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Advanced Industries Practice

Manufacturing process innovation for industrials

Industrial manufacturing levels in the United States have been falling for decades, but process innovation is gaining steam and could reinvigorate this struggling sector.

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In 1947, manufacturing accounted for 25 percent of GDP in the United States. By 2019, it was down to just 11 percent, and it has slumped further throughout the COVID-19 pandemic. Industrial manufacturing—of products such as flow-control pumps, heating and air-conditioning systems, and food-processing equipment—has been particularly hard hit. That decline has widespread repercussions, since this sector alone has been responsible for more than half of the overall manufacturing contraction in the United States over the past 30 years. Industrials also employ the highest proportion of manufacturing labor in the country.

Within the industrial sector, the challenge is even more acute for companies with revenues under $2 billion. Over the past ten years, the value these smaller companies created, as measured by total shareholder returns, has trailed that of larger companies by 41 percent (Exhibit 1). But as the US economy continues its transition into the next normal, a shift toward end-to-end market demand, coupled with innovation across manufacturing processes, presents these smaller industrial businesses with a path to improvement.

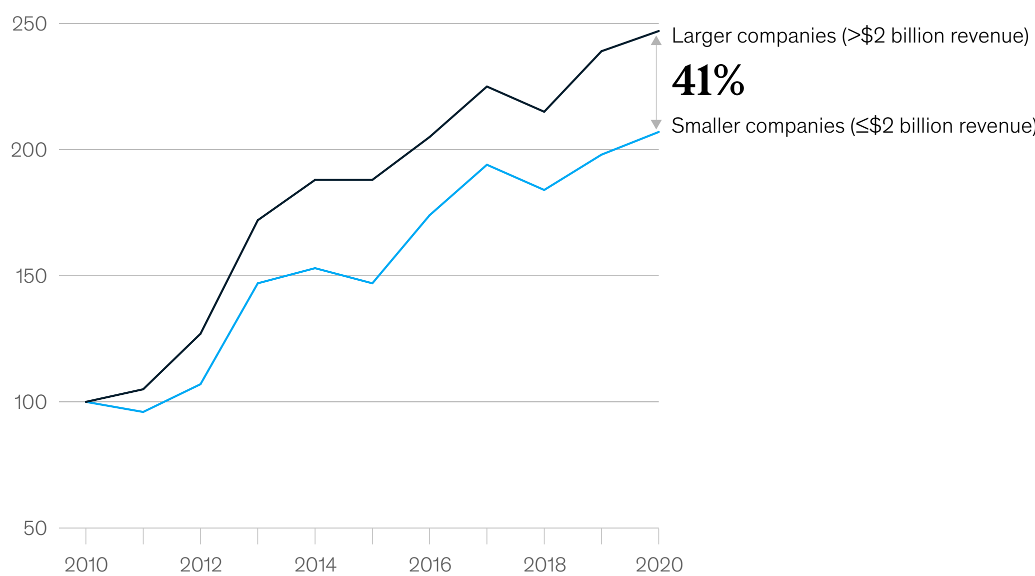
Shifts are already under way. Traditional approaches, which focused on finding regions with the lowest labor costs, are starting to be supplanted by technology-led, flexible, and efficient manufacturing performed at sites closer to the point of use. As the pace of innovation accelerates across industries, having the flexibility to add product features and functionality becomes paramount. High mix and high configurability are increasingly replacing the "a few options fit most" approach. And there are likely to be new opportunities, enabled by localized supply chains and shorter lead times, to hold minimal inventory.

To fully enable these shifts, continued innovation will be necessary—industrial manufacturing processes must become more flexible, efficient, and precise. Thankfully, the pace of innovation

Exhibit 1

Smaller industrial companies—those with revenues under $2 billion—have lagged behind their larger peers in performance over the past decade.

Total shareholder returns across industrial sector,[1] North America, cumulative average, % (2010 = 100%)



[1]This analysis included 790 public companies.
Source: McKinsey Corporate Performance Analytics; McKinsey analysis

New manufacturing capabilities will increase the need for small, highly skilled workforces and integrated networks of smaller, specialized, and flexible plants.

in manufacturing techniques has skyrocketed by more than 150 percent, as measured by the number of new patents registered in the United States alone over the past two decades (Exhibit 2). Rapid innovation is enabling new processes—such as laser metal deposition and cutting, ultrasonic soldering, and thermal-diffusion galvanizing—that must be developed, adopted, and scaled. These new manufacturing capabilities, which improve precision, geometric complexity, and compatibility with advanced materials, will increase the need for small, highly skilled workforces and integrated networks of smaller, specialized, and flexible plants. Of course, not all innovation is created equal or can add the same value. Yet players that adopt the right combination stand to gain an outsized share of the market.

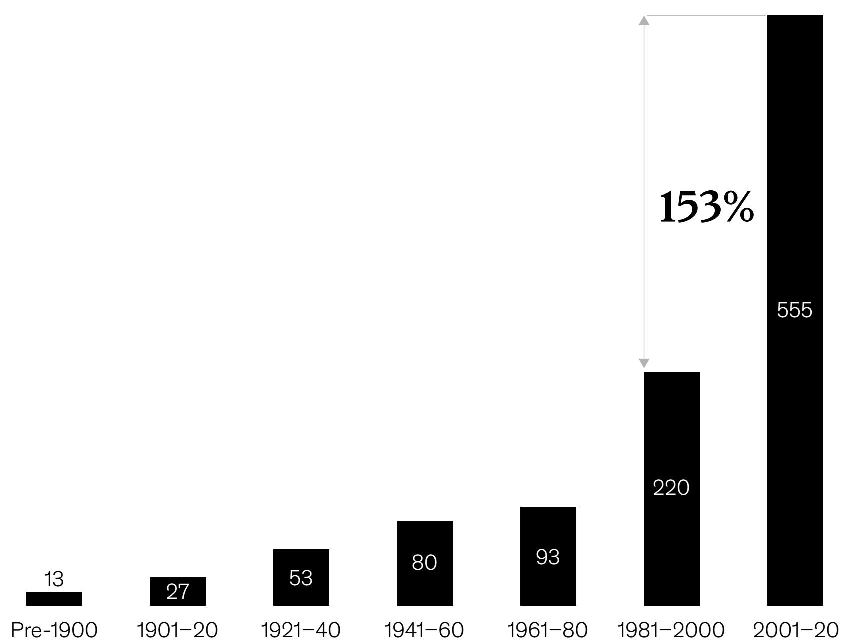
Understanding the opportunities

To help us understand the opportunities available, we developed the Manufacturing Process

Exhibit 2

The pace of innovation in manufacturing processes is accelerating rapidly.

Total US patents registered on industrial manufacturing processes, thousands



Source: Analysis of US patent-registration data for industrial manufacturing

Innovation Index, or MPI2. To analyze the industrial manufacturing space, we created a comprehensive taxonomy consisting of seven core techniques, such as shaping, forming, and joining; 39 technologies, such as casting, milling, and welding; and 194 discrete processes, such as extrusion molding, laser cutting, and fused deposition (Exhibit 3).

We determined the pedigree of each process by assessing three core capabilities—level of precision, geometric complexity, and throughput speed—and three economic drivers—compatibility with advanced materials, scalability, and pace of development (Exhibit 4). This pedigree is then reflected in an MPI2 score, enabling processes to be ranked against others.

The first capability factor—precision—considers the evolution from a traditional multistep iteration process to single-step, high-precision manufacturing. Medical stents, for example, were typically produced using three techniques: etching, electroforming, and die casting. The limited ability to achieve high precision in the first pass required the application of secondary and tertiary manufacturing processes, such as surface milling and etching, to reach the required level of precision. The shift to high-precision manufacturing greatly improves accuracy and consistency, eliminating the need for follow-on machining operations.

The second capability factor—geometric complexity—considers the ability to create the complex, multidimensional shapes increasingly required for highly engineered products, such as

Exhibit 3

A comprehensive taxonomy spanning core techniques, technologies, and processes makes it possible to analyze industrial manufacturing.

Core techniques						
1 Primary shaping	**2** Forming	**3** Dividing	**4** Joining	**5** Coating	**6** Property changing	**7** Additive
39 technologies, including						
Casting, molding, sintering, spray forming	Bending, rolling, stamping, pressing, forging, widening	Milling, drilling, sawing, cutting, grinding, turning, punching	Welding, riveting, packaging, gluing, filling, soldering	Painting, chroming, galvanizing, metal spraying	Heat treating, magnetizing, irradiating	Binder jetting, material jetting, material extrusion, powder bed fusion, sheet lamination, directed-energy deposition, photopolymerization
194 processes, including						
Extrusion molding, centrifugal casting, plasma sintering, die casting, matrix molding	Air bending, forge rolling, deep-drawing, elastomer bending, embossing	High-feed milling, orbital drilling, plasma cutting, laser cutting, fine blanking	Weld assembly, laser soldering, dip brazing, wave soldering	Air and airless spraying, hot-dip galvanizing, nickel–chrome plating, roller, thermal-diffusion galvanizing	Annealing, hardening, case hardening, cold sterilization, magnetizing	Continuous liquid interface production, laser metal deposition, polyjet, fused deposition molding, solid ground curing

Source: American Society for Testing and Materials ASTM42; Deutsches Institut für Normung DIN8580; McKinsey analysis

Exhibit 4

The Manufacturing Process Innovation Index uses six factors to determine the pedigree of each process.

	Factor		What matters	What good looks like
Inherent capabilities	1	Precision	What is the level of precision? Is it repeatable and sustained?	Femtosecond fiber-cutting laser with 12-micrometer resolution for medical stents
	2	Geometric complexity	Can the process handle 1-D, 2-D, or 3-D? Are “trapped” geometries possible?	Selective laser melting process enabling rocket-engine designs with 30% less weight and 20% more efficiency
	3	Throughput speed	How many parts per minute or hour? Is the process sustainable without sacrificing precision or complexity?	The active wire-welding process is more than 2 times faster than traditional arc systems, while maintaining flatness and precision
Economic drivers	4	Compatibility with advanced materials	Which materials can be processed? Are high-strength, lightweight options available?	6-axis continuous fiber reinforced 3-D printers for automotive, replacing manual processes
	5	Scalability	Can capacity be scaled without 1-for-1 capex increase? Can process be optimized for high volumes?	Auto-load add-ons for laser cutting to increase throughput on existing equipment 1.5–3x
	6	Pace of development	Is IP activity accelerating or slowing? Are many companies investing in R&D?	Elastomer bending with 47x increase in patent filings over past decade; enables new high-strength nanocomposite components

steel-alloy parts for aviation or polymer-based dental-restoration products customized to each patient’s specific requirements. A number of existing manufacturing processes, including plasma cutting, laser welding, and high-speed milling, can produce complex shapes, but additive technology is the most important of them. For example, in the automotive sector, where additive manufacturing is starting to be adopted, this technology makes it easy to prototype and test designs for metal engine parts with complex, customized shapes. In production, it ultimately enables better performance in a smaller package.

The third capability factor is throughput speed. Advances in many manufacturing processes are enabling faster throughput, while automation and process optimization are reducing preparation and cycle times. For example, traditional molding techniques, such as matrix molding, can produce only one piece per hour. Blow-molding techniques have increased this to 1,500 pieces per hour, and extrusion molding can now produce over 500 pieces per hour, depending on the materials involved.

In addition to the inherent capabilities of precision, speed, and geometric complexity, other factors can increase value. Many industries are improving their performance by using advanced materials, such as carbon fiber, high-strength steel, and ceramics. These new high-strength, lightweight materials are outclassing traditional aluminum and steel alloys in strength-to-weight performance, robustness, and durability: for instance, new aircraft designs that include 50 percent carbon fiber–reinforced polymers for the cabin, wings, and fuselage have helped reduce fuel consumption by 20 percent over the past 20 years.

The shift to carbon fiber in the manufacture of wind-turbine blades has also improved performance. This lighter, more rigid material allows the manufacture of thinner, larger blades that increase output to more than 8 MW/hour, from 1.3 MW/hour. Moreover, the lighter carbon-fiber blades also reduce the stress on the turbines and tower, further improving performance and longevity. While the value of these materials is apparent, processing them is significantly more challenging because it requires specialized manufacturing technology and capabilities.

The economic scalability of a given manufacturing process can increase value as well. The ability of a process to increase throughput and optimize for high volumes correlates directly with maximizing returns on investment for associated equipment. Improvements in laser-cutting techniques, for example, are meeting industry demands for better cutting performance. Throughput volumes are increasing and costs per part are falling because of innovations (including nesting software, fiber technology, and automatic material feeding) that have significantly improved laser-cutting scalability.

Finally, the pace of development for a given industrial manufacturing process also has an impact on value. US patent filings are one example. An evaluation of the filings for 194 discrete processes makes it clear that the pace of innovation has accelerated for most processes. Consider elastomer bending. The first patent for this process was issued in 1984, so it is a relatively recent innovation. The number of new patents for this technique rose by 4,700 percent from 2010 to 2020, compared with the decade prior. The number of patents for more traditional, long-standing processes is also increasing. The first patent for trepanning was issued in 1847. The number of patents was up 450 percent from 2010 to 2020, compared with 2000 to 2010.

Findings from the MPI2

We applied the six parameters, which together make up the Manufacturing Process Innovation Index, to two segments of the industrial value chain: equipment providers, whose tools are used for industrial manufacturing and assembly processes, and manufacturing service providers, which make custom components, such as precision castings and machined parts built to OEMs' specifications. We found that the six parameters correlate strongly with financial performance, with MPI2 a particularly strong indicator of a company's ROIC (Exhibit 5). (For more information on our assessment methodology, see the sidebar, "Determining the MPI2 score.")

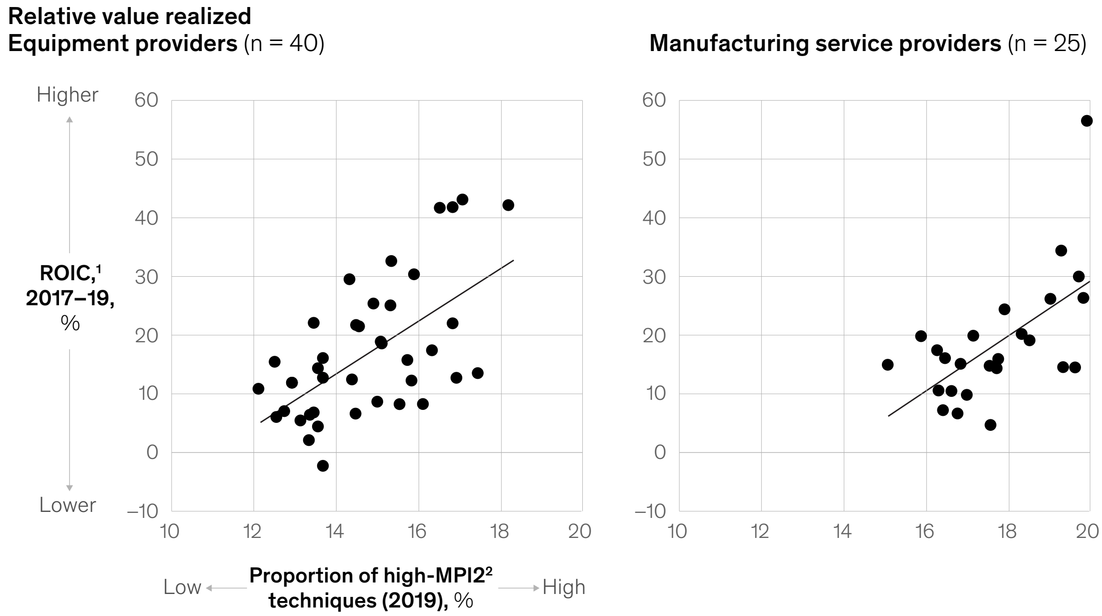
Determining the MPI2 score

The first stage of determining the MPI2 score involves assessing an industrial company's profile and products. This assessment is then used to map the company's capabilities, as well as the key techniques and technologies that are either manufactured (for equipment providers) or leveraged (for manufacturing service providers).

From this map, we can use the MPI2 model to score each company along the three core capability factors (level of precision, geometric complexity, and throughput speed) and three economic drivers (compatibility with advanced materials, scalability, and pace of development). Each is weighted according to the relevant market segment (equipment provider or manufacturing service provider), and the overall score is calculated by adding the individual scores for each technique.

Exhibit 5

The Manufacturing Process Innovation Index is a strong indicator of ROIC performance.



[1]Return on invested capital.
[2]Manufacturing Process Innovation Index.
Source: CapIQ; McKinsey Corporate Performance Analytics; McKinsey analysis

To better understand how the MPI2 score is determined, let's take a deep dive into dividing, one of the seven industrial manufacturing techniques. Within the range of cutting technologies available, laser cutting has the highest MPI2 score (25). It also offered as much as 10 percent year-over-year growth over the period studied, outpacing other processes. Laser cutting has benefitted from a steady pace of innovation during the past 60 years, from the earliest CO_2 laser (in the 1960s), which delivered the first commercial cut, to the recent introduction of optical-feedback systems that increase precision and therefore make it possible to process advanced materials and three-dimensional geometries.

Among the six factors that define MPI2 scores, laser cutting offers enhanced precision—as much as 0.025 mm with reduced thermal stress, as well as throughput speeds of 1,000 to 5,000 inches per minute, putting waterjet and plasma techniques in the shade. The enhanced capabilities of laser cutting give it the highest MPI2 score of any technology, offsetting the high cost of fiber lasers and the even higher cost—as much as $2 million—of a comparably equipped CO_2 laser.

Welding technologies have also evolved greatly in recent years. The first electric arc welding method, using carbon electrodes, was developed as far back as 1880. Shielded metal arc welding was commercialized in 1950, enabling the fabrication of large steel structures. In 2008 laser-arc-hybrid welding was developed, and by 2017 more than two million industrial-welding robots were in operation around the globe.

We can also look at the range of processes available among welding technologies and examine their MPI2 scores individually. Although flux-cored arc welding has the lowest growth rate among the four technologies scored, its market size—$7.5 billion—far exceeds that of the nearest runners-up: shielded metal arc ($1.4 billion) and tungsten inert gas ($0.7 billion). Moreover, flux-cored arc welding exceeds or matches the highest MPI2 scores in half of the category drivers and outperforms all other techniques in precision, throughput speed, and pace of development.

Understanding the opportunity for equipment providers

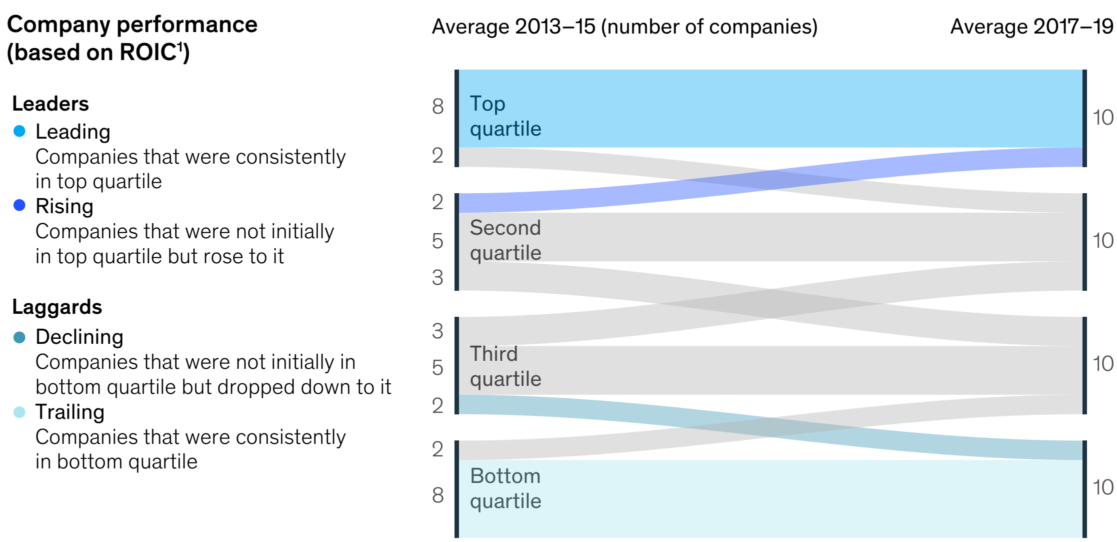
The landscape of providers supplying industrial manufacturing equipment is fragmented and highly competitive. The top 20 to 30 companies, with average revenues of about $9 billion, account for 25 percent of the market. The remaining 75 percent market share is scattered among more than 5,000 organizations, the majority of them privately held, with revenues from $20 million to $2 billion. Traditional technologies still command a majority of the revenue, particularly in primary shaping and forming, such as rolling, bending, and molding. But the surge of innovation in industrial manufacturing processes over the past 20 years has led to the creation of many smaller, focused equipment providers.

Moreover, performance levels are sticky. Among 40 public equipment providers we analyzed, only three—previously positioned in the second and third quartiles—joined the leaders in the top quartile over a six-year period. Companies that started in the lowest quartile remained there (Exhibit 6). As noted earlier, MPI2 scores correlate strongly with performance. Consider the average ROIC for the 40 companies from 2017 to 2019. Those classed as either leading or rising had a significantly greater proportion of high-MPI2 techniques (Exhibit 7).

MPI2 helps demystify the factors that drive value creation across a complex manufacturing-

Exhibit 6

The performance of top- and bottom-quartile publicly held equipment providers changed little across business cycles.

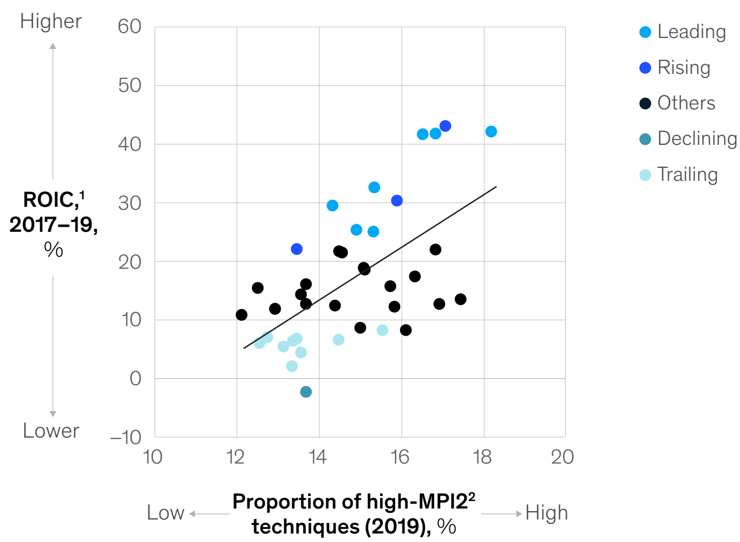


[1]Return on invested capital.
Source: CapIQ; McKinsey Corporate Performance Analytics

Exhibit 7

Manufacturing Process Innovation Index scores also correlate well with performance across cycles.

Equipment providers, relative value realized, (n = 40)



[1]Return on invested capital.
[2]Manufacturing Process Innovation Index.
Source: CapIQ; McKinsey Corporate Performance Analytics; McKinsey analysis

process landscape, but the findings are valuable only if stakeholders act on the insights. We have identified important steps that company leaders, board members, and investors can take once they have reviewed their manufacturing processes through an MPI2 lens.

Actions for company leaders

High-MPI2 leaders consistently innovate by pursuing new processes, improving existing products, and actively shaping portfolios through M&A. In organic innovation, this means developing new manufacturing processes with the greatest potential for creating value arising from the following activities:

— deploying capital and R&D resources to develop entirely new approaches and protecting those projects during downturns

— reducing time to market versus competitors by significantly shortening each stage of the development cycle and executing effectively

— regularly reassessing and rationalizing the product portfolio to meet evolving customer needs and dropping legacy offerings with low value-creation potential

Organic growth can be difficult for industrials, given the fragmented landscape and their more limited ability to support large new-technology investments, particularly for companies with revenues under $2 billion annually. There are many opportunities for consolidation and inorganic growth, however, and an active M&A strategy can enable faster access to new manufacturing processes.

Organizations that deploy M&A effectively can increase the breadth of their product offerings in manufacturing processes likely to generate high value. They can also provide end users with complete ecosystems—increasing scale and market influence—and create cost-free revenue streams through smart products that improve the operations of their customers.

Effective execution also involves taking steps to improve some dimensions that MPI2 measures: throughput speed, precision, geometric complexity, and compatibility with advanced materials. Ideally, this improvement occurs rapidly—potentially, within four to six months of a project's start—to help companies stay ahead of the competition. Finally, leaders should not hesitate to cannibalize their current portfolios by eliminating legacy projects and pursuing instead high-growth opportunities, which add to the competitive edge.

Strong execution will require a new playbook (Exhibit 8). Raising the level of innovation, for instance, calls for a clear vision and strategy, an end-to-end willingness to innovate, and a highly mobilized organization that drives change quickly and effectively at scale. Company leaders must not only become product champions but also create new ecosystems through M&A, assessing the value of synergies and ensuring a strong governance process. Companies must set rigorous rules for expansion as well.

Actions for board members

To help capture value from MPI2 insights, board members should first evaluate the position, strategy, and governance of their companies to determine if these factors support growth. For instance, board members should identify the manufacturing-process segments that will deliver the most value and the end markets best positioned to benefit from it. They should also determine whether a company's approach to innovation, product development, and product improvement is congruent with the chosen strategy.

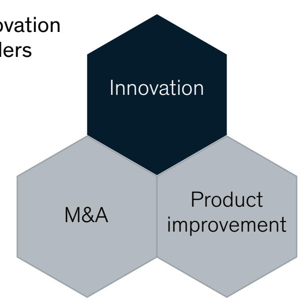
Finally, board members should not only ensure that their companies have a governance model that makes it possible to measure progress but also select the best internal and external indicators

Exhibit 8

Industrial-manufacturing companies looking to achieve a step change in performance need a new playbook.

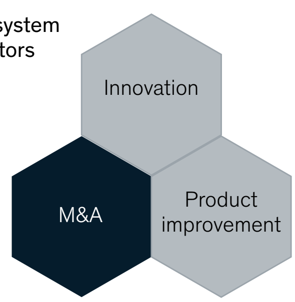
Elements of new playbook

Innovation leaders



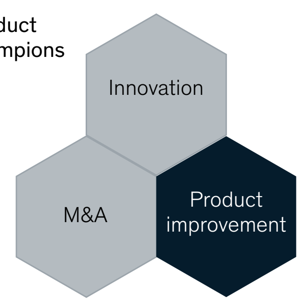
- Clear vision and strategy
- End-to-end innovation system for bigger, better ideas
- Mobilized, prioritized organization
- Fast, effective operation at scale

Ecosystem creators



- Rigorous rules for expanding or rationalizing portfolio
- Active M&A engine
- Synergy-value assessment
- Portfolio-governance process

Product champions



- Voice of customer
- Design thinking
- Concurrent engineering
- Complexity optimization

to track (for instance, those related to product performance, regulatory issues, customers, and the competition).

Actions for investors

Investors should identify the manufacturing processes and underlying technologies that produce value or are likely to do so in the future. They should also judge how a given company's portfolio is positioned to compete along the innovation dimensions most closely linked with value. Finally, investors should determine whether momentum is increasing in target end markets for a company's manufacturing processes and technology.

The timing of investments is important too. Ideally, investors should examine the innovation cycle for different emerging technologies before deciding when to allocate funding. Important considerations include market traction; the pace of disruption for relevant manufacturing-processes, technologies, and techniques; and the impact of regulatory changes or geopolitical headwinds on product offerings.

Finally, investors must consider how they want to capture value. For instance, they may wish to increase revenues by combining multiple high-MPI2 products into a single portfolio. They could also attempt to achieve cost synergies by creating high-MPI2 products that share as many commonalities and platforms as possible to optimize development spending. And they might augment this with higher margin software offerings, unlocked through the creation and expansion of digital ecosystems.

The frequency and severity of shocks disrupting industrial manufacturers have risen over the past year and are expected to increase over time, whether from supply-chain, workforce, or product-demand challenges. As companies across the industrial manufacturing value chain try to mitigate these risks by evaluating new options such as nearshoring and production flexibility, the importance of high-value manufacturing techniques rises.

Identifying sources of value creation is challenging for a complex landscape comprising myriad techniques, materials, and processes. MPI2 can help to demystify this space, helping operators, board members, and investors to push the next frontiers of industrial manufacturing performance in the United States and beyond.

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