy, *The Circularity Gap Report* (2021); Circular Flanders and VITO resilience survey, 2020, (n=540); Bain Elements of Value consumer survey, 2021 (n=8,303); World Economic Forum, *The World Needs a Circular Economy* (2020)

New sources of value

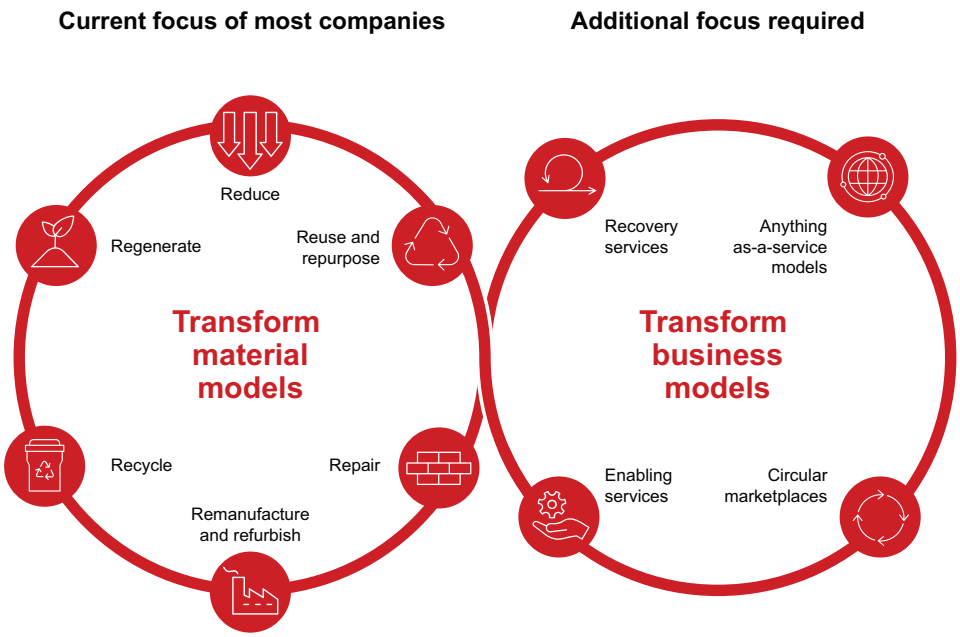
Today, new machine sales and long-running service contracts still generate the largest share of the industry's profit. Many companies sell new equipment at low-single-digit margins and often rely on their service business for more than 50% of total profit over the lifetime of the product.

That business model is not going to disappear. But leading machinery companies are starting to create value by combining machinery sales and service contracts with circular material models designed to reuse valuable parts and resources. In some customer segments, machinery companies are launching circular business models, including selling products as a service *(see Figure 2)*.

Senior executives at these companies understand that circular operations improve efficiency and boost organizational resilience by increasing raw material self-sufficiency while providing new streams of revenue. For these firms, secondary markets take on a more strategic role. While remanufacturing is not new, circularity leaders view it as an increasingly important element of operations, along with product repair and regeneration, repurposing, and recycling.

Machinery executives expect remanufacturing to reduce costs by 20% to 60%, according to our research. Over the next 5 to 10 years, we believe that the value created by new material models could represent up to 20% of revenue. Executives report that circular supply chains reduce their material

Figure 2: Circular transformations will solve the most pressing business issues by redesigning existing material and business models with circular principles



Source: Bain & Company

use by 28%, on average, decreasing dependence on scarce resources and cost. At the same time, they say that circular practices eliminate 39% of greenhouse gas emissions, on average.

German pump maker Wilo, for example, aims to continually reduce its use of primary raw materials by reusing components and materials. When the company recently suffered supply chain disruptions resulting from shortages of magnets and rare earth materials from China, its leadership team launched an initiative to collect old pumps from the field in order to secure scarce raw materials. The company also introduced disassembly for returned and scrapped products. Those practices led to higher margins. By 2025, Wilo's management team aims to reduce annual raw material consumption by 250 tons through circular operations. The effort involves reusing 30,000 components per year, shifting to 100% reusable packaging, and boosting the recycling rate to 90%.

Leading machinery companies are starting to create value by combining machinery sales and service contracts with circular material models designed to reuse valuable parts and resources.

Another industrial equipment maker launched a strategy to reduce its material use by replacing the wooden crates (one-time-only use) in which it packaged its outbound mowers and snow throwers with reusable metal crates. It contracted with a supplier of metal crates for the handling and transport of its goods to customers. The company forecast that the "rented metal" program would save $16 million to $19 million in annual procurement costs, of which $11 million would be realized through negotiations with suppliers and customers. In addition, the move from wooden to metal crates is expected to reduce carbon emissions related to the shipment of those goods by 75%.

Leading machinery makers also are taking a more strategic approach to remanufacturing. Caterpillar operates nine remanufacturing locations globally and offers more than 7,000 remanufactured components and parts, which are priced 40% to 50% below the cost of new parts. It also offers machines rebuilt with used or remanufactured parts typically after two to three years in operation for key components (engine, suspension, transmission). The company has set a goal of growing its remanufacturing business by 15% per year, which is faster than its overall business.

New business models

In the future, machinery companies will design products for greater longevity, sell more products as a service, and tap into circular marketplaces. All three approaches can underpin a circular business model. Selling machinery as a service is not new, but in the context of the broader circularity agenda, advances in technology are making such business models more feasible and more profitable. Service-based businesses may include charging customers for extending the life of their products, upgrades

or retrofits, end-of-life decommissioning, taking back equipment, and remaking used equipment. Companies may charge a one-time fee for a service, ongoing fees, or even payments based on a client's guaranteed output.

Such models are becoming increasingly attractive and strategically important as the commoditization of machinery and equipment starts to squeeze revenue. Service-based business models offer companies a way to improve efficiency, resource resilience, and customer loyalty while offering clients a lower cost of ownership.

The early service-based models that are gaining traction in machinery and equipment sectors focus on creating value while also achieving sustainability benefits. In particular, companies are tapping into three new sources of value: reducing material consumption, extending a product's life span, and increasing product utilization.

The early service-based models that are gaining traction in machinery and equipment sectors focus on creating value while also achieving sustainability benefits.

German machinery maker Trumpf has introduced a pay-per-part business model. That is, Trumpf remains the legal owner of the machine, and the customer pays a fee per part produced. The model offers customers financial flexibility, allowing the company to avoid significant capital expenditures on machinery. Trumpf takes care of all maintenance, repairs, production planning, and programming.

Trumpf's pay-per-part model offers customers the advantage of a fixed price per piece prior to production, helping reduce the need for qualified workers. Though pay-per-part contracts remain less than 1% of Trumpf's total business, they are a win-win for the company and its customers. At the same time, they give Trumpf's management valuable experience with outcomes-based business models.

Under pay-per-part contracts, Trumpf rents its own engineers and mechanics to its customers, who, in turn, need fewer employees. The arrangement provides Trumpf with valuable data on the performance of its machines. Overall, the pay-per-part contracts enable Trumpf engineers to manage material use more efficiently, reducing carbon-dioxide emissions by up to 65%. After 8 to 10 years, Trumpf takes back the machines and refurbishes them or reuses selected parts.

Getting started

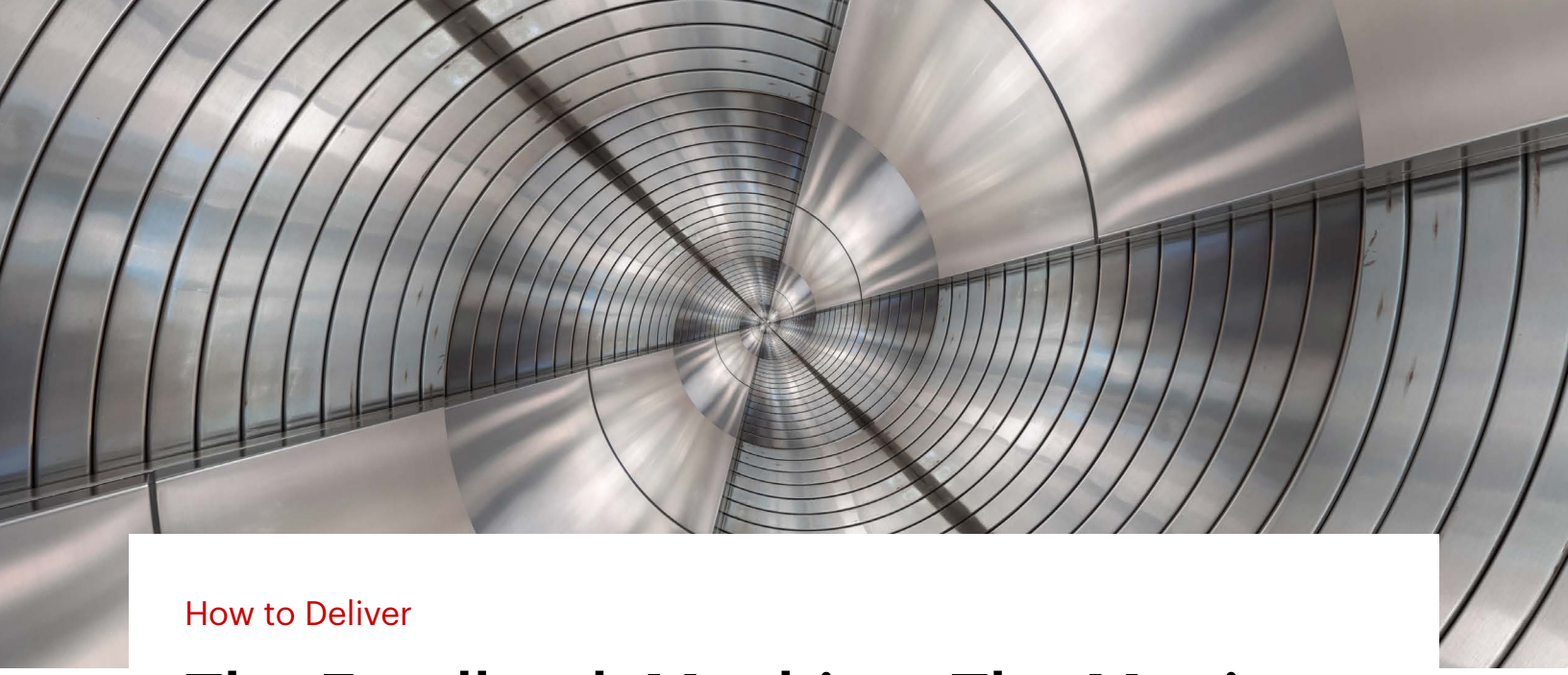
Leading machinery companies begin developing a circular strategy by exploring different value creation opportunities. Executive teams examine how recycling could generate value and how to build circular design concepts into product development and engineering. They also determine whether the company will need access to raw materials or if they can harvest critical parts from the installed base. Ultimately, each company must determine how to evolve machines and equipment into a more comprehensive solution that paves the way for selling outcomes as opposed to products.

In our experience, emerging leaders in circularity follow three key steps when launching a circular strategy:

- They explore key market trends, including how technology and regulations will impact the business, to envision what future business models could look like and how profit pools are likely to shift.
- These companies develop strong partner ecosystems to improve access to vital assets and capabilities because circular business models don't work alone. Ensuring that materials and products flow through a circular chain requires a network of internal and external stakeholders.
- Leadership teams take an Agile approach to deploying circular strategies and adopt a customer mindset, building their capabilities and operating model as they go and continually evolving them to match the pace of change in the external environment.

In the coming decade, many machinery and equipment companies will make circular operations and business models a core part of their strategies. The shift is an opportunity to enhance resilience, efficiency, recurring revenue, and customer loyalty while lowering the use of scarce resources. Service-based business models will become increasingly attractive to customers eager to trim capital expenditures. Those that develop circular strategies ahead of rivals will have an edge competing for new sources of value.

How to Deliver



How to Deliver

The Feedback Machine: The Magic of Closed-Loop Product Life Cycle Management

Leaders use data from every stage of a product's life to increase speed to market and reduce costs.

By Patrick Hui, Bodo Koerber, Dennis Kuesters, Prashanth Parthasarathy, and Bill Radzevych

At a Glance

- 70% of machinery customers expect more personalized or customized products than they received three years ago.
- In a closed-loop engineering system, every phase of a product's life cycle feeds back data into the system.
- Leading companies implementing closed-loop product life cycle management have reduced time to market by more than 20%.

Faster, cheaper, and customized. These three key words are on the mind of every machinery executive striving for innovation. Closed-loop product life cycle management (PLM) can help achieve all three by cutting time to market, reducing costs, improving quality, and enabling product customization.

Closed-loop PLM includes the set of processes and technologies that manage the entire life cycle of a product, from conception to end of life. In a closed-loop system (also referred to as a digital

thread or closed-loop engineering), data is collected in real time from every life cycle phase, which enables ongoing optimization.

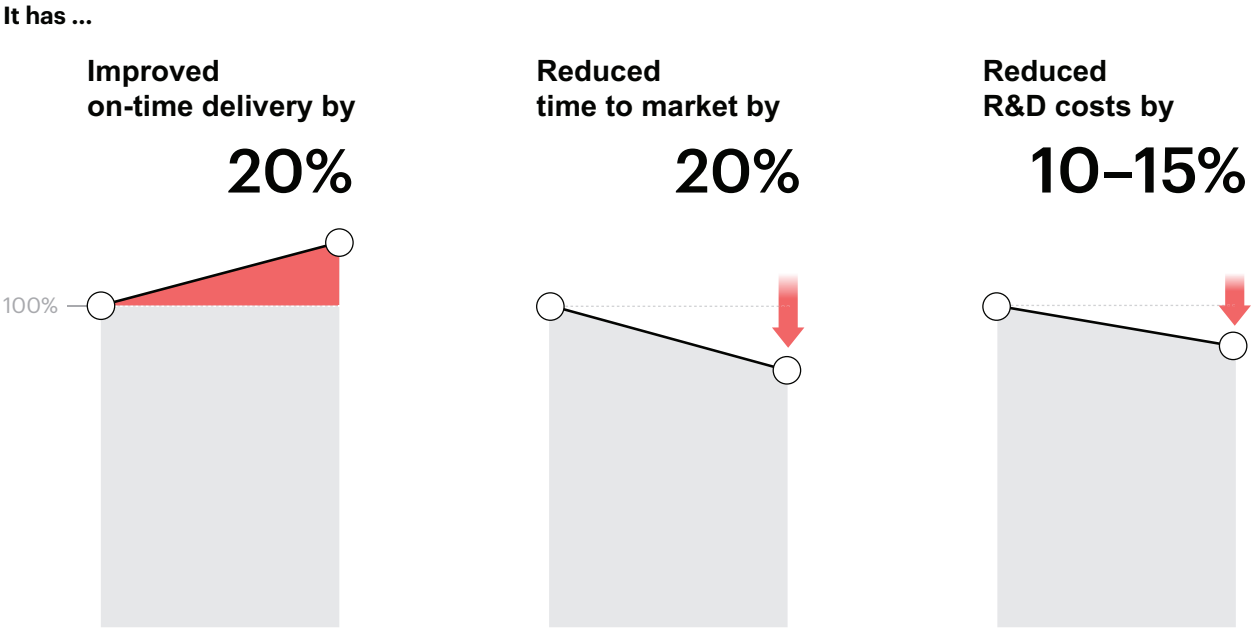
It's not easy to implement, but the benefits of closed-loop PLM are significant. Leading companies using closed-loop PLM have improved their on-time delivery by more than 20% and reduced time to market by more than 20%, according to Bain research. They have also been able to reduce R&D costs by 10% to 15% *(see Figure 1)*.

High expectations from customers

Producing products faster and with a greater degree of customization has become table stakes for machinery and equipment companies. In fact, 68% of customers expect the same quality of products they received three years ago, but more quickly. And 70% of machinery customers expect more personalized or customized products than they received three years ago, according to Oxford Economics.

Delivering products that meet these expectations, however, poses a challenge given the complexity linked to customization. Streamlining design, iteration, and validation stages can also be difficult when dealing with complex PLM, computer-aided design, and computer-aided manufacturing systems; multiple iterations; and collaboration among engineering teams.

Figure 1: Closed-loop engineering gets products to market faster and cuts costs



Source: Bain analysis

Faster

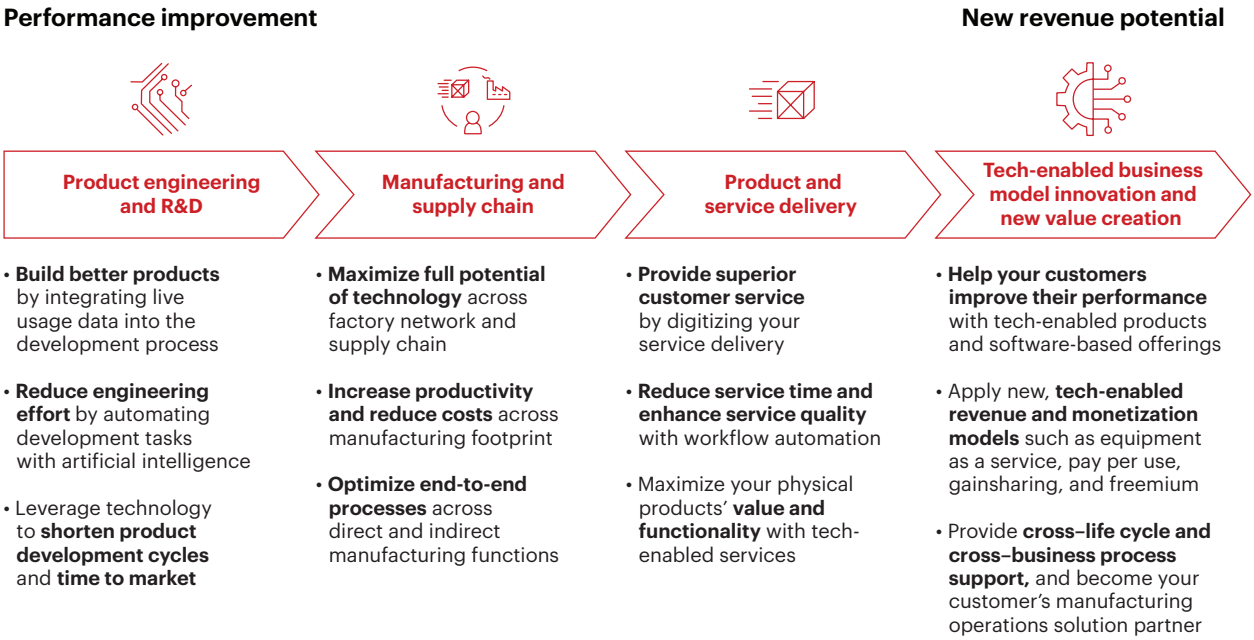
Many machinery leaders have gotten the memo from customers: Among the top priorities in engineering and R&D for machinery companies over the next three years is shortening time to market, according to Bain research.

Integrating hardware and software rapidly with zero defects has always been difficult. It's even harder now with a widening base of code and hardware. And that's not to mention the challenges of combining two different development approaches: Software development requires ongoing iteration in contrast to hardware development, which is generally very sequential.

Closed-loop PLM can help address these challenges. This approach includes IT tools, such as PLM software, as well as operations, management, governance, and organizational structure. In short, it's not just about reducing the number of engineering changes; all functions and businesses are brought into closed-loop PLM *(see Figure 2)*.

Our research shows that closed-loop PLM reduces time to market by more than 20% by enhancing parallel process development. Specifically, it allows cross-functional teams that could be working in different locations to develop products together using digital tools and in parallel with other teams. These teams can make data-driven decisions more quickly. The collected data also provides more

Figure 2: Closed-loop engineering delivers benefits at every stage in the product life cycle



Source: Bain analysis

transparency in the supply chain so that there is a single source of truth in terms of the cost of components, for instance. Finally, defect feedback from earlier models can automatically and simultaneously be fed back into new product development.

Emerging leaders are finding other benefits, too. Olbrich, a developer of customized machine solutions and factory design, deployed a PLM system that has reduced the time to prepare a quotation by more than 50%. Olbrich can also now design factory plants more quickly as it can reuse certain design aspects. It is also able to create new projects faster and more easily since article, customer, and project data are automatically added from the quotation phase. Finally, the company has greater transparency into ongoing projects thanks to real-time evaluation of projects' progress.

Cheaper

Beyond the obvious cost savings from speeding up time to market, a closed-loop PLM approach enables better access to product data and an increased ability to reuse designs in product development. It also facilitates better management of the bill of materials. Since all components are logged, estimations of product costs are more accurate. Companies that use closed-loop PLM have lower R&D costs as the collaborative approach requires fewer engineers to develop a product.

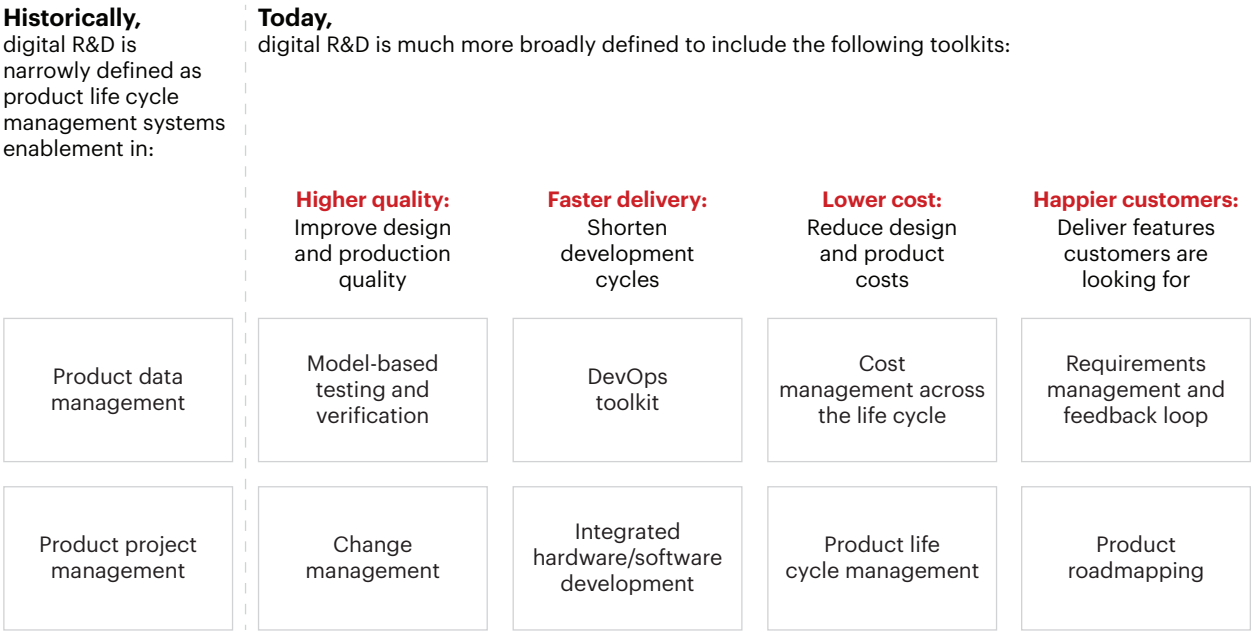
Beyond the obvious cost savings from speeding up time to market, a closed-loop PLM approach enables better access to product data and an increased ability to reuse designs in product development.

The cost reductions can be significant. Kampf, a manufacturer of slitting and winding machines, has built a powerful product data management system that reduced error costs by 50% and increased productivity by 15% to 20%.

Higher quality

A closed-loop PLM approach provides a much more structured way to integrate data from various sources to better understand customer needs, analyze customer insights, and manage customer requirements. Companies that make the most of this data during product development have an edge when tailoring and customizing their products. In addition to helping companies listen to their customers, a closed-loop PLM approach allows them to gather learning about usage patterns from products in the field.

Figure 3: Closed-loop engineering helps companies produce better, faster, and cheaper products



Source: Bain analysis

In closed-loop systems, it is possible to solicit and collect feedback from customers and the market during the life cycle of the product and feed it directly into the development of next-generation products. The closed-loop PLM approach also enables more comprehensive quality management and asset management systems as it integrates data flow between the two *(see Figure 3)*.

Where to begin with closed-loop PLM

Strategy: Ask which business objectives you are trying to meet with a closed-loop PLM approach. These may include reducing R&D costs, speeding time to market, gaining market share, getting closer to customers, or becoming an innovator with best-in-class technologies.

Organization: Adopt a mindset to act cross-functionally within your organization. Communicate to employees the integral role of closed-loop PLM. Upskill existing employees, and hire new talent with expertise in closed-loop PLM.

Data: Analyze how product data is currently used in product development. Identify high-priority use cases that allow quick deployment of digital twins and scalability in product development. Also, ensure an online connection of equipment or machinery so that any type of usage patterns or data about defects can flow directly back to product development.

Technology: Determine which technology system supports any missing elements and improves related key performance indicator gaps. Be 100% transparent, and communicate clearly to machinery users which types of data are collected and go into tools such as the digital twin. Many technology companies, such as phone companies, have end user agreements that define how usage data is being shared and used for future product development.

Closed-loop PLM is a huge investment, but it also presents a tremendous opportunity. Companies that start now and work with partners that can share lessons learned from those already reaping the benefits of closed-loop PLM have the chance to leapfrog ahead of competitors in the coming years.

How to Deliver

Artificial Intelligence Rockets to the Top of the Manufacturing Priority List

Increased adoption of artificial intelligence significantly boosts productivity and improves performance.

By Prashanth Parthasarathy, Guido Vetter, Bodo Koerber, Caperton Flood, and Sehoon Min

At a Glance

- 75% of advanced manufacturing companies say that adopting technologies such as artificial intelligence (AI) is their top engineering and R&D priority.
- AI is already improving productivity across the value chain, including in procurement, maintenance, and logistics.
- Scaling AI, including machine learning use cases, to generate value is a top priority for 78% of executives across industries.

As machinery and equipment companies build new tech muscle, they are investing heavily in artificial intelligence (AI). In fact, the AI market in industrial machinery, which includes intelligent hardware, software, and services, is expected to reach $5.46 billion in 2028, according to the Business Research Company.

Why? From supply chain volatility to cost pressures to the shortage of skilled workers, AI can help address top challenges facing machinery and equipment executives.

Many machinery executives increasingly see AI adoption as an urgent task. In the broader advanced manufacturing industry, 75% of executives say that adopting emerging technologies such as AI is their top priority in engineering and R&D, according to Bain research. Yet, while many companies have collected a mountain of data, a basic enabler of AI, most are not using it.

Leading advanced machinery companies offer a clue to success. Before investing in AI, they identify their core business challenges and how AI can help them improve processes and overall performance. That includes evaluating how specific types of AI, such as machine learning (ML) or generative AI, use data to create value. Early movers are using AI to solve key problems in procurement, assembly, maintenance, quality control, and warehouse logistics.

Some forward thinkers are beginning to deploy generative AI to synthesize huge volumes of unstructured data in order to revolutionize knowledge work, such as retrieving and summarizing relevant information from across the enterprise to answer questions from employees. Others are experimenting with generative AI service bots that partner with field technicians, for instance, to recognize more quickly when maintenance is required and to improve the quality of that work.

Those who are pulling ahead are also integrating AI solutions into processes and back-end systems.

The opportunity

Artificial intelligence is a broad term that encompasses technologies such as basic data analytics, ML, deep learning, and generative AI. Winning companies start by identifying their top business challenges and then selecting the specific AI solutions best suited to solve their key issues.

Ongoing disruptions such as Covid-19 and geopolitical instability have forced organizations to improve supply chain resilience and sustainability. The challenge is moving beyond reacting to problems after they happen. AI, however, can report supply chain bottlenecks in real time, predict potential disruptions in advance, and enable proactive planning to mitigate impacts to supply chains from an end-to-end business perspective.

AI can also track employee productivity and measure costs across all levels. AI helps companies shift their business models from simply selling machinery to offering machinery as a service, in which after-sales support and maintenance become part of the core offering. This includes applying ML to predict when equipment or parts need replacement, thereby reducing unplanned production downtime.

Finding qualified workers remains a challenge across the industry, especially for more complex engineering tasks. AI provides workers with information and insights to free them to focus on activities that add more value. It can also help train and upskill new workers to quickly come up to speed.

Generative AI in manufacturing is in its infancy, but many believe it will transform the sector. Specifically, the large language models that underpin generative AI fundamentally change how people interact

with systems and documents. Generative AI can surface hidden insights from unstructured data that can lead to dramatic improvements in productivity, customer service, and financial performance.

Prioritizing the right business problems to solve

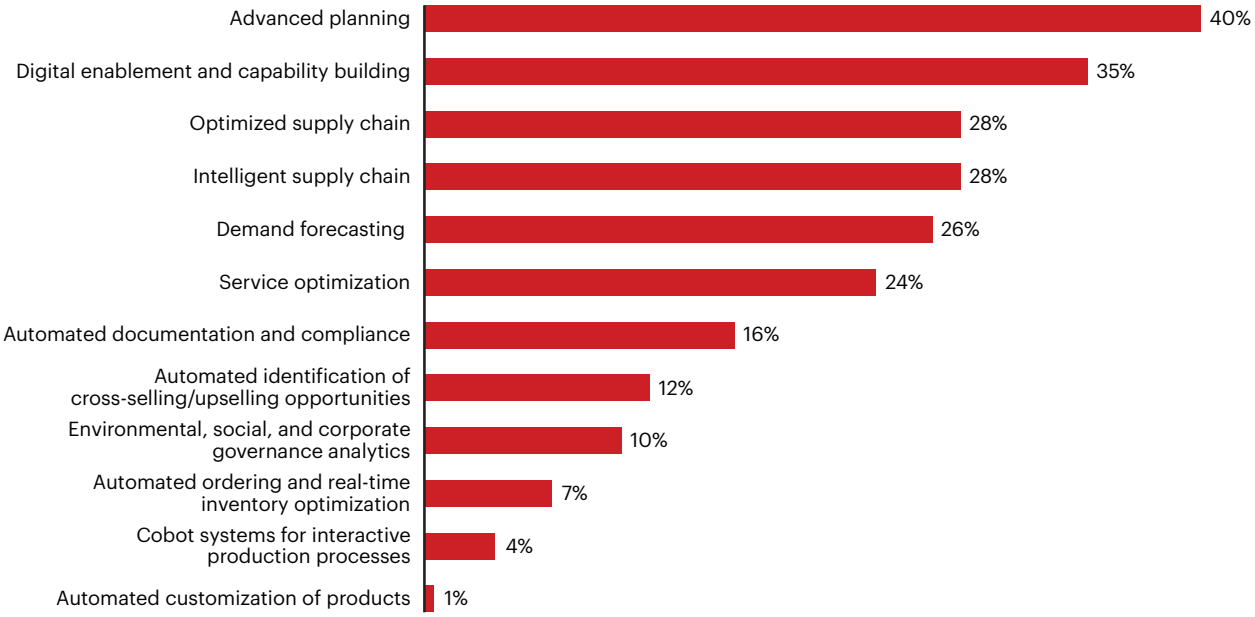
More than 90% of machinery companies already collect and store production data, according to a recent Bain survey. But most do not know how to derive value from that data. One reason is a lack of understanding about where AI can deliver the greatest returns.

Front-runners are already using AI to solve a variety of supply chain challenges (from cutting costs in procurement to using predictive monitoring) to identify failures before they occur in industrial assets, equipment, and infrastructure. In short, AI enables many digital applications that are top of mind for the industry *(see Figure 1)*.

Three specific areas (of many) in which companies are cashing in on AI include minimizing assembly defects/improving quality control; boosting productivity; and streamlining warehouse management.

Minimizing assembly defects/improving quality control: AI can help identify mistakes in real time to improve assembly efficiency and product quality. For example, one machinery original equipment manufacturer (OEM) adopted AI-based video processing to track manual assembly activities, automate

Figure 1: Artificial intelligence–enabled applications in industrial manufacturing will span the supply chain over the next five years



Notes: Participants were asked to "please identify the top three most important applications of digital technologies for your company over the next five years" from a list; graph shows percentage of respondents selecting the use case
Source: Bain Digital GPS Benchmark Survey 2022 (total N=1,400; industrial manufacturing n=136)

quality checks of manual assembly activities, and help optimize the use of resources and employees. Those solutions helped the machinery OEM reduce failures in the assembly process by as much as 70% while also cutting down efforts for quality checks by 50% for some lines.

In another case, a material supplier for machinery OEMs used computer vision to detect foreign objects in chemical bulk material instead of relying only on human inspections. The accuracy of the automated inspection increased by 80%, to greater than 99%, compared with today's mainly manual visual inspection.

Boosting productivity: AI can also supercharge employee productivity, providing a boost to companies short on staff. One machinery manufacturer adopted an AI-powered industrial copilot that converts natural language into code and translates old programming languages into natural language, completing both tasks more expeditiously and at a higher quality than human developers. Among other benefits, engineers using this AI solution were approximately 5% more productive, according to preliminary results. Downtime costs also went down as there were fewer data deployment errors and issues were mitigated more quickly.

Streamlining warehouse management: AI can also help ensure that warehouses operate as efficiently as possible, meaning that they carry the appropriate items to meet demand and minimize extra inventory. One equipment machinery company, for instance, adopted an AI-based inventory management system that helped it minimize overstock while still fulfilling all orders.

AI also provides more flexible job production planning so that companies can allocate specific assembly activities to the most relevant assembly expert at a given time to maximize productivity. As a result, the manufacturer can simultaneously enhance the quality of its products and adjust processes to meet specific customer needs. In short, AI allows companies to customize and personalize without negatively affecting planning, productivity, and costs on the shop floor.

Navigating common AI obstacles

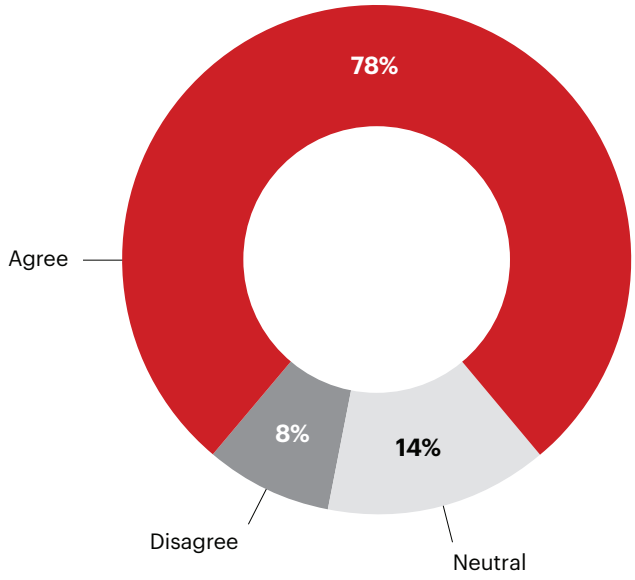
Scaling AI and taking successful AI pilots from one manufacturing line to other lines or other plants is not easy, but it is important. A 2022 survey by MIT Technology Review Insights showed that scaling AI use cases to generate value is the top priority for 78% of executives across industries *(see Figure 2)*.

Top-performing companies monitor their return on investment throughout the AI implementation and ensure that they factor in all costs. While this may seem obvious, many companies forget to log computation costs on the cloud, for instance. Leaders also conduct regular governance checks (e.g., every quarter) to reassess their AI investment decisions.

Legacy software systems and fragmented data can also often pose problems as they create a chaotic data environment with low-quality data. The best teams standardize analytics systems and platforms to enable multiple AI use cases. They also use unified data models that allow them to merge many fragmented data sources into one.

Figure 2: Artificial intelligence priorities for executives

Scaling artificial intelligence/machine learning use cases to create business value is a top priority



Source: 2022 survey by MIT Technology Review Insights

To keep pace with rapid changes in AI, leaders use modular and loosely coupled components, connected via microservices, to make it easy to replace software. When integrating generative AI, they ensure that these new components enhance the existing data architecture. Successful companies also verify that efficient processes and tools (MLOps/DevOps) are factored into the technical architecture so that they can deploy AI at scale.

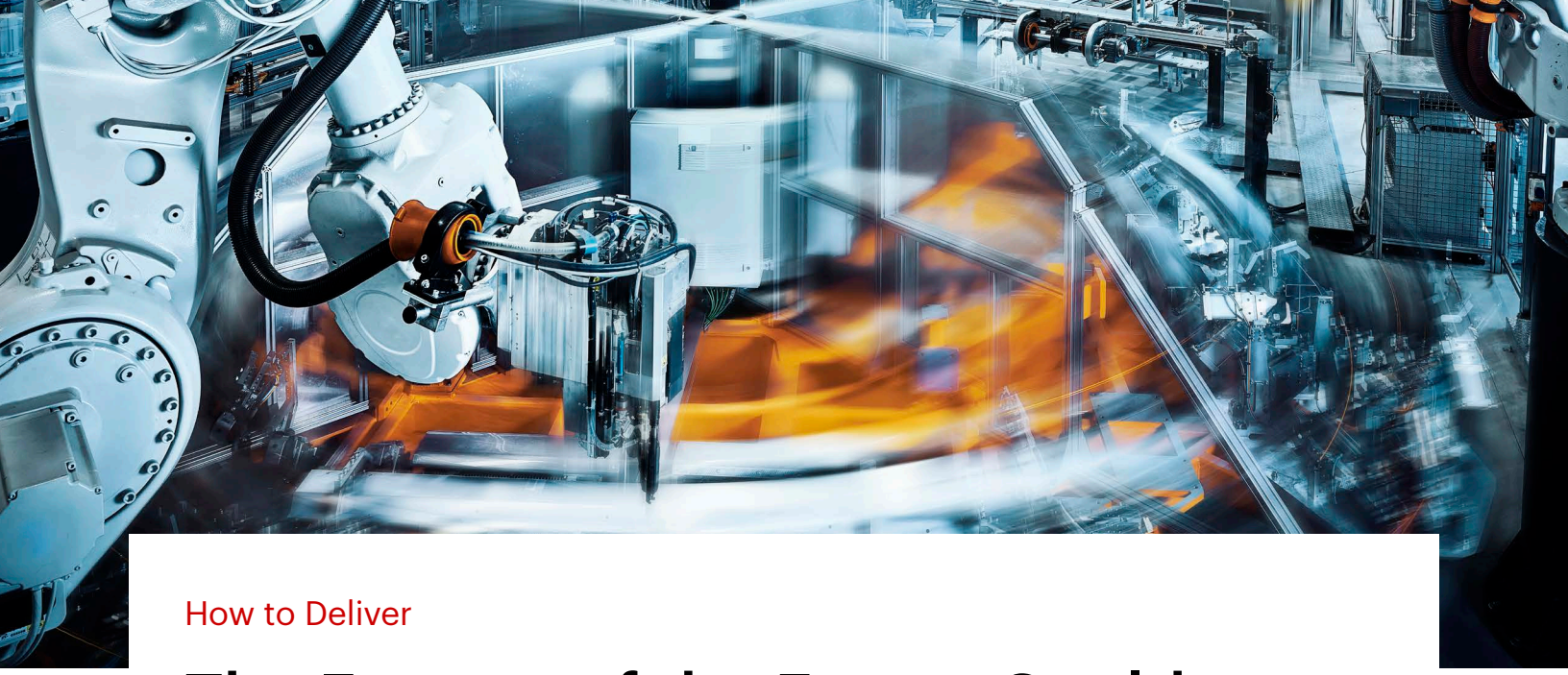
Leaders in AI also embrace a test-and-learn approach. Machinery engineers typically favor rigorous thinking and perfect product design. Software and AI work, however, require a test-and-learn, fail-fast approach using Agile methodology. In successful AI implementations, plant engineers and AI experts collaborate closely to create, test, and refine AI models until they meet the company's goals.

Finally, machinery companies often struggle to find and retain employees with strong AI skills. To build in-house AI capability, many are bringing in external AI experts to train existing employees and increase data literacy throughout the entire workforce.

To retain skilled workers who may feel that some aspects of the work are uninteresting, successful companies have several approaches. Some are automating simple AI tasks so that experts can focus on more data- and analytics-intensive work. Others are developing expert squads to handle more complex AI use cases and crack data insight problems.

While each company faces different AI challenges, the leaders are addressing three core dimensions. First, they determine where AI unlocks the greatest value for the business. Second, they tailor the technology to address core problems and integrate it with their IT and operational technology setup. That means making sure that the technology is flexible so that it can be applied to immediate use cases but is also scalable in the future. Finally, they are developing a data culture that integrates AI skills and AI-enabled ways of working into the operating model.

AI has captured the imagination of machinery executives. As a growing number of companies experiment with and deploy new solutions, they are raising the industry bar for productivity and performance. Companies that defer investing will need to run twice as fast to keep pace.



How to Deliver

The Factory of the Future Could Boost Productivity by 30% or More

The key is integrating lean, digital, artificial intelligence, and sustainability measures.

By Thomas Frost, Jörg Gnamm, Stefan Silberstein, Mike Duvall, and Lisa Kabus

At a Glance

- Most machinery companies could improve productivity by 30% to 50% with a “factory of the future” approach.
- Approximately 60% of machinery companies have started implementing their “factory of the future” strategy.
- Successful companies integrate digital tools, sustainability, and lean operations into their future roadmap.

Machinery chief operating officers (COOs) are under increasing pressure from all sides, including customers, markets, and competition, to deliver additional value. Some are using digital tools or Industry 4.0 technologies such as artificial intelligence (AI), robotics, and additive manufacturing to counter these pressures and deliver significant value. Others are using traditional operational excellence approaches.

The most recent Bain research, however, shows that most machinery companies fail to truly capitalize on these levers, leaving 30% to 50% of productivity value on the table as they bring their factory of the future to life.

Why? Machinery and equipment manufacturers still rely heavily on traditional lean manufacturing approaches. They may be exploring how to incorporate digital tools or Industry 4.0 and sustainability measures, but they still do so in separate organizational silos.

Top performers, however, are incorporating an integrated approach in which digital technologies enable an upgraded state across the board and address real pain points.

Successful companies also define the standards and interfaces that work across their information technology (IT) and operational technology (OT) infrastructure as well as the operating model. In this way, they can extend scaled impact beyond pilot projects and create a "factory of the future" roadmap for their existing and future plants that clearly identifies the short-term and long-term steps to unlock value.

Pain points

Machinery and equipment firms struggle to future-proof their factories for various reasons. Challenge No. 1 is siloed thinking. Many companies use traditional operational excellence approaches, and in parallel, they implement digital for digital's sake or Industry 4.0 use cases that are fully separate. Instead, they need to integrate the new Industry 4.0 technologies with their existing operational excellence approach and standards.

Companies also often fail to integrate OT and IT from an operational and systems aspect. In fact, the top pain point with scaling the production system was feeling overwhelmed when selecting IT and OT vendors, according to a recent Bain survey. Part of this stems from the fact that COOs and chief information officers do not always work hand in hand as much as they could. As a result, they lack a transparent overarching vision, and they do not adequately communicate the case for change.

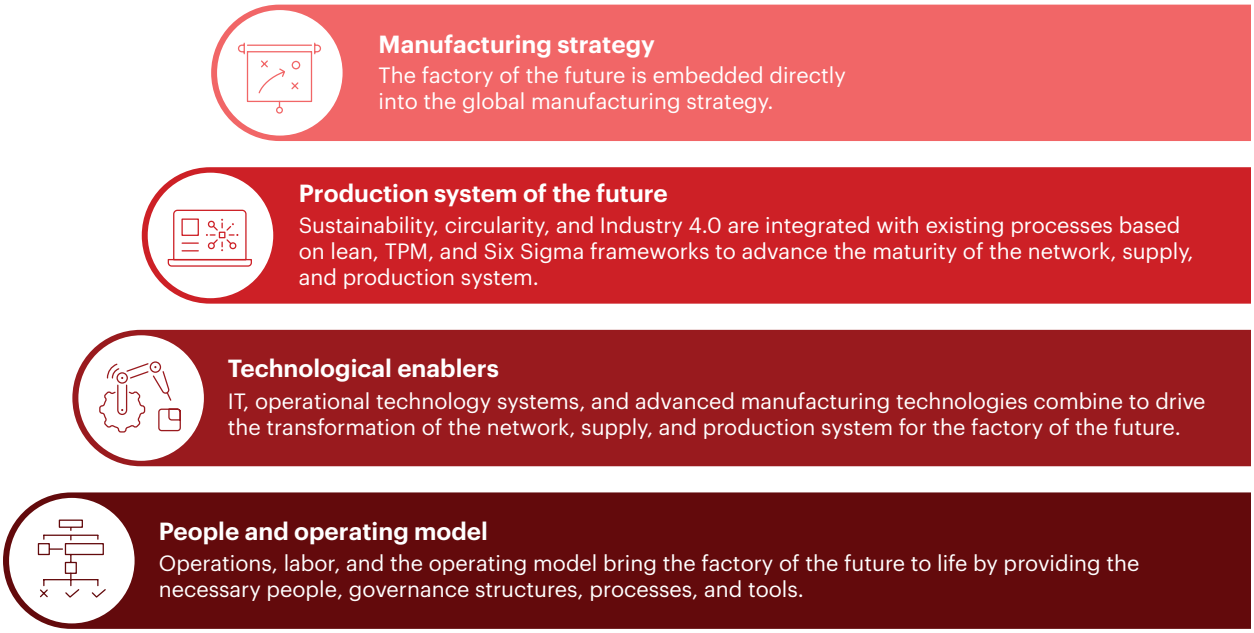
Finally, companies do not connect sustainability and circularity with broader business objectives and implement them throughout the production system.

Designing the factory of the future

In order to achieve results at scale, leading companies are going beyond just applying selected technologies or operating in functional silos. Instead, they are adopting an integrated approach, challenging the legacy status quo means of operation, and considering a new setup of their entire production system. In short, they are paving the way toward the factory of the future through the following four steps *(see Figure 1)*.

- **Clarify the future strategy:** The factory of the future cannot simply be a bolt-on project; it needs to be integrated in the overarching business strategy. Consequently, the future strategy should incorporate market, customer, and economic requirements as well as social, environmental, and corporate governance demands. It should also define a specific path toward developing the factory of the future, identifying the short-term and long-term goals along the way.

Figure 1: Four steps toward the factory of the future



Source: Bain & Company

- **Build the production system of the future:** The new production system defines the new ways of working and standards needed to progress toward an integrated factory of the future. This approach moves beyond traditional operational excellence approaches and interconnects these existing approaches with sustainability and digital tools or Industry 4.0 technologies.
- **Identify the technological enablers:** The IT/OT systems need to support the production system and include the appropriate reference structure, data architecture, databases, and interfaces so that they are cross-functional today and flexible to adapt to future requirements. This technology foundation should also enable interfacing throughout the supply chain with customers and suppliers.
- **Make employees the backbone:** The organizational structure places employees at the center, supercharged by technology and with sustainability embedded throughout the organization. Upskilling existing employees and recruiting employees with the appropriate new skills will be key.

Unlocking value regardless of your starting point

While nearly 60% of the machinery and equipment companies that Bain surveyed have started their journey toward an integrated factory of the future, none have fully optimized efficiency. There are,

however, tangible business benefits no matter what maturity level a machinery or equipment supplier starts at. An average machinery factory in Germany, for example, is currently at a level of circa 2.5 on a six-level maturity scale *(see Figure 2)*.

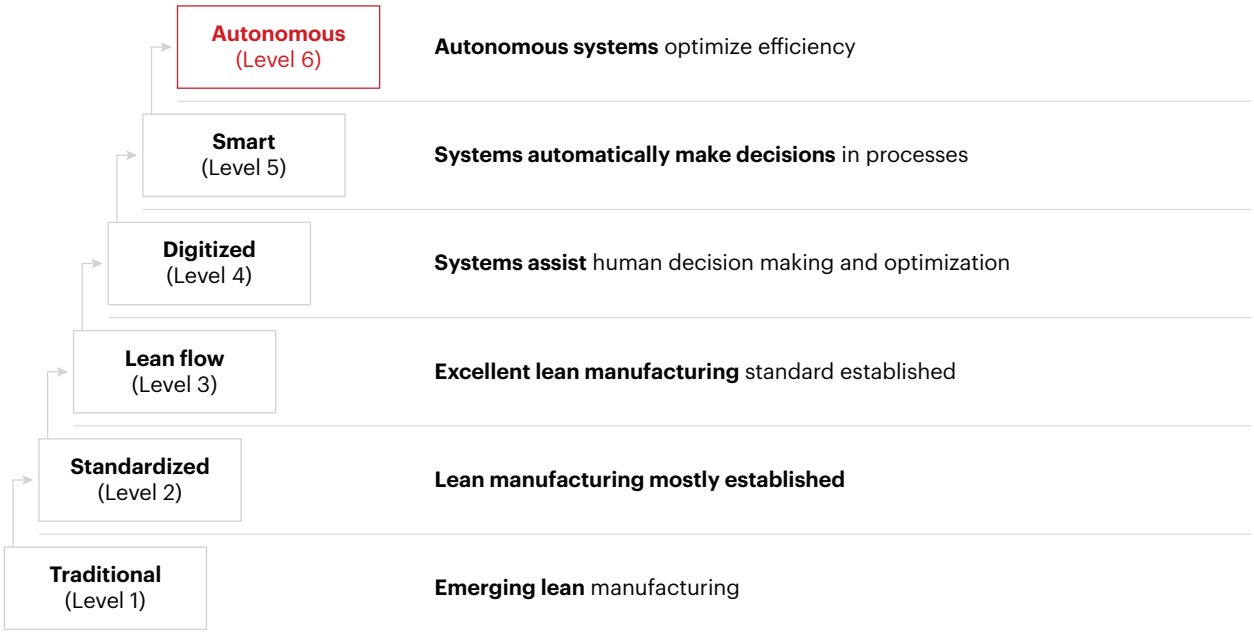
Establishing a transparent starting point and ambition is key to identifying the relevant and applicable technologies that enable this step-change ascension through the maturity levels.

For example, a low-maturity utility equipment supplier used the logic and framework of the factory of the future to move from maturity level 1 to 2. The team implemented end-to-end traceability for every SKU and optimized warehouse operations for more efficient organization, location tracking, and stock updates. As a result, they were able to reduce inventory by 50% and decrease lead time by 40%, which led to an additional 7% in sales. They also implemented inventory management and systematic performance management systems. All of these moves contributed to delivering more than 95% of products and services on time and in full.

Moving higher

Even relatively high-maturity companies still stand to benefit. For example, a global manufacturer started around level 3.5 maturity. It had excellent lean manufacturing standards, and systems were in place to assist human decision making and optimization. In an environment of more than 1,000

Figure 2: Maturity-level scale



Source: Bain & Company

SKUs and 350 changeovers a day, however, it was increasingly inefficient for employees to manually develop flexible production schedules.

The company decided to use AI in situations in which traditional analysis and optimization were falling short. These tools included engaging digital twin simulation to help de-bottleneck the overall system, deploying smart scheduling solutions, and installing live process analytics to reduce inspection requirements. These solutions all contributed to achieving a 40% increase in overall output.

Beyond its focus on productivity improvement, the company has gone a step further. It also uses self-learning AI tools to continually monitor and adjust production parameters to assure quality. This has enabled the elimination of inspection requirements and is able to provide an early warning of up to 36 hours ahead of potential equipment failure.

To move up completely to a level 5 (or smart) state, this company will need to scale this lighthouse project across all factories and apply the lessons learned from this work across the entire production system.

Getting started

Each transition to the factory of the future will vary by company, by plant, and even by specific value stream within a plant, depending on the maturity level and the short- and long-term ambitions. No one size fits all. Most important is to start now by defining true business goals and the future vision.

For example, a move from level 3 to level 5 in smart maintenance could address and evolve maintenance process companies. In this way, the company could move from traditional lean elements—such as process failure mode effects analyses and defining maintenance plans, including inspections and preventative elements—toward predictive models and live-condition monitoring and notification. Finally, they could strive for automated intervention protocols, autonomous operations, and live interactions with original equipment manufacturers for spares and services.

Or consider a company moving from level 3 to level 5 in factory performance management. Its plants would move from daily data downloads and reviews of hidden black-box data to having more live data feeds and being tracked against dynamic targets based on current conditions. Then, it could move further toward live intervention suggestions or autonomous rescheduling and prioritization across key work orders and assignments, while providing root cause analysis and longer-term suggestions for optimization.

With a system-wide, end-to-end perspective, it is possible to move beyond functional silos and create a step-change ascension through maturity levels. Machinery and equipment manufacturers acting now to implement a “factory of the future” strategy will reap the benefits in productivity gains and increased savings. These leaders are already starting to shape their market and industry, remaining agile to adapt to future conditions.

Bold ideas. Bold teams. Extraordinary results.

Bain & Company is a global consultancy that helps the world's most ambitious change makers define the future.

Across 65 cities in 40 countries, we work alongside our clients as one team with a shared ambition to achieve extraordinary results, outperform the competition, and redefine industries. We complement our tailored, integrated expertise with a vibrant ecosystem of digital innovators to deliver better, faster, and more enduring outcomes. Our 10-year commitment to invest more than $1 billion in pro bono services brings our talent, expertise, and insight to organizations tackling today's urgent challenges in education, racial equity, social justice, economic development, and the environment. We earned a platinum rating from EcoVadis, the leading platform for environmental, social, and ethical performance ratings for global supply chains, putting us in the top 1% of all companies. Since our founding in 1973, we have measured our success by the success of our clients, and we proudly maintain the highest level of client advocacy in the industry.

For more information, visit **www.bain.com**