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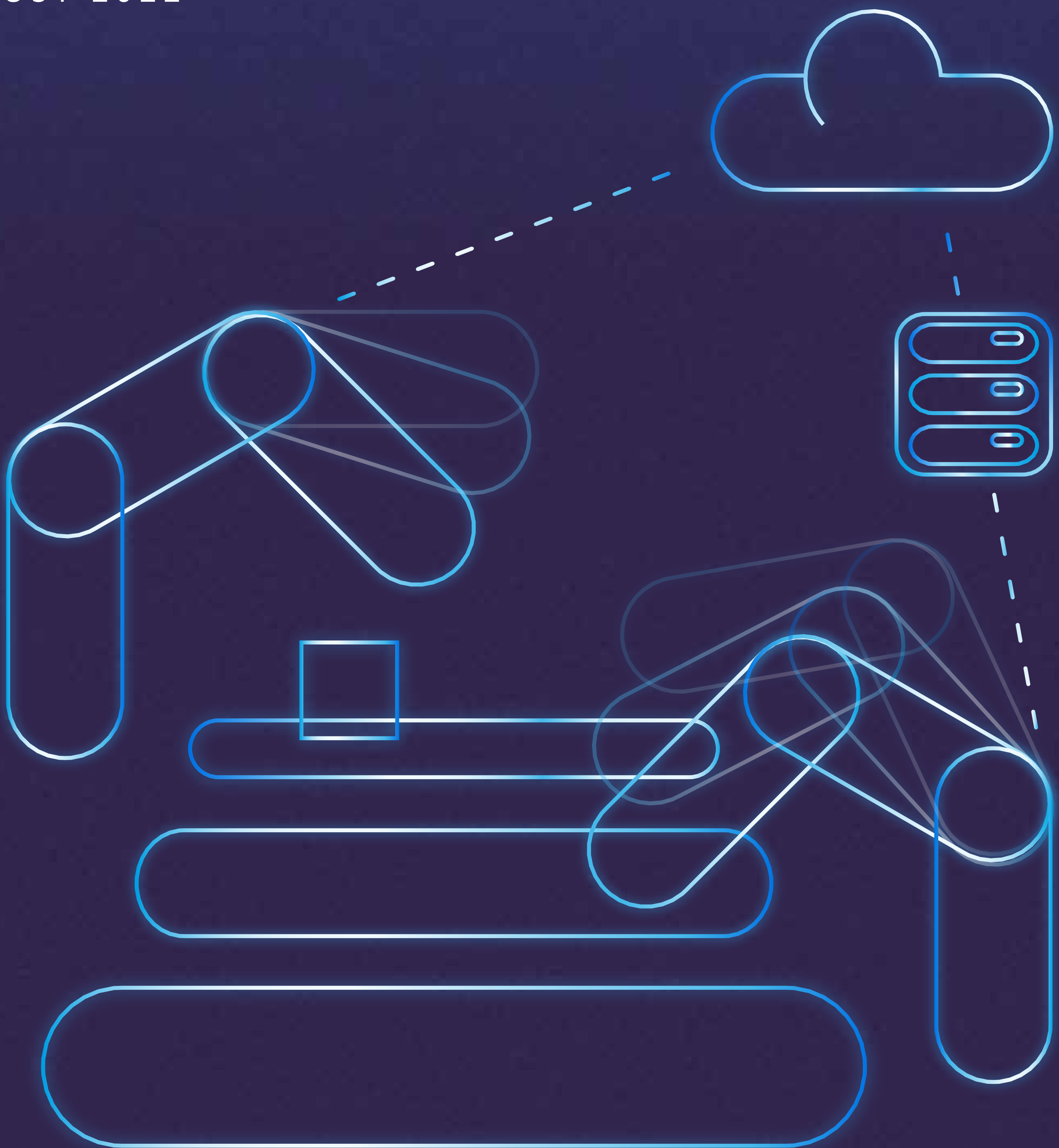
IoT Signals
Manufacturing Spotlight

AUGUST 2022



IoT Signals – Background

The Internet of Things (IoT) is rapidly changing the world around us by transforming a huge range of physical objects through digital intelligence. The transformative power of IoT is revolutionizing the way companies do business—helping them become faster, smarter, safer, and more efficient.

IoT Signals is a series of impactful thought leadership content curated by Microsoft to inform the community about the latest developments and technology trends in the IoT world.

The first report was published in 2019 and provided a broad understanding of IoT in diverse industries—such as manufacturing, energy, healthcare, and retail—through comprehensive survey-based research.

For this edition, Microsoft, Intel, and IoT Analytics have developed an IoT Signals report focused exclusively on manufacturing. IoT Analytics surveyed 500 decision makers working in discrete, hybrid, or process manufacturing and conducted in-depth interviews with a subset of them.

The goal of this IoT Signals report is to uncover fresh learnings and insights about the current and future state of IoT technology in manufacturing companies' plans for digital transformation. Specifically, we focus on manufacturing operations and smart products. We hope that the findings will help to propel the manufacturing industry toward faster and more effective adoption of these transformative technologies.

Why read this paper?

To succeed in today's dynamic world, manufacturers need to become more agile, resilient, and sustainable. As a result, companies invest in capabilities to make their products and operations smart, drawing upon concepts and technologies such as digital transformation, Industry 4.0, IoT, IT–OT convergence, artificial intelligence (AI), digital real estate, and driving a digital-first culture.

This paper presents insights from companies that have embarked upon their digital transformation journey. We explore the driving forces of digital transformation and companies' immediate plans and key challenges. We also delve into how companies see the roles of technology, process, and people in helping them accelerate their plans.

We draw upon selected interviews and survey data from 500 manufacturing professionals across the globe involved with IoT-based Smart Factory and Smart Product initiatives. Read this paper to understand what is behind the following key findings:

1. Manufacturers are accelerating their Smart Factory efforts post-COVID-19

Nearly three-quarters of the respondents (72%) have scaled from the proof-of-concept (PoC) stage and are in various stages of implementing their Smart Factory strategy. Their improvement ambition for the next three years is 66% higher than the level of improvement they have already achieved in the previous three years.

2. Operational improvement remains the biggest goal

Four out of five manufacturers consider overall equipment effectiveness (OEE) to be the most KPI to measure the success of their Smart Factory strategy. They expect the biggest improvements in the next three years to occur in cybersecurity, sustainability, and quality.

3.Investments are shifting to industrial automation based process control.

Quality control and condition-based maintenance have been the focus of most Smart Factory projects to date. The need for greater agility and modularity is leading manufacturers to shift their investment focus in the next three years toward industrial automation-based process control (e.g., investments into industrial gateways connected to the cloud and software-based PLCs). They plan to increase these investments by 29%.

4. Challenges to scaling Smart Factory initiatives are changing.

Manufacturers have overcome previous challenges related to getting data from assets and interfacing with cloud infrastructure. Today, half of the respondents face challenges in developing new software applications. Eight out of 10 of the respondents report having at least one very important skill gap, with the biggest relating to data science, AI, and cybersecurity.

5. IT–OT convergence is happening

With 76% of manufacturing assets now connected, many workloads, as well as applications, are moving away from on-premises infrastructure to public and private cloud deployments, especially the latter. Software-as-a-Service is becoming the dominant type of deployment. At the same time, IT tools such as containers are making their way onto edge hardware and into factories.

6. Strong investments in Smart Products are expected

Manufacturers not only optimize their own operations but also, in many cases, realize new revenue streams from smart connected IoT products sold to customers. Those that already sell Smart Products expect their share to increase from 33% today to 47% by 2025, with a heavy focus on value-added services such as remote support or predictive maintenance.

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Methodology

The centerpiece of this research is a 30-minute online survey conducted in April and May 2022. A total of 500 respondents from around the world participated. The respondents were end-users of IoT technologies and responsible for the digital transformation-related decisions in their work. They held mid-management to senior management positions in various process, hybrid, and discrete manufacturing industries. They were based in North America (40%), Europe (35%), or Asia-Pacific (25%). They work at a large corporation with more than 25,000 employees (28%), a medium-sized manufacturer with 5,000 to 25,000 employees (35%), or a smaller company with 500 to 5,000 employees (38%). We screened the respondents based on their knowledge of their employer's Smart Factory or Smart Product strategy.

IOT ANALYTICS

In addition to managing and analyzing the survey, the team at IoT Analytics, also conducted several in-depth follow-up expert interviews and drew upon proprietary Industry 4.0 research to enrich the data sets and this report with relevant quotes, examples, and case studies.

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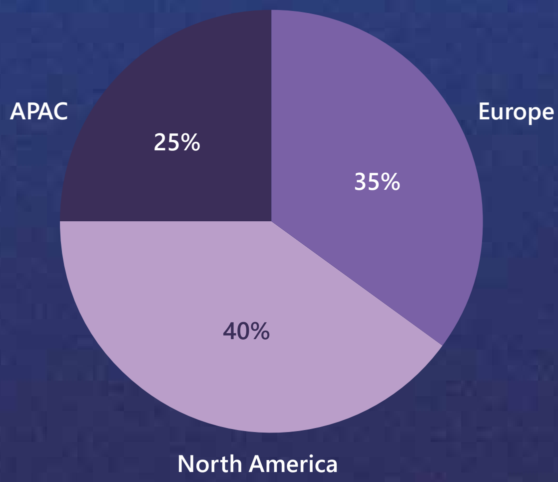
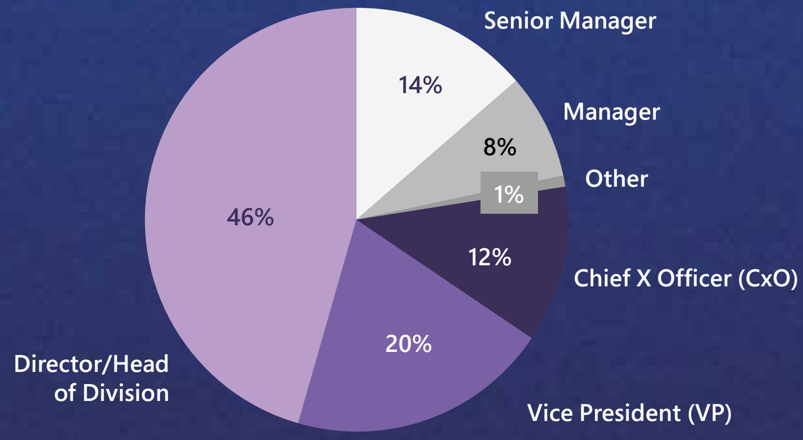
Overview of n=500 survey participants

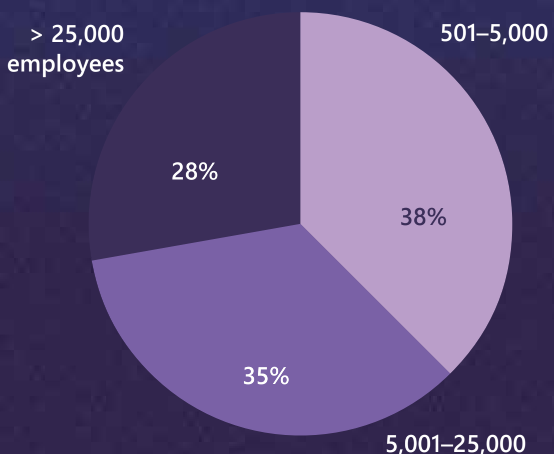
Location



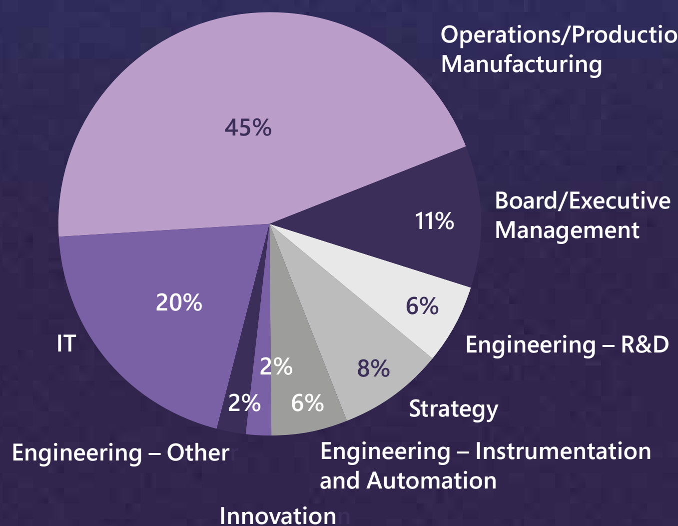
Seniority



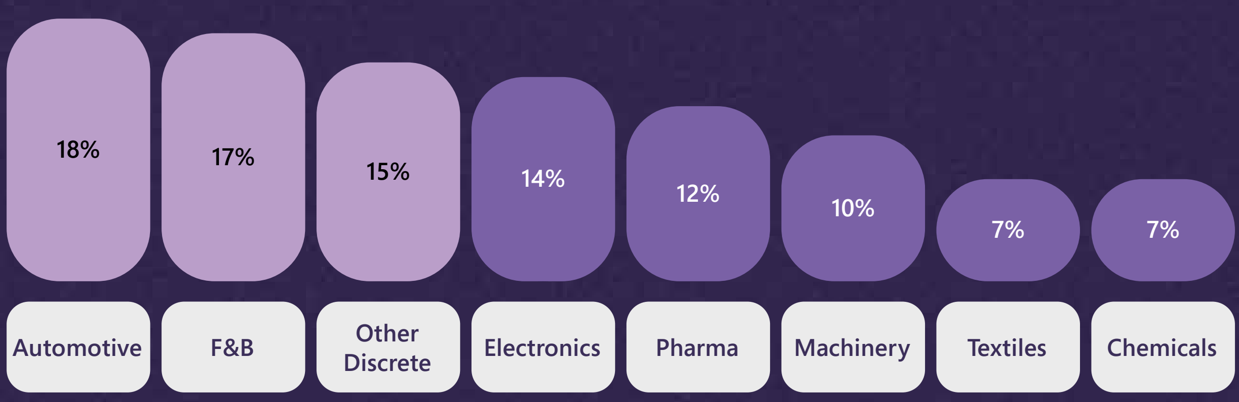
Size of the employer



Department



Industry of the employer



1. Introduction

The macroeconomic environment has been especially unpredictable and dynamic since the COVID-19 pandemic began in early 2020. New challenges are constantly leading to new obstacles that manufacturers must surmount. As a result, agility is no longer just nice to have, it has become necessary.

To succeed in this environment, manufacturers need a new paradigm for their operations: the Smart Factory. Here is a brief overview of the trends driving the need for change, how the Smart Factory helps manufacturers adapt, and the imperatives and challenges of implementation:

Manufacturers must respond to four major trends

Trends relating to consumer and company behavior are having a profound impact on manufacturing operations:

1. Customization.
Many consumers are no longer satisfied with mass-produced designs and products. For example, in response to fast-changing social media trends, consumers want products that meet their personal specifications—and they want these customized items delivered quickly.

2. Regionalization.
Globalization is reversing as trade tensions, geopolitical conflicts, and the COVID-19 pandemic have heightened the risks associated with complex supply chains. Where possible, companies want to source inputs and manufacture products close to their consumers.

3. Digital differentiation.
Traditionally, digital skills resided in a manufacturer's IT department. Various trends including remote work, rising labor costs, and the increasing use of shop-floor automation have elevated digital skills from supporting capabilities to a source of competitive advantage.

4. Sustainability.
For many consumers, climate change is now a reality. Motivated by extreme weather, organized activist movements, and government regulations and incentives, a growing number of consumers prefer to purchase climate-conscious products and brands with a low or decreasing carbon footprint. Sustainability also drives value from an operations perspective. For example, the recent surge in energy costs around the world is motivating organizations to invest in renewable energy.

How the Smart Factory helps manufacturers adapt

The Smart Factory helps manufacturers adapt to these trends. Agility and modularity make it easier to customize products, and supply chain resilience facilitates regionalization. A digital-first culture empowers workers, while sustainable operations help in achieving climate goals and other important targets relating to well-being or sustainable communities. Leading companies are already taking major steps toward realizing this technology-enabled vision:

- **Agility and modularity.** In a Smart Factory, winning companies use agile and modular setups to produce customized products rapidly and economically. This flexibility is essential for meeting consumer demand and producing at a smaller scale in regional facilities.

Example: A German manufacturer of electronic power transmission components transformed its lighthouse factory using automated guided vehicles, cobots, and digital twins. These technologies enable customer orders to navigate through the shop floor autonomously. The factory is designed for maximum agility and modularity—each order is customized and executed in a way that eliminates any waiting time between consecutive operations.

- **Supply chain resilience.**
  Winning companies are using advanced technologies to safeguard their supply chains from disruptions and to quickly respond when shocks occur.

Example: A US agricultural equipment manufacturer that relies on global sourcing has deployed a digitized supply chain platform. A visualization tool illustrates each supplier's components flow to various nodes and factories. The platform automatically notifies the appropriate commodity managers if disruptions appear likely. Even during the worst phases of COVID-19, the platform allowed the company to sustain production without major sourcing issues.

- **Digital empowerment.**
  To promote competitive advantage, winning companies foster a digital-first culture that empowers employees to design and use innovative technology applications.

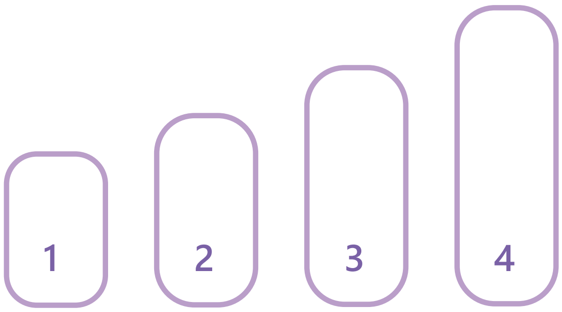
Example: A large European chemical company is rolling out a new corporate strategy that emphasizes using digital technologies in operations. The company encourages employees to use an agile, fail-fast methodology to determine which technologies work in operations at individual sites. It is investing heavily to train and empower agile teams. These efforts are generating a healthy pipeline of ideas focused on operational improvement. One facility demonstrated €5 million savings in recurring costs within a year.

- **Sustainable operations**
  Winning companies are taking innovative steps to credibly reduce their carbon foot print.

Example: A leading global pharmaceutical manufacturer sought to promote sustainable operations through energy conservation at a large European plant. The company created a multi-departmental sustainability team and engaged employees of all levels to propose ideas. Initially, smaller low-cost initiatives (such as turning off lights during breaks) educated workers on the potential for energy savings. These small ideas grew into a full-scale sustainability transformation. The plant now has two wind turbines, several solar cells, a cogeneration facility, and a water treatment plant. It obtains 35% of its energy from its own renewable sources and more than 56% of the waste produced is recycled or reused.

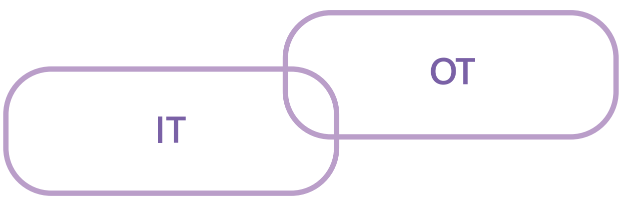
Three imperatives for digital transformation

To achieve these benefits of a Smart Factory, manufacturers need a digital transformation—the focus of this report. Manufacturers must follow three transformational imperatives (Exhibit 1.1)



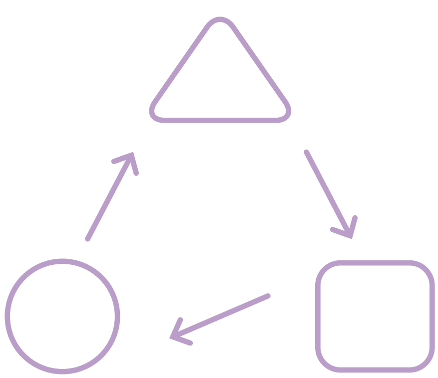
1. Adopt Industry 4.0.

In the past decade, we have seen the arrival of the fourth industrial revolution, also known as Industry 4.0. Manufacturers are using IoT technologies such as cloud, data analytics, and AI to continuously improve operations and products. The Smart Factory applies Industry 4.0 technologies to enhance manufacturing methods, while Smart Products incorporate internet-based and value-adding services. The Industry 4.0 concept is also referred to as the industrial IoT, smart manufacturing, and the connected factory, among other terms.



2. Integrate IT and OT.

Industrial setups have used operational technology (OT) for many decades, including programmable logic controllers (PLCs) and sensors. The heavy usage of IT systems—for example, ERP and MES—began in the 1990s. Today, advanced technologies (such as AI and cloud and edge computing) enable the convergence of OT and IT ecosystems in factories. To take advantage of information-driven factory dynamics, manufacturers must deploy enterprise architectures that integrate the best of both worlds. And the integration can go in each direction—for example, adopting IT-based software containerization approaches on the shop floor or virtualizing highly sophisticated OT or asset models in the IT world via digital twins.



3. Foster a digital-first culture.

In a digital-first culture, the entire organizational culture shifts from process-driven to data-driven. The key attributes are experimentation, cross-functional collaboration, automated information exchange, decentralized decision-making, and transparent communication at all levels. Teams and individuals prioritize achieving strategically focused goals over adhering to processes. A corporate structure with minimal hierarchy promotes agility and speed.

What are the challenges to scaling?

In taking these transformative steps, many manufacturers are encountering challenges. Our study found that the digital transformation of operations is well underway and 84% of the surveyed companies have developed a Smart Factory strategy. But the study also found that manufacturers face several challenges in scaling their initiatives:

1. Absence of data skills.
Companies' most significant capability gap relates to data skills, which lie at the heart of digitized manufacturing operations. Reskilling their workers is a major challenge. "We find it really tough to train the employees on these technologies, particularly building up digital twins," said a senior engineer of a large US machinery and equipment manufacturer.

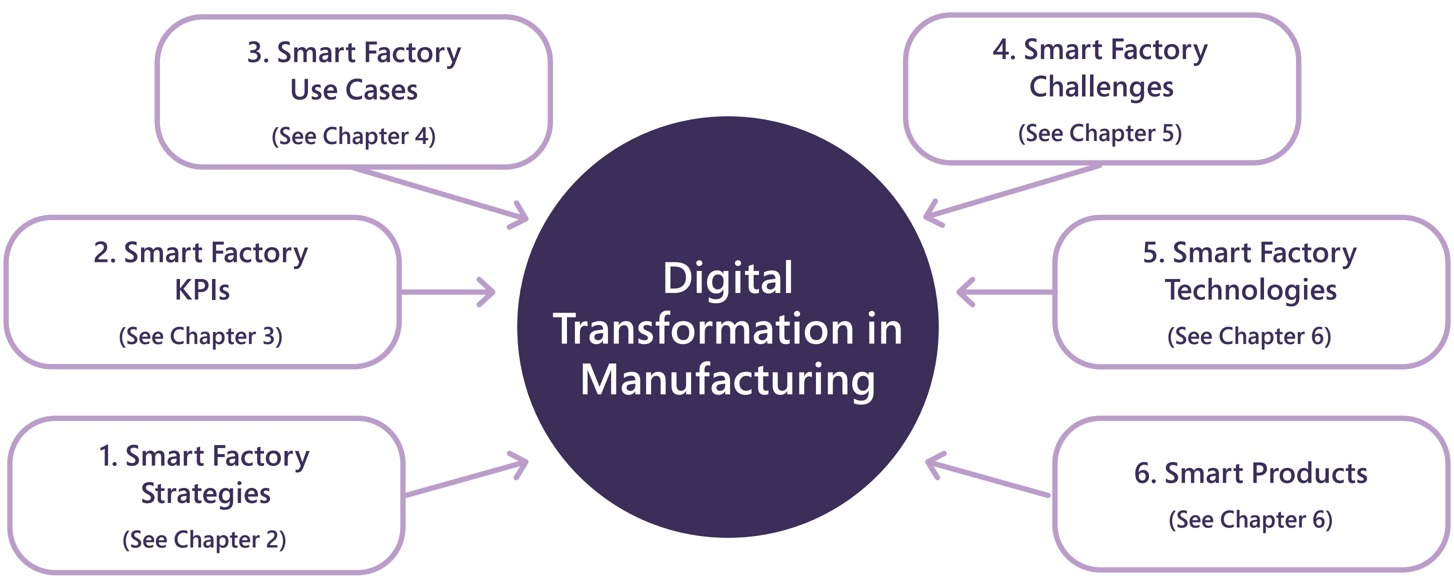
2. Incomplete IT—OT convergence.
Many companies have struggled to implement an enterprise architecture that integrates IT and OT. "Digital technology needs the right IT—OT enterprise architecture to perform as intended and maximize the benefits," explained the engineering director of a UK transportation equipment manufacturer.

3. Inadequate change management.
Transitioning to a digital-first culture is a complex process that requires support from all levels of the organization. Some companies have learned the hard way that change-management efforts are crucial. "A successful technology implementation requires ensuring that operators and engineers 'buy in' from the beginning of the project," said the engineering director of a UK transportation equipment manufacturer.

4. Difficulty developing applications.
As digital transformation initiatives mature—from collecting data to centrally storing and accessing it to actually using it—companies need new and much more interconnected applications. "The challenge for innovators now is adapting existing applications and developing new ones that allow them to use their data pools," explained Knud Lasse Lueth, CEO of IoT Analytics.

To help decisions makers understand these challenges, our study used real-world feedback to analyze six key components of digital transformation in manufacturing (Exhibit 1.2). In the following chapters, we present the study's findings to provide a comprehensive perspective on current deployments of the Smart Factory and an outlook on what to expect in the future.

Exhibit 1.2: Six key components of digital transformation in manufacturing



2. The state of digital transformation in manufacturing

Manufacturers are doubling down on digital transformation post-COVID-19 and plan to continue these initiatives in the coming years.

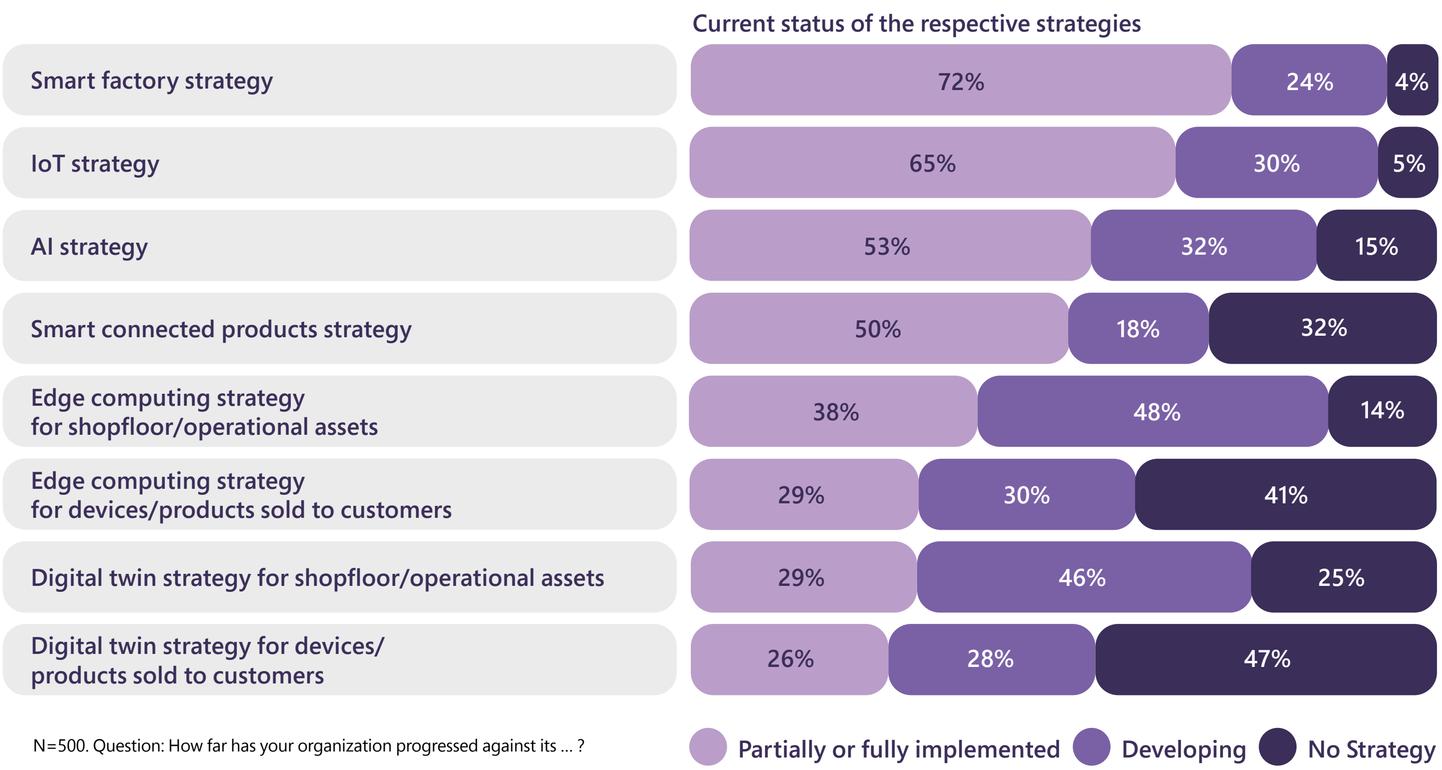
To combat uncertainties and sustain their businesses, manufacturers have launched various digital transformation initiatives including the Smart Factory, IoT, edge computing, digital twin, and smart products. We asked survey respondents about the current state of these initiatives to better understand the real-world direction and strategic prioritization of their efforts. Here's what we found:

Implementation is underway

Most respondents have advanced their Smart Factory and IoT strategies beyond the PoC stage (Exhibit 2.1). Nearly three-quarters (72%) are in various stages of implementing their Smart Factory strategy. Similarly, nearly two-thirds (65%) are in various stages of implementing their IoT strategy. Most of these companies have a dedicated Smart Factory roadmap that follows a holistic vision and includes key investments into new hardware and software technologies and change management for the entire organization.

> **Example: Launching a Smart Factory strategy**
> In 2016, a large German automotive supplier developed a "Production 2030" vision that prioritizes nine topics including advanced robotics, AI, and sustainable production. The key goal is to make manufacturing more modular, flexible, and digitized. In early 2022, of the 70 factories in the network, four pilot factories had adopted the holistic digital vision with an execution plan for the next five years. Six more factories are expected to follow in 2022.

Exhibit 2.1: Progress of key transformation strategies – Companies are most advanced in their smart factory and IoT strategies.



N=500. Question: How far has your organization progressed against its … ?

AI, edge computing, and digital twins and gaining traction

Many respondents recognize the importance of AI and have made progress in developing their strategies. 53% of companies have partially or fully implemented their AI strategy. Companies are also focused on imple-ment-ing edge computing strategies for their factory assets and smart connected products. 38% have fully or partially implemented an edge computing strategy for their factory, while 29% have done so for their products. Digital twin adoption is not as widespread. Respondents are giving almost equal attention to implementing dig-ital twin strategies for their factory assets (29%) and products (26%).

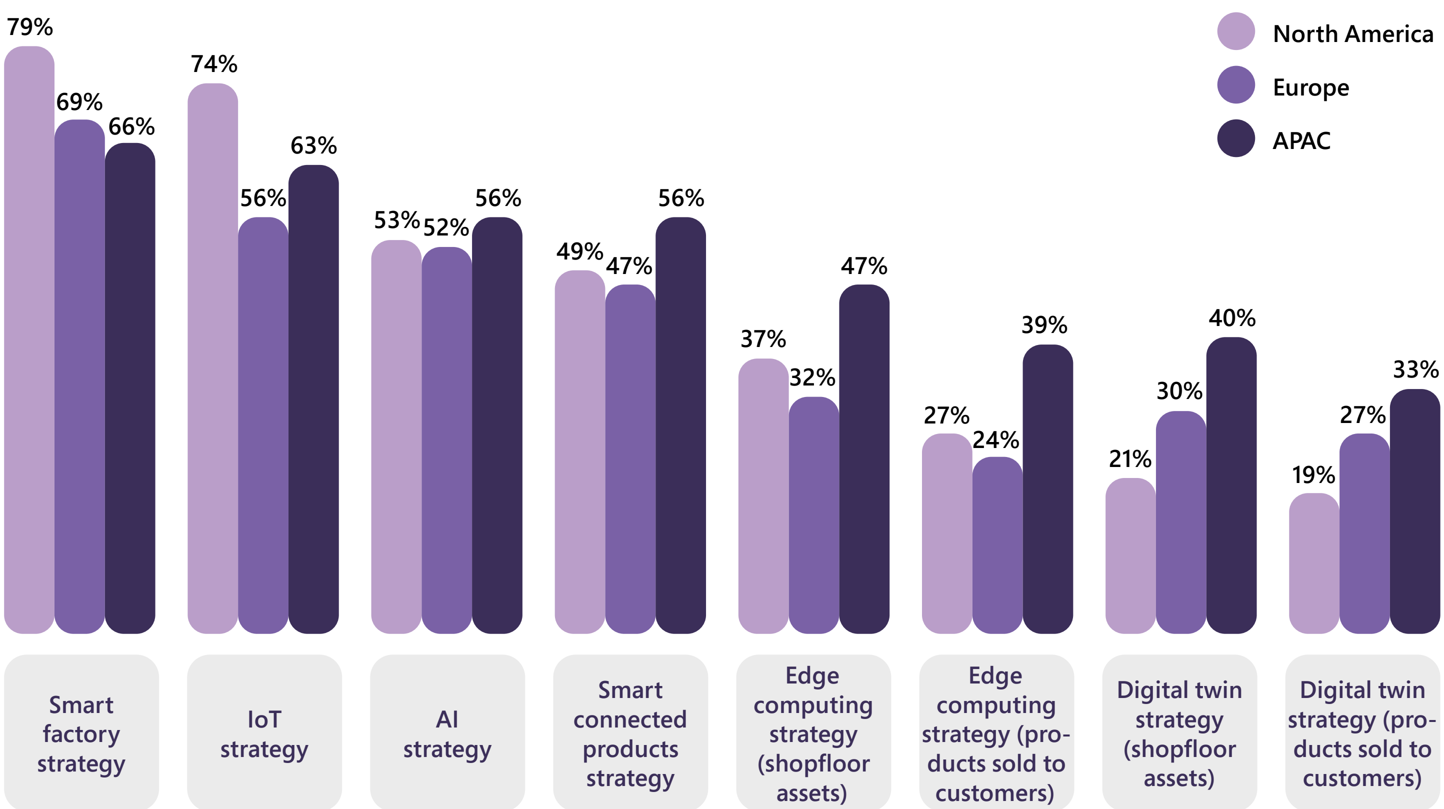
North American manufacturers are the frontrunners

Among respondents in North America, 80% have imple-mented or are implementing a Smart Factory strategy, versus 70% in Europe and 66% in Asia-Pacific (Exhibit 2.2).

Practitioner's perspective: The transformative power of IoT and AI

The digital director at a European machinery company emphasized the transformative power of IoT and AI: "IoT is changing the way we do business. We expect that in a few years we would not need to travel to a customer to do a commission or provide software maintenance on the machine. We are investing in AI and ML, so we can predict machine failures. In general, we are putting much more focus on software development."

Exhibit 2.2: Progress of key transformation strategies by region – Smart factory strategy progress most advanced in North America



N=500. Question: How far has your organization progressed against its ... ?

Smart Factory decision-making is mostly centralized

Respondents indicated that decision-making authority for Smart Factory topics mainly resides with the corporate center, including the selection of software used organization-wide and on the shop floor (Exhibit 2.3). Approximately one-third (35%) said decisions regarding which IoT use cases to deploy are taken by the central IT function, while approximately one-quarter (27%) say that the central OT function is responsible. OT corporate centers are highly involved only in decisions related to OT security (44%), OT data tools (48%), and OT infrastructures, such as PLCs and DCS (43%). CxOs and HR mainly take decisions on change management (CxOs are highest at 31%) and workforce upskilling decisions (HR is highest at 47%).

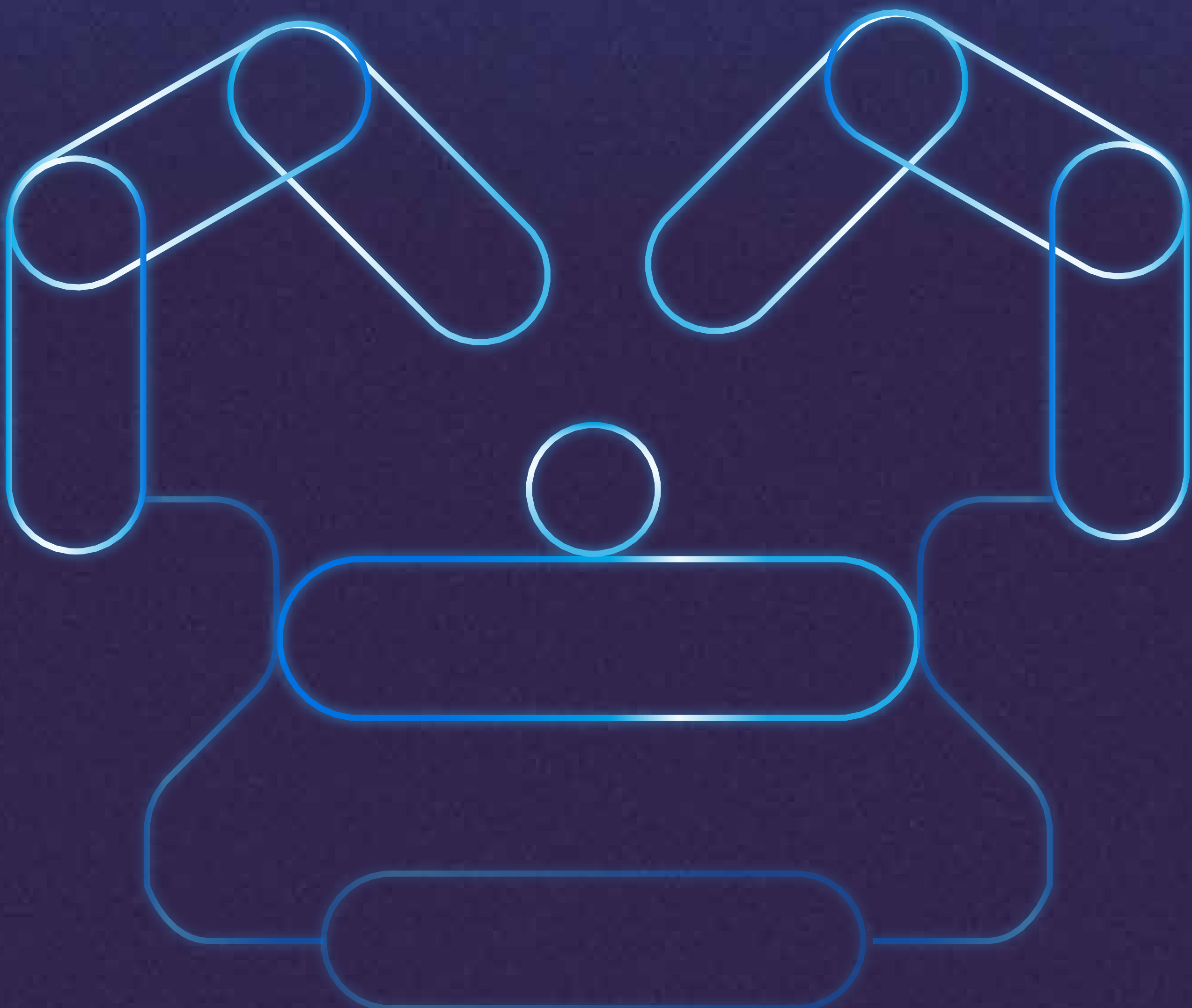


Exhibit 2.3 Smart factory decision-making: Centralized decision-making dominates

	Decision-makers / Type of decisions	Corporate Center							Decentral in factories			Others
		IT	OT	CxO	Strategy	R&D	HR	Other	Factory head	IT	OT	Other
Mainly IT decisions	IT infrastructure (e.g., servers, cloud)	67%	6%	18%	3%	1%	0%	0%	1%	3%	0%	0%
	IoT platform or related software	54%	15%	20%	2%	0%	1%	1%	4%	2%	1%	0%
	Build vs. buy decision for factory software	38%	21%	21%	6%	2%	3%	2%	4%	2%	0%	0%
	MOM/MES software	36%	20%	17%	4%	5%	2%	1%	6%	5%	3%	2%
	IoT use cases to prioritize	35%	27%	15%	6%	1%	3%	1%	7%	2%	1%	2%
	Hardware and software for connected machinery/assets/products sold to customers	34%	28%	16%	7%	4%	3%	1%	2%	2%	1%	1%
	Tools/applications to handle and manage factory data globally	32%	21%	22%	6%	4%	4%	2%	6%	1%	2%	1%
Mainly OT decisions	OT security software/services	34%	45%	12%	3%	0%	1%	0%	2%	1%	2%	0%
	OT* infrastructure (e.g., PLCs, I/O, DCS)	24%	43%	14%	2%	1%	3%	1%	4%	2%	5%	1%
	Tools/applications to get data out of the machines/OT infrastructure	22%	48%	12%	4%	1%	2%	1%	4%	2%	4%	1%
Other	Data historians	29%	19%	15%	5%	11%	4%	3%	9%	2%	3%	1%
	Driving the required change management in the factories	12%	18%	31%	19%	2%	3%	2%	7%	2%	1%	2%
	Reskilling/upskilling/enabling the workforce in the factories	12%	16%	6%	5%	1%	47%	2%	8%	2%	0%	2%

*OT = operational technology. N=500. Question: Who and where is the final decision-maker for the following crucial IoT/smart factory decisions in your organization?

X% = Share of final decision-making authority

Practitioner's perspective: The importance of targeting the right technologies

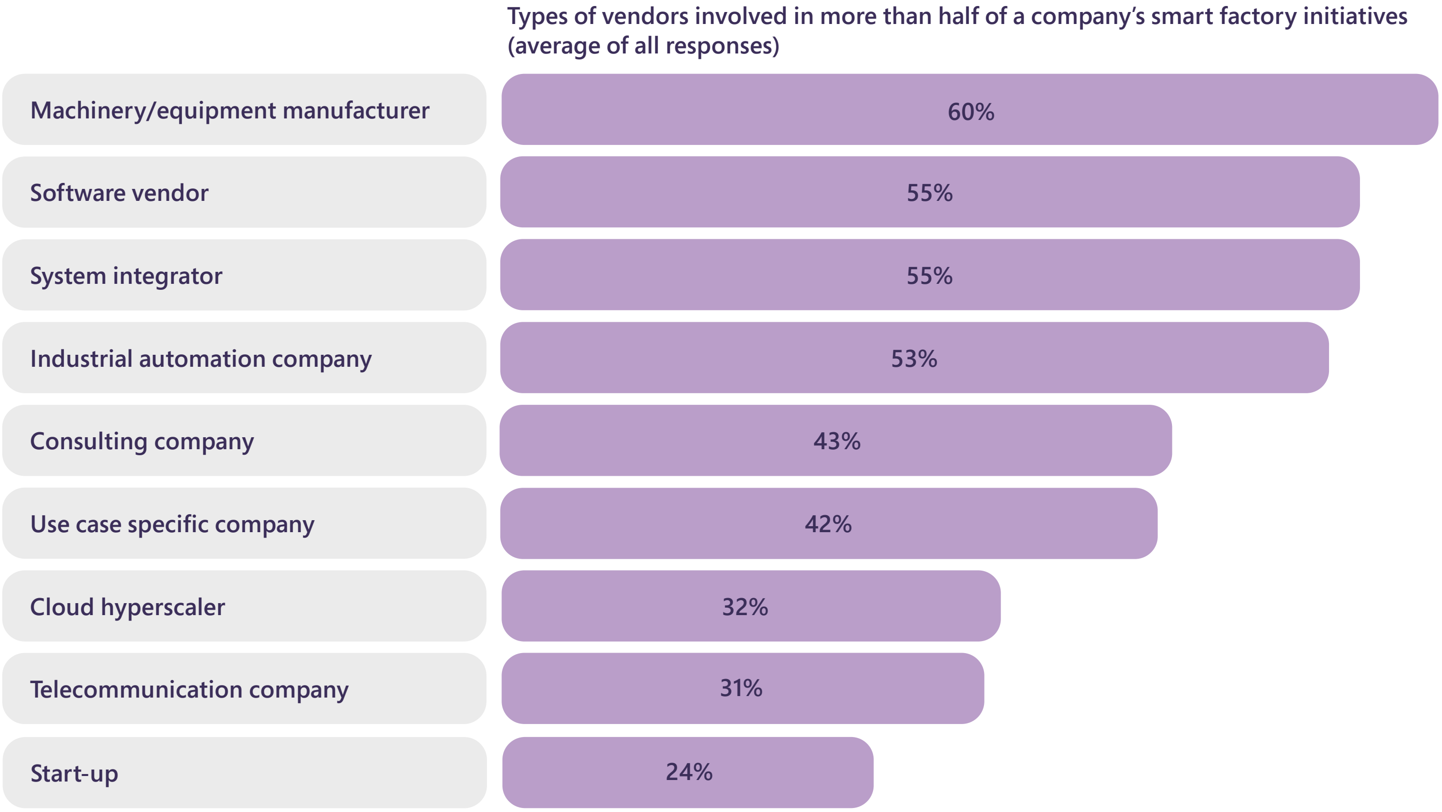
The former VP of manufacturing at a global automotive manufacturing company stressed the importance of targeting technology investments to address the most important operational pain points: "Some of these new technologies are great, but I've found that it's wrong to overwhelm the factory with too many of them. Our biggest successes have been using technology in a very targeted way to reduce waste in the manufacturing process. For example, relatively low-cost RFID technology allowed us to reduce our material handling costs in one plant by 50% because there had been tremendous waste in that process. The key is to have a good understanding of the available tools and surgically install them in a brownfield site whenever they are very applicable."

Machinery and equipment manufacturers play a crucial role

As manufacturers work on these new digital transformation initiatives, they look for external support. However, not all types of external vendors have the same importance. When asked which vendors they involve in the Smart Factory, 60% of respondents chose machinery and equipment vendors.

The next three most important vendors were system integrators (55%), software vendors (55%), and industrial automation companies (53%). Respondents said that a much smaller role is played by use-case-specific companies, telecommunication vendors, cloud hyperscalers, and start-ups. Indeed, only 24% said that start-ups were involved more than half of the time (Exhibit 2.4).

Exhibit 2.4: Companies look to OEMs for smart factory support most often



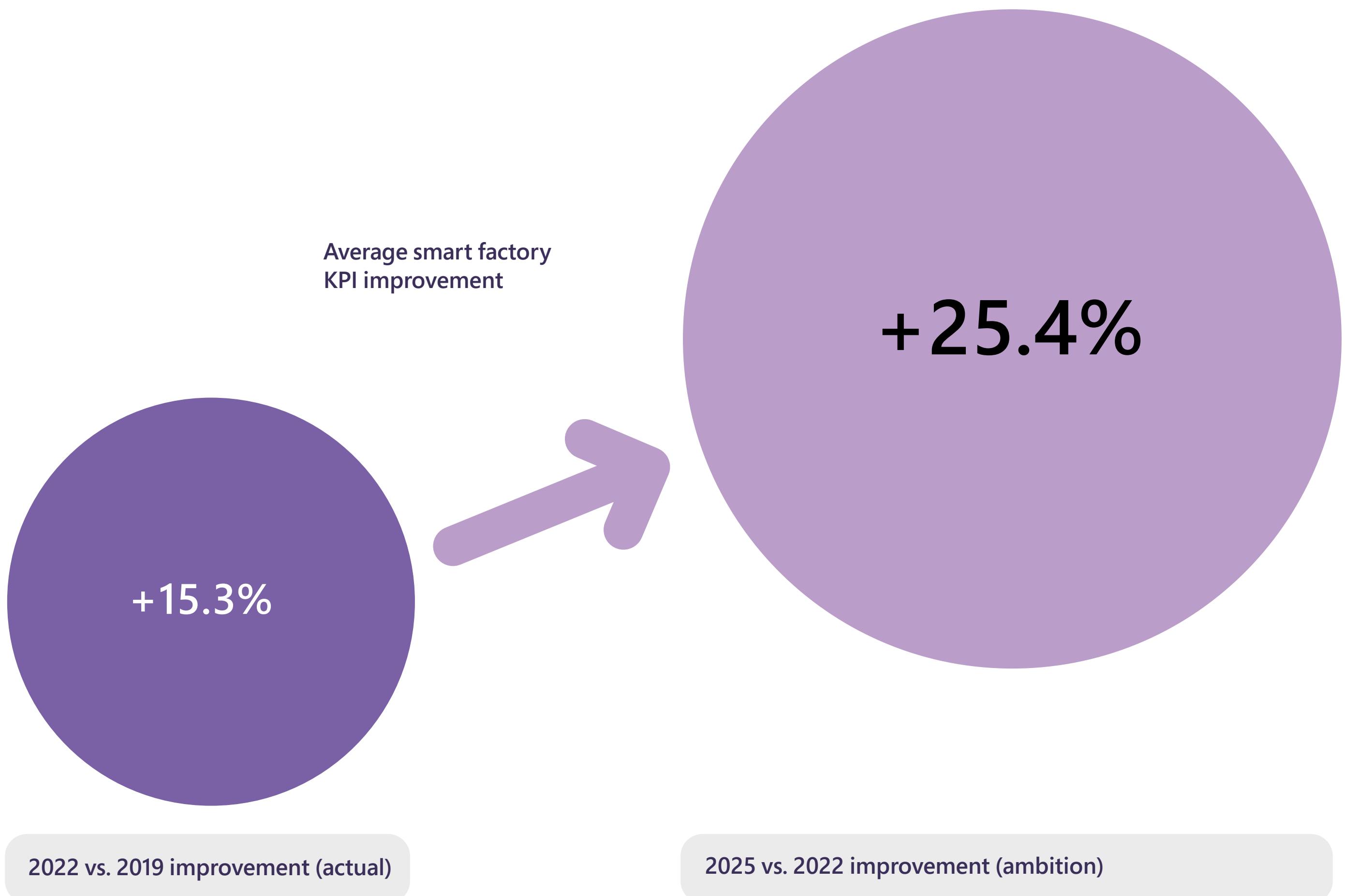
N=404. Question: Looking at your smart factory/industry 4.0 projects, how often are each of these types of vendors involved?

Near-term ambitions are 66% higher than in previous years

Manufacturers are ambitious about putting AI, edge computing, digital twins, and other Smart Factory technologies to work as part of their transformations (Exhibit 2.5). As per the survey, factory KPIs improved by 15.3% in the last three years. But respondents' ambition for KPI improvement for the next three years (until 2025) is 66% higher (25.4%). This points to the likelihood of seeing accelerated efforts to deploy Smart Factories in the immediate future.

Exhibit 2.5: Manufacturers are accelerating their smart factory efforts post COVID-19

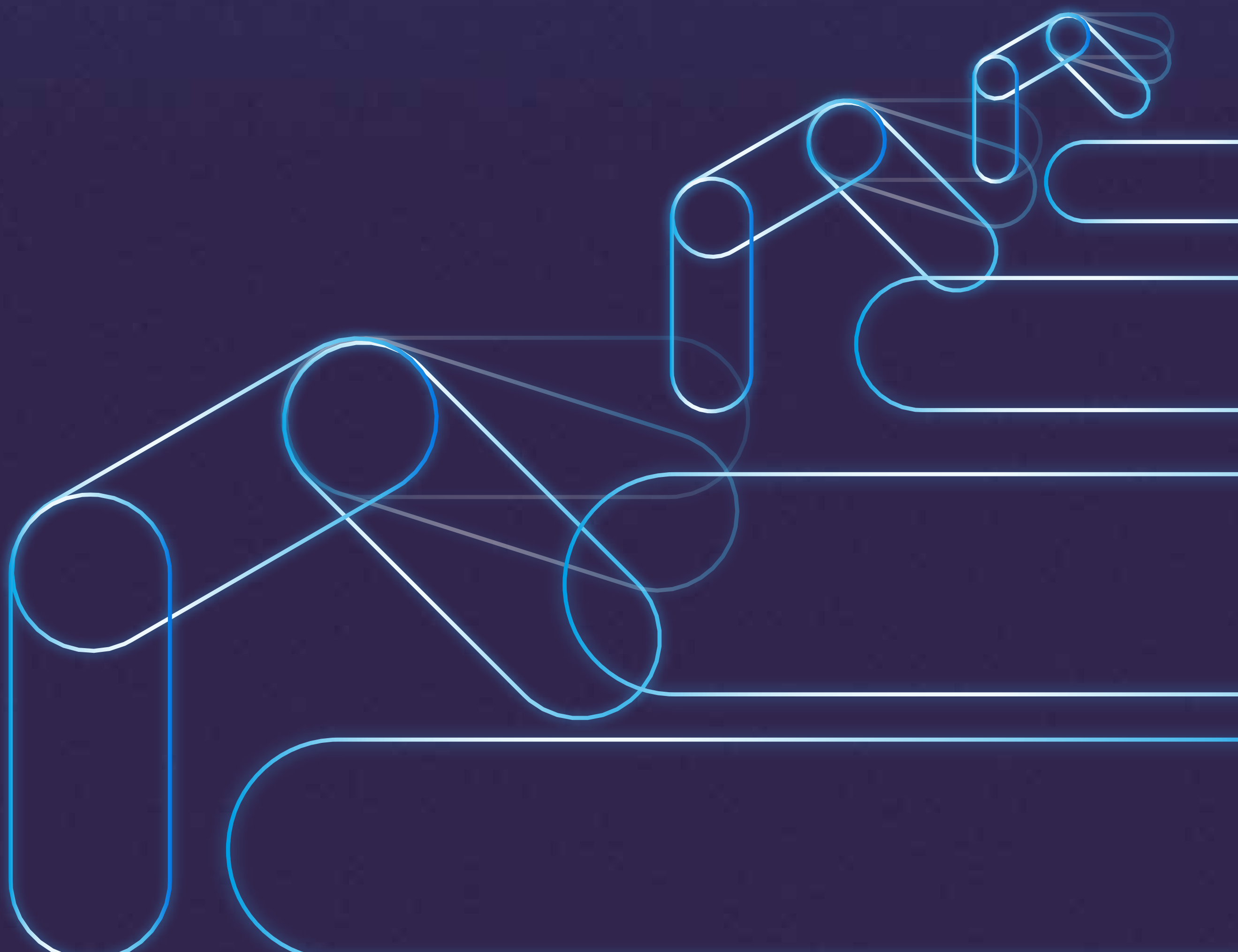
How much have your KPIs improved since 2019 due to your current smart factory/IoT strategy?
How much improvement are you planning prior to 2025 (the next 3 years)?



PP = percentage points.
N=500. Question: Thinking about your smart factory strategy, which of the following KPIs are most important for measuring its success?

In their push to deploy Smart Factories, which KPIs are manufacturers using to measure success? The next chapter delves into the details behind these numbers.

3. KPIs used to measure Smart Factory success



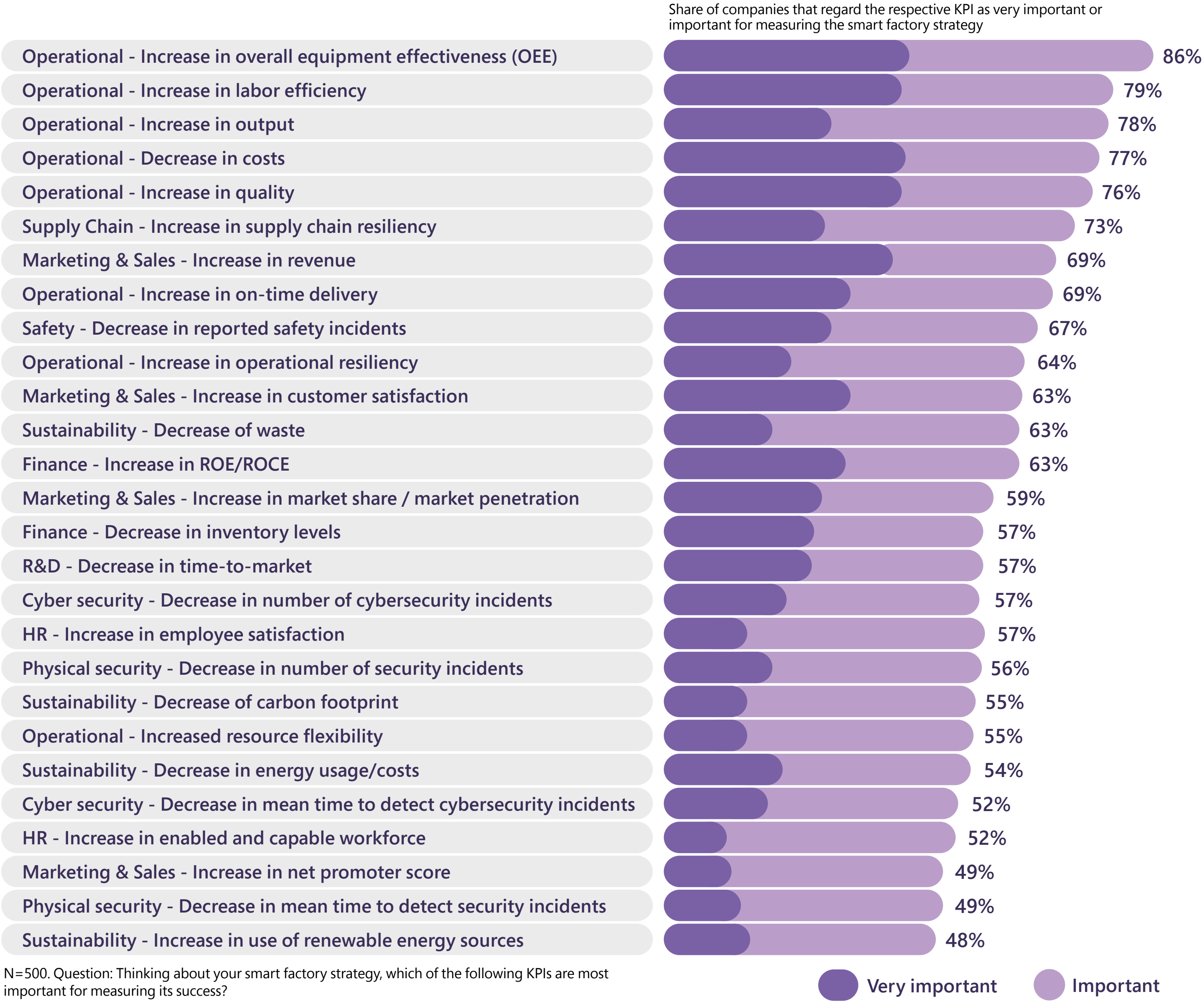
Operational improvement tops workforce enablement and sustainability as the leading KPI for measuring the success of a Smart Factory strategy.

Companies gauge the success of their Smart Factory strategy by measuring KPIs across multiple areas. Our survey asked respondents to rate their preferences for measuring their success among 27 Smart Factory KPIs. Respondents' preferences provide a window into understanding the types of value that manufacturers seek to create when implementing a Smart Factory.

Operational goals are the top KPI

Across all regions and industries, respondents are highly focused on improving operational performance, including OEE, labor efficiency, and output. 86% consider OEE to be the most important KPI for measuring a Smart Factory's success (Exhibit 3.1).

Exhibit 3.1: Operational improvement is the biggest goal for manufacturers



N=500. Question: Thinking about your smart factory strategy, which of the following KPIs are most important for measuring its success?

What explains the different prioritization of KPIs among manufacturers?

Our previous research found that a Smart Factory's production characteristics are largely responsible. The realization of a Smart Factory concept in a high-variety, high-volume discrete manufacturing automotive plant will be very different from that of a low-variety, high-volume process-based oil refinery. While the automotive plant may focus more on goals such as increasing output and product quality, the oil refinery may prioritize improving worker safety and reducing energy usage. Incentives and regulations may also play a role. For example, respondents' low prioritization of increasing renewable energy sources—only 48% consider it to be an important or very important KPI—may reflect the fact that Renewable Energy Credits in some markets foster credits for purchasing rather than on-site generation.

Cybersecurity incidents and waste reduction have the biggest improvement potential

Given manufacturers' ambitious targets for the next three years, some of the least-prioritized KPIs to date are expected to see the highest improvement (Exhibit 3.2). On average, during the next three years, respondents plan to reduce cybersecurity incidents at the organizational level by 33% and decrease waste by 32%. Other KPIs with the highest potential include safety incidents (30% decrease), energy usage (30% decrease), and mean time to detect cybersecurity incidents (30% decrease).

Exhibit 3.2: Manufacturers accelerate improvement of sustainability KPIs

KPI Type	KPI	Ambition ('22-'25)		Increase in ambition	
Operational	Increase in overall equipment effectiveness (OEE)	28%	★★★	10%	↑↑↑
	Increased resource flexibility	27%	★★★	10%	↑↑↑
	Increase in labor efficiency	27%	★★★	9%	↑↑
	Increase in quality	27%	★★★	13%	↑↑↑↑
	Increase in on-time delivery	26%	★★	11%	↑↑↑↑
	Increase in output	26%	★★	10%	↑↑
	Increase in operational resiliency	26%	★★	10%	↑↑↑
	Decrease in costs	23%	★	9%	↑
Sustainability	Decrease of waste	32%	★★★★	13%	↑↑↑↑
	Decrease in energy usage/costs	30%	★★★★	7%	↑
	Decrease of carbon footprint	28%	★★★	14%	↑↑↑↑
	Increase in use of renewable energy sources	26%	★★	11%	↑↑↑
Marketing & Sales	Increase in customer satisfaction	29%	★★★★	13%	↑↑↑↑
	Increase in revenue	25%	★★	10%	↑↑↑
	Increase in net promoter score	23%	★	9%	↑↑
	Increase in market share / market penetration	20%	★	10%	↑↑
Cybersecurity	Decrease in number of cybersecurity incidents	33%	★★★★	10%	↑↑↑
	Decrease in mean time to detect cybersecurity incidents	30%	★★★★	7%	↑
Physical security	Decrease in number of security incidents	31%	★★★★	9%	↑↑
	Decrease in mean time to detect security incidents	27%	★★★	8%	↑
Finance	Decrease in inventory levels	26%	★★	11%	↑↑↑
	Increase in ROE/ROCE	23%	★	9%	↑↑
HR	Increase in enabled and capable workforce	21%	★	9%	↑↑
	Increase in employee satisfaction	24%	★	8%	↑
Safety	Decrease in reported safety incidents	30%	★★★★	11%	↑↑↑↑
Supply Chain	Increase in supply chain resiliency	28%	★★★	12%	↑↑↑↑
R&D	Decrease in time-to-market	25%	★★	8%	↑

Ambition (based on % of KPI improvement planned):

★: <25% ★★: 25% - 27% ★★★: 27% -29% ★★★★: >=29%

Increase in ambition (based on difference last 3y vs. next 3y):

↑: <+9% ↑↑: +9% - +10% ↑↑↑: +10% - +11% ↑↑↑↑: >=+11%

Ambition
Improvement (in percentage) of KPI planned from now (2022) to 2025 (next 3 years).

Increase in ambition
Difference (in percentage points) between "Ambition" (next 3 years) and the actual improvement 2019 – 2022 (last 3 years)

N=500. Question: How much have the following KPIs improved due to your current smart factory/IoT strategy since 2019 (last 3 years)? How much improvement do you plan prior to 2025 (next 3 years)?
Note: "Improvement achieved since 2019" (e.g., if you decreased costs from $100 million to $50 million, consider it a 50% improvement; if you increased your OEE from 50% to 60% consider it a 20% improvement and not 10 percentage points improvement).

Microsoft intel.

Ambitions to reduce carbon footprints have accelerated significantly

The ambition gap—between improvements achieved in the past three years and ambitions for improvements in the next three years—provides insights into which KPIs are likely to see the fastest near-term acceleration. We found the highest ambition gap, and thus the likelihood of the fastest acceleration, with carbon footprint reduction, increase in customer satisfaction, and quality KPIs (Exhibit 3.2). The gap and outlook for acceleration were lowest for energy cost reduction. This reflects that rising energy costs worldwide have caused respondents to lower their targets for decreasing these expenses.

Many companies are not gauging workforce enablement

Paradoxically, while many respondents cite a skilled and trained workforce as the most important success factor for smart manufacturing, only about half of the respondents (52%) consider an enabled and capable workforce to be an important KPI for measuring a Smart Factory's success. Moreover, many manufacturers have below-average goals for improvement set for the next three years (compared to other KPIs).

Companies that do not enable their workers to adapt to smart manufacturing are likely to find that an untrained and uneducated workforce is the biggest impediment to success. Without the right training, people cannot use technologies properly and ideate user-centric solutions. Moreover, people's enthusiasm for adoption stays low.

Practitioner's perspective: Workforce enablement matters

A VP at a UK machinery and equipment company explained the importance of complementing technology with a well-trained workforce: "Training, training, training. It is difficult to simply deploy Smart Factory technologies. One needs to spend a lot of time understanding the use cases and training end-users (external and internal) on how to use the technology effectively. It's as much about communication and culture (behavior) as technology. It cannot be mentioned enough how important it is for leadership to identify the advantages of the new technologies and explain how they help the people who will be deploying and adopting."

Sustainability KPIs are gaining importance

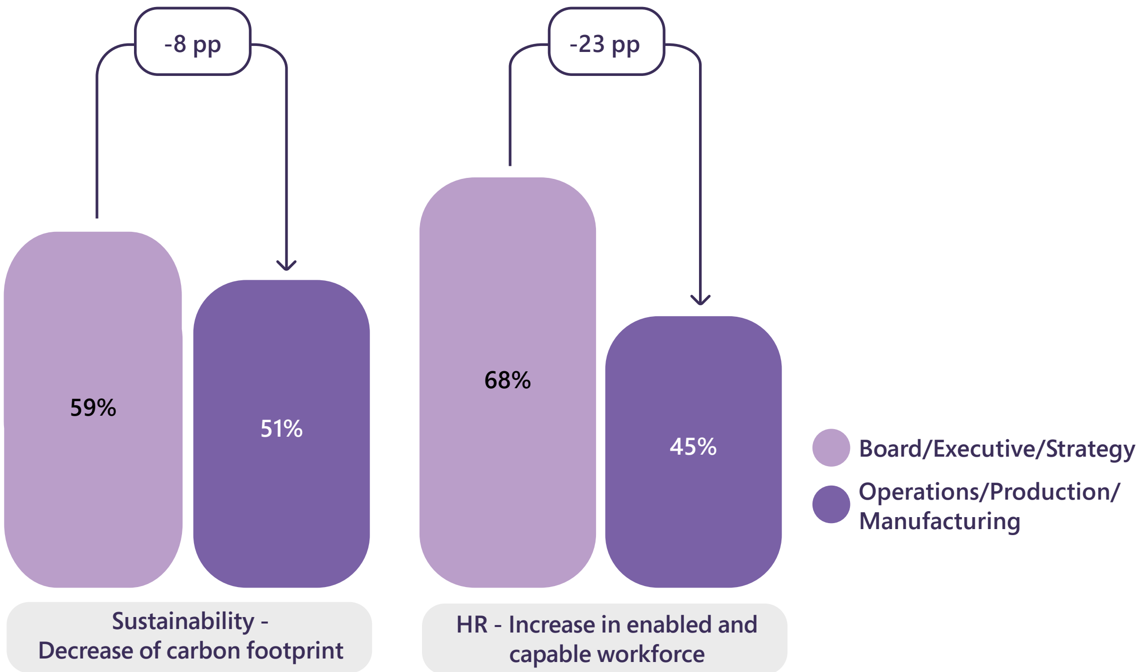
Although sustainability improvements are not the main driver of Smart Factory strategies, manufacturers are devoting more attention to the topic and often see it as complementary to the existing operational KPIs. Respondents ranked "decrease in waste" as the KPI with the second-highest overall ambition and "carbon footprint reduction" as the fastest-accelerating KPI (Exhibit 3.2). This indicates that respondents recognize the opportunity for tangible improvements and are likely to boost the importance of sustainability KPIs in the coming years. Moreover, improving a sustainability KPI often correlates with improving an operational KPI and vice versa. For example, a reduction in energy usage or waste may lead to a reduction in costs, while an increase in process efficiency may lead to lower energy use and a better carbon footprint. Sustainability KPIs have greater importance today in the board room than on the shop floor, as we discuss next.

Corporate boards and on-site operations leaders have slightly different priorities

We found greater interest at the executive, board, and corporate stakeholder levels for several topics, including considering sustainability and enabling a capable workforce in a Smart Factory strategy (Exhibit 3.3). For example, 59% of board members participating in the survey believe that "decrease of carbon footprint" is an important KPI, versus 51% from operations. 68% of board members place high importance on an "enabled and capable workforce," compared to 45% of respondents from operations. In the near future, these topics will likely be managed more from the top down rather than primarily initiated from operations or factory levels.

Exhibit 3.3: Board members give greater emphasis to sustainability and enablement KPIs

Share of respondents that see the respective KPI as important or very important for measuring smart factory success (by job role of respondent)



PP = percentage points.
N=309. Question: Thinking about your smart factory strategy, which of the following KPIs are most important for measuring its success?

Practitioner's perspective: The difficulties in measuring sustainability on the shop floor

A former VP of manufacturing at a global automotive manufacturing company cited visibility of impact to explain why sustainability KPIs are perceived as less important on the shop floor: "Workers can clearly see the cost and performance impact of the day-to-day deliverable metrics on the shop floor. They can see the output immediately. But sustainability KPIs are much more difficult to measure and visualize, which makes it hard for someone on the shop floor to understand their importance. In my view, manufacturers need to make sustainability part of their corporate values so people can understand the importance for themselves and the organization."

To achieve their ambitious KPI targets, manufacturers need to prioritize the right use cases and allocate budgets accordingly. Next, we discuss which use cases they are prioritizing.

4. Prioritized use cases

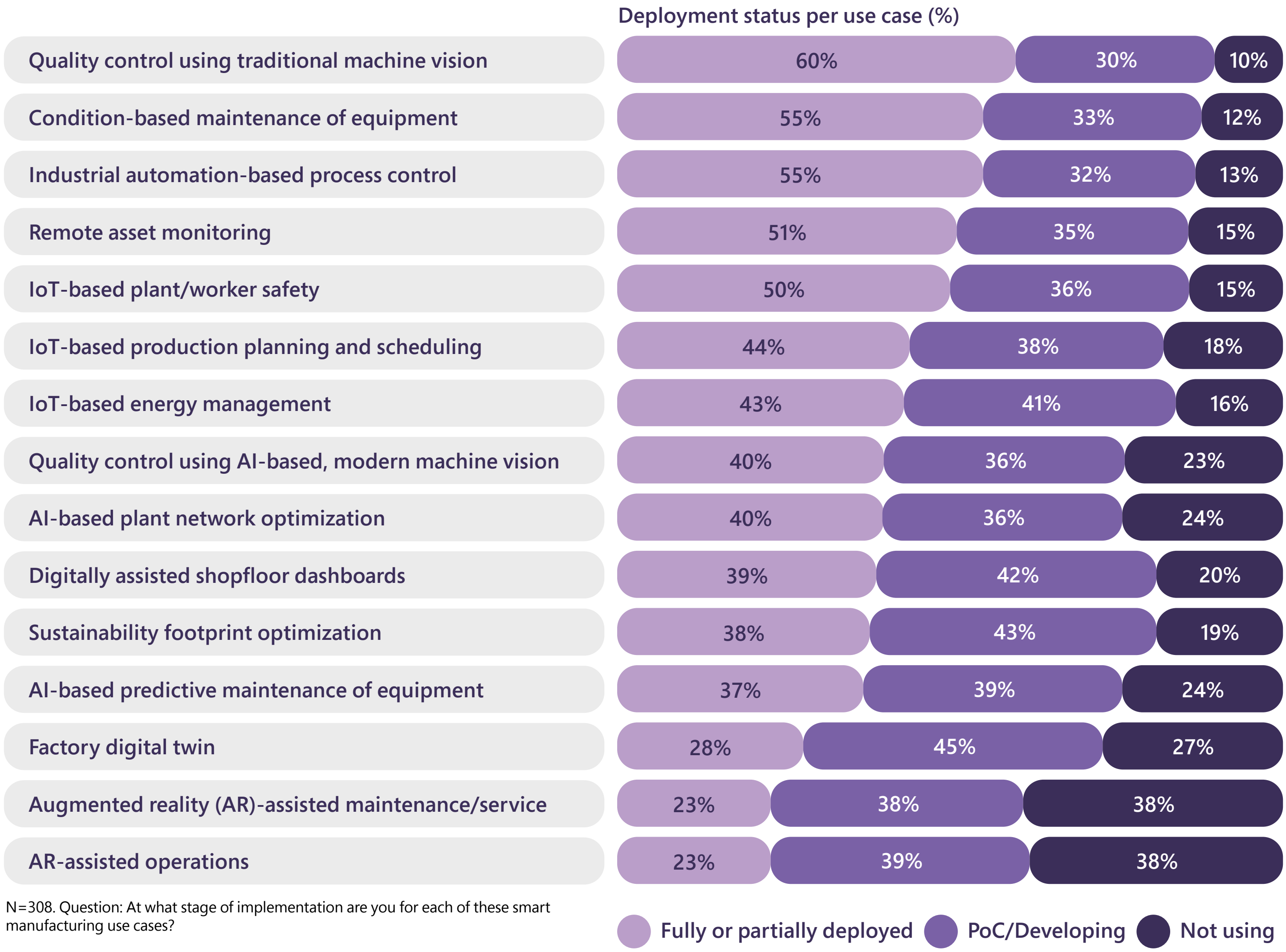
In implementing the Smart Factory, manufacturers are initially focusing on use cases relating to quality control, process control, and asset monitoring.

First movers have already deployed several Smart Factory use cases. Their priorities shed light on what has worked in the Smart Factory to date and point to the most valuable use cases going forward.

The top four use cases today

Respondents indicated that the leading use cases in terms of partial or full deployment are quality control systems using traditional machine vision (60%), industrial automation-based process control systems (55%), a condition monitoring system (55%), and a remote asset monitoring solution (51%) (Exhibit 4.1).

Exhibit 4.1: Quality, condition-based maintenance and industrial automation are the top smart manufacturing use cases today



N=308. Question: At what stage of implementation are you for each of these smart manufacturing use cases?

The priorities for the next three years

In the next three years, respondents said they plan to increase investment by 29% for industrial automation-based process control, by 28% for condition-based equipment maintenance, by 27% for both IoT-based plant worker safety and energy management, and by 26% for AI-based quality control and sustainability (Exhibit 4.2).

These findings suggest that manufacturers around the world are realizing tangible benefits from their initial use case deployments and thus willing to boost their investments and efforts to implement the Smart Factory.

Exhibit 4.2: Industrial automation expected to top investments in next 3 years

	Average planned investment in the next 3 years per smart manufacturing use case (in percentage compared to today)
Industrial automation based process control	+29%
Condition-based maintenance of equipment	+28%
IoT-based plant / worker safety	+27%
IoT-based energy management	+27%
IoT-based production planning and scheduling	+27%
Quality control using AI-based, modern machine-vision	+26%
Sustainability footprint optimization	+26%
Factory digital twin	+26%
AI-based predictive maintenance of equipment	+26%
AI-based plant network optimization	+25%
Digitally assisted shopfloor dashboards	+24%
Quality control using traditional machine-vision	+24%
Remote asset monitoring	+24%
AR-assisted operations	+23%
AR-assisted maintenance/service	+22%

N=260. Question: How much is your organization planning to invest in each of these smart factory use cases in the next 3 years compared to today?

The industrial metaverse is not yet a priority

Manufacturers are not quite ready for the "metaverse"—new technologies that allow users to interact digitally. Digital twins and augmented reality (AR) technology, which are key ingredients for the industrial version of the metaverse, have not been widely adopted yet. Respondents said that they are still in the development and PoC stage for digital twins (45%) and AR use cases (39%). Their plans to increase spending in the next three years are above average for digital twins (26% increase) but below average for AR (22% increase).

Manufacturers prioritize many use cases in parallel

Although the survey asked about 15 use cases, larger manufacturers are implementing hundreds of individual Smart Factory projects across their plant network at the same time. Many of these projects fit into the use-case categories listed in the survey, but some are specific to their industry or individual plant's setup and thus cannot be captured in one simple analysis. For manufacturers, it has become important to develop a sound process that allows for experimentation and quick prioritization of the projects with the highest impact.

Example: Smart Factory use cases at a chemical manufacturing facility

A chemical factory in Benelux groups Smart Factory use cases into five levels of maturity:

1. **Ideas** (currently 20 recent ideas). On-site teams constantly ideate solution ideas for existing problems.
2. **Proof of Concept** (currently 11 projects at this stage). The best ideas go into PoC.
3. **Pilot** (currently 7 projects at this stage). When the PoC works, the company conducts small pilots with user groups in the plant.
4. **Roll-out** (currently 10 projects at this stage). If the pilot proves successful and an ROI can be calculated, the solution is rolled out to the entire site.
5. **Operational** (11 solutions since 2018). Eleven projects have evolved from idea to fully operational in the past three years, including a remote asset monitoring solution that facilitates regular maintenance.

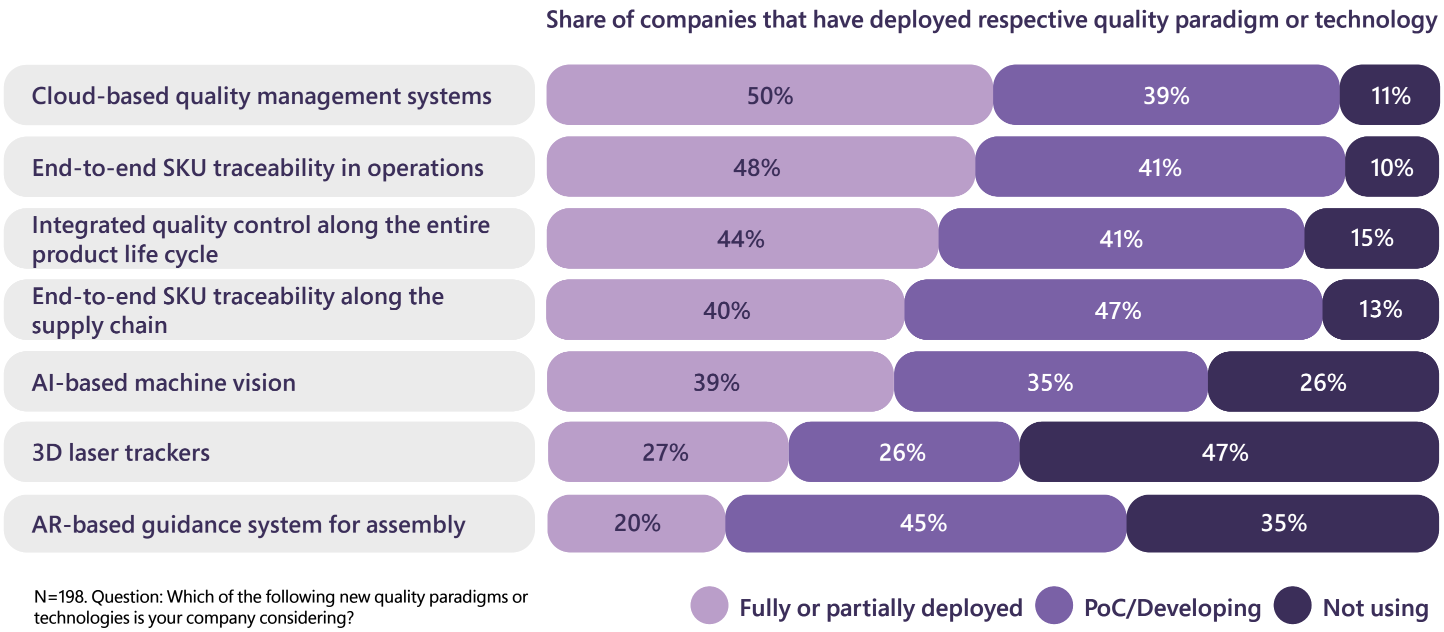
Next, we focus on a selection of three important categories of use cases: quality and compliance, industrial automation, and digital twins.

4.1. Deep dive: Quality and compliance

Manufacturers are focusing on cloud-based quality management systems (QMS) software and end-to-end traceability in operations.

Given that increasing quality is one of the top five KPIs for Smart Factory initiatives (see Chapter 3), it is not surprising that manufacturers are prioritizing investments in quality processes today and in the future. To further improve the quality of manufactured goods, respondents indicated that they have fully or partially deployed cloud-based QMS (50%) and end-to-end SKU traceability in operations (48%). AI-based machine vision is also increasingly being used to complement traditional machine vision (Exhibit 4.3).

Exhibit 4.3: Deployment status of various quality-related technologies



N=198. Question: Which of the following new quality paradigms or technologies is your company considering?

Practitioners' perspectives: How manufacturers invest in increased quality

- **"We currently have a dedicated team working on cloud-based AI and QMS systems."** Strategy director at a German wood-products manufacturer
- **"We are deeply investigating AI vision due to the amount of labor we use for inspection. The aim is to detect faults in real time."** VP of quality at a US Tier I automotive supplier
- **"We started using robots for quality checks. It has saved us time while boosting quality and customer satisfaction."** VP of operations at a US aerospace manufacturer

Example: Using machine vision and a modern QMS to assure precise airbag assembly

Assembling the explosion system of an automotive airbag requires extreme precision, which is often challenging for humans to achieve. People can get tired and experience limitations with their vision. A US-based automotive supplier is using machine vision to enable the precise positioning of explosion units. The machine vision system continuously monitors if the explosive unit is inserted and oriented correctly. The system measures the orientation of the components and tracks that data in real time. This allows the user to stop the system before thousands of units are improperly produced.

The company has used the machine vision system along with a modern QMS that collects IoT sensor data and robot-based automation data. Diverse sensors capture various attributes, such as robot movement, temperature, production output, and other quality assurance parameters. The QMS triggers an alert if any of the parameters is out of specification.

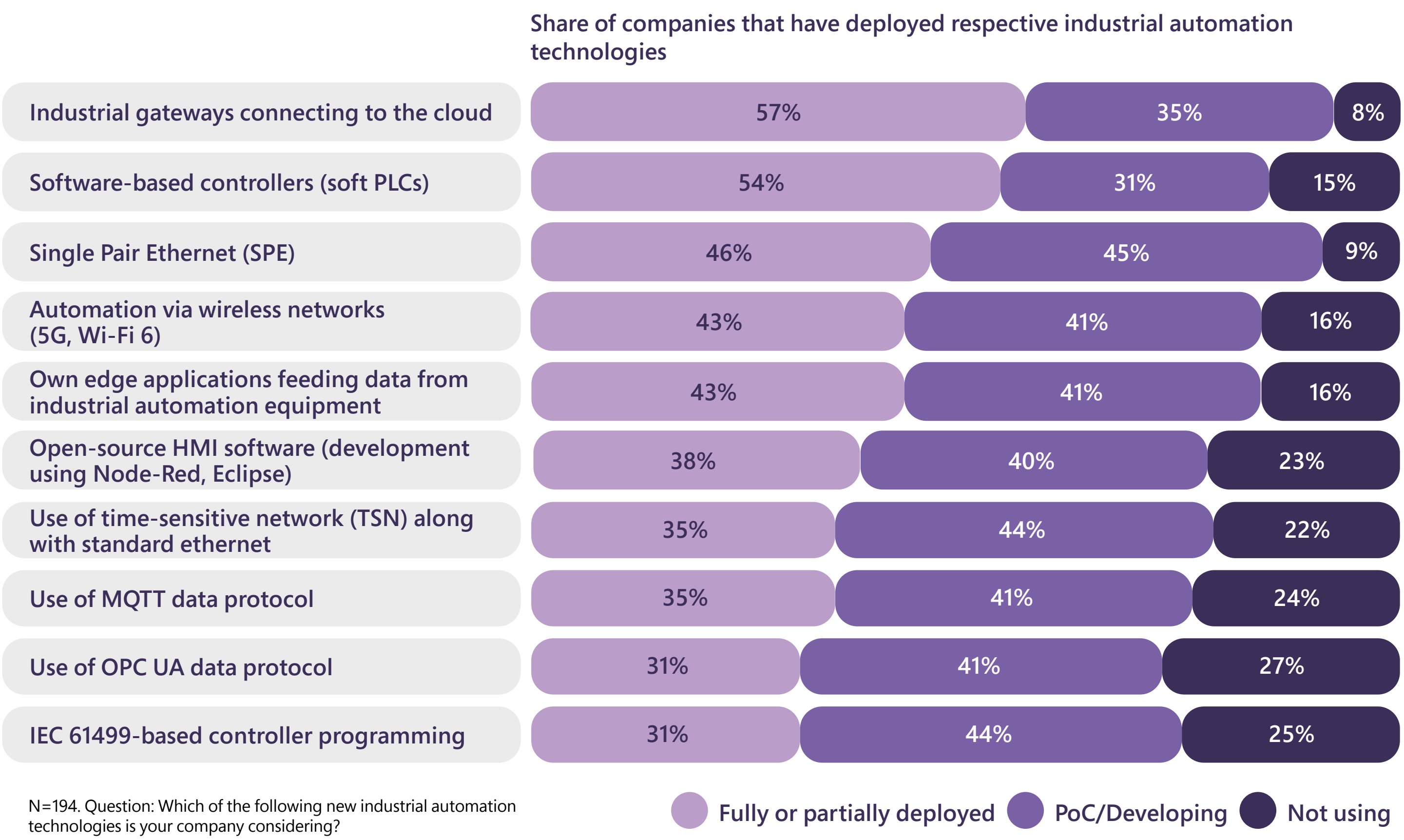
4.2. Deep dive: Industrial automation

Industrial automation is becoming cloud-connected and software-based

Industrial automation systems (PLCs, DCS systems, IPCs, I/Os, and related hardware) are essential for any factory producing goods at scale. In a sense, they can be seen as the heart of manufacturing processes. As factories aim to become more agile and modular, industrial automation systems must give end-users the flexibility to change machine setups, manufacture new product variants, or change the flow of entire plant setups. With many factories still using decade-old equipment that has many limitations, it is not surprising that manufacturers plan to increase their investments in next-generation industrial automation by more than 29% during the next three years (see Exhibit 4.2).

More than half of respondents said that they have already partially or fully deployed two key industrial automation technologies: industrial gateways connecting to the cloud (57%) and software-based PLCs (54%) (Exhibit 4.4).

Exhibit 4.4: Deployment status of various industrial automation technologies



N=194. Question: Which of the following new industrial automation technologies is your company considering?

Modern industrial gateways often act as edge controllers and can also directly connect to the cloud. In this new cloud-to-edge continuum, these devices play a key role in running and managing edge applications that perform tasks beyond data ingestion (such as analytics, control, and visualization). Software-based controllers enable the decoupling of control workloads from proprietary hardware. As a result, these workloads can be virtually deployed anywhere from the cloud or an on-premises server to industrial PCs or even smaller devices. This provides the user with immense flexibility in adding IoT-based features, such as visualization and analytics along with control operations.

Wireless networks in manufacturing facilities (fully or partially deployed by 43% of respondents) have been widely discussed. These networks can play a significant role in enabling non-mission-critical use cases that require mobility. For example, a parts transfer operation using mobile robots within factory premises can be easily controlled via wireless automation. Also, AR use cases that require the user to move across multiple machines or work stations to perform maintenance or assembly are better suited to untethered networks such as 5G and WiFi.

Practitioners' Perspectives: Intelligent automation adds tremendous value

A US logistics executive highlighted the great value gained from industrial automation-based process control in warehouses: "IoT devices engaging employees in automated and semi-automated solutions have created 25% productivity gains in the areas of their implementation."

The IT director of a Tier I automotive supplier emphasized the valuable applications of intelligent automation using robots. "In our factory, we use IoT, AI, and robots to create intelligent automation. We employ robots to assemble the charger for electric automotive vehicles. IoT devices on the robots continuously analyze their efficiency and optimize the way the charger is assembled every single time."

4.3. Deep dive: Digital twin

When implementing digital twins, internal skill gaps and integration difficulties are the manufacturers' biggest challenges.

Only 28% of respondents have started rolling out a digital twin solution. Of those, only 1 out of 7 have fully deployed it in their plants. Although there is no standard definition of "digital twin," broadly speaking, they are virtual working representations of assets, products, and plants. The use case is important for manufacturers as production processes, products, and equipment become replicated virtually to visualize, simulate, and predict manufacturing operations.

Examples: Three ways to use digital twins

Here are three examples of how manufacturers use digital twins today:

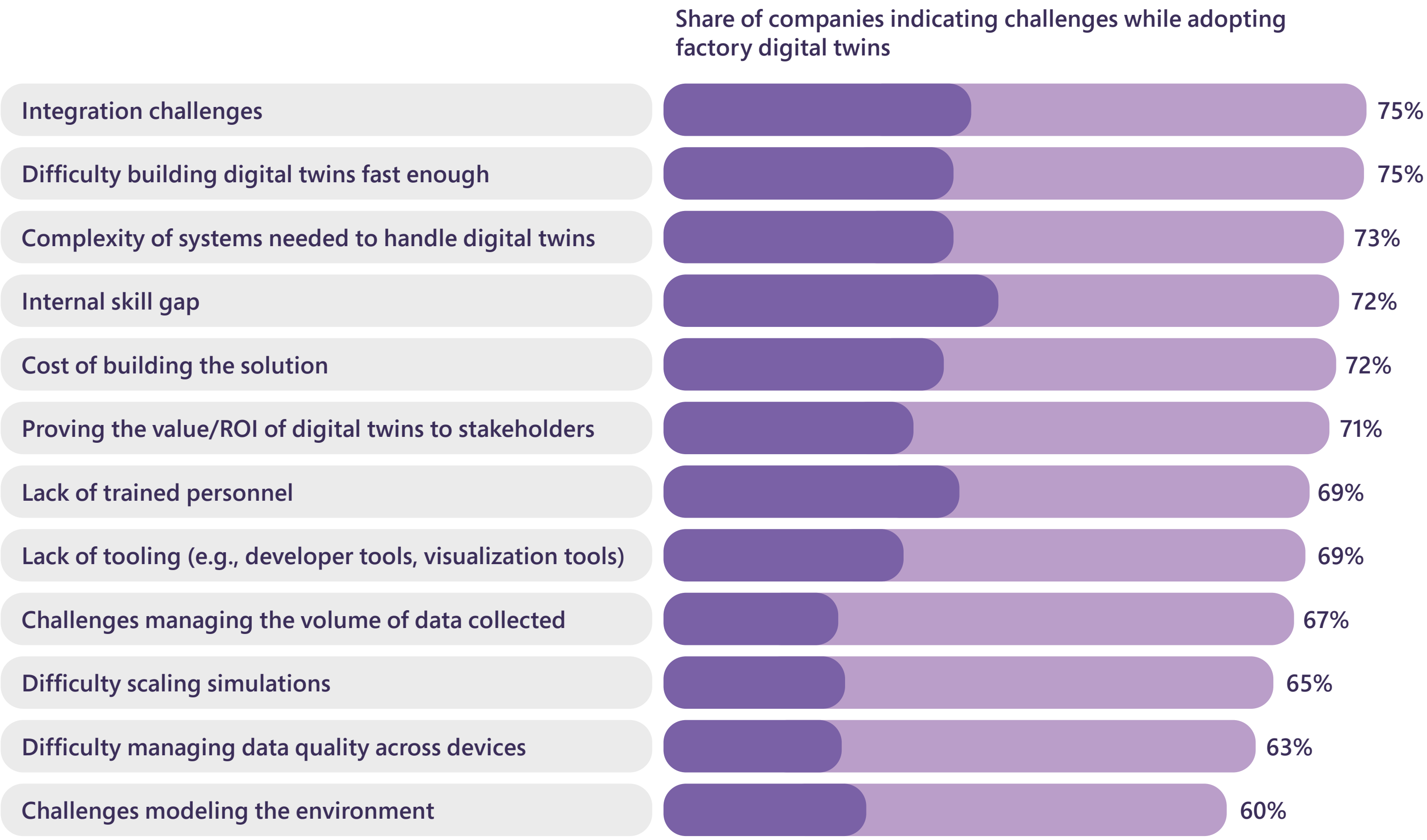
Example 1: Optimize operations. A manufacturer of commercial transportation equipment is developing digital twins to run its factory and processes through virtual reality and discrete event simulation. The company seeks to better understand how the factory and processes are affecting the product and how it can optimize them. The capability to run what-if scenarios helps the company to improve its capacity planning.

Example 2: Verify design. An automotive manufacturer has developed a digital twin to verify tooling design before installation. The twin also supports design changes and installation improvements for future upgrade capabilities.

Example 3: Improve training. A chemical production unit uses a digital replica of its plant for training purposes to help staff prepare for major manufacturing disruptions. Just like how pilots train for their job in ground-based flight simulators, key operations personnel can use the digital twin of the plant to train for critical operations situations. The overall goals are to improve plant safety and enable people to act quickly and appropriately.

Despite the promise of factory digital twins, manufacturers reported several key challenges when implementing them (Exhibit 4.5). The top challenges, cited by three-quarters of respondents, are difficulty in integration (75%), the speed of building the twin (75%), and the overall system complexity (73%). Respondents also reported that they lack the necessary skills and find building the twins to be relatively expensive.

Exhibit 4.5: Challenges while adopting factory digital twins



N=179. Question: How challenging has the following been while adopting factory digital twins (a digital twin being defined as "the use of digital models to simulate, forecast, and optimize manufacturing processes and entire plant setups")?

Respondents said that data quality, data modeling, and simulation are less challenging. This highlights that many companies do not regard the barriers to getting started with digital twins as the biggest challenges to deployment.

Once manufacturers identify their high-priority use cases, they must transition from PoC tests and pilots to full-scale deployment. In the next section, we explore the technical and non-technical challenges to scaling.

5. Challenges to scaling solutions

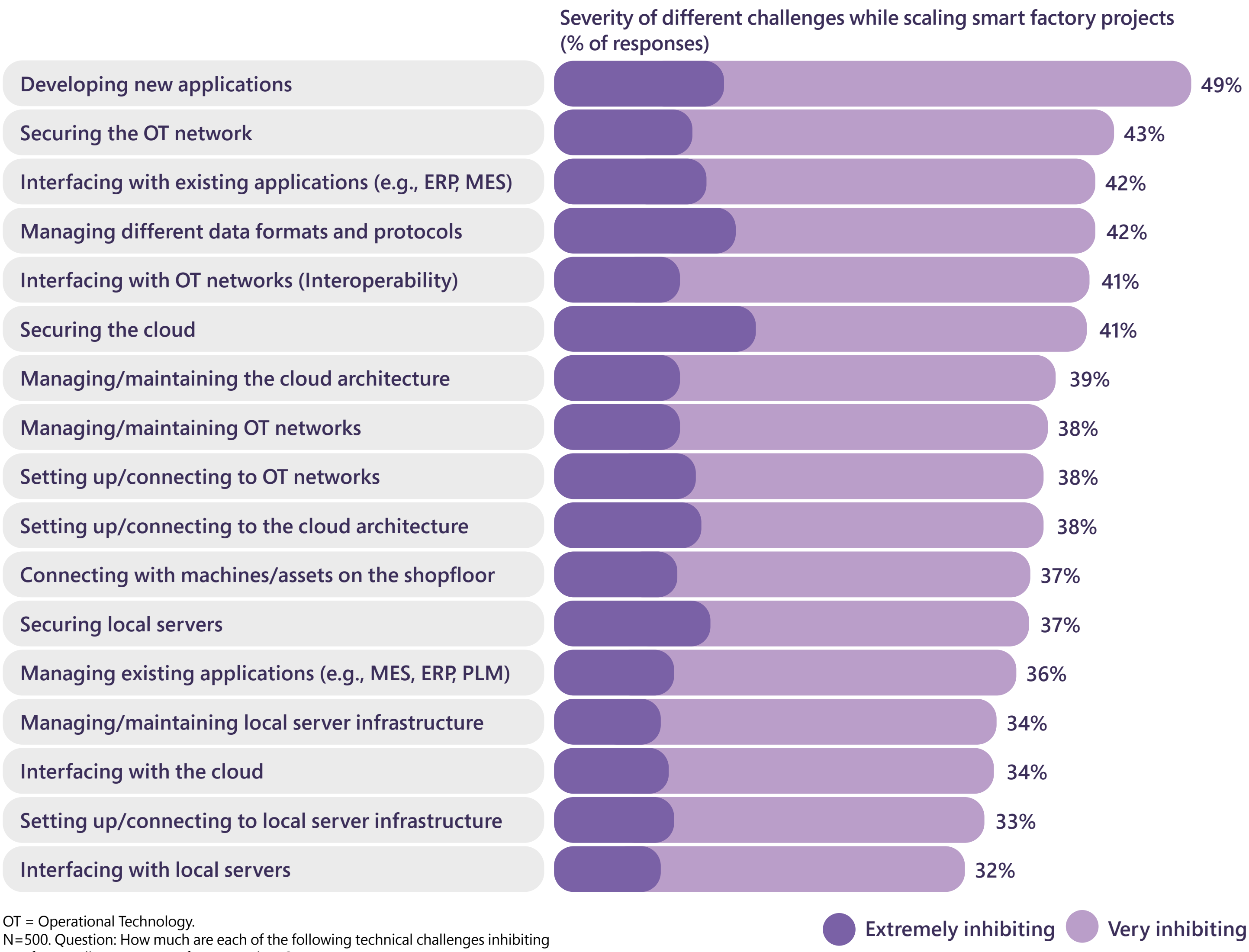
The biggest barriers to faster and more comprehensive Smart Factory adoption include technical challenges relating to OT security, the development of new applications, and skill shortages in data science, AI, and IT cybersecurity.

In scaling Smart Factory solutions from pilots to full deployment, manufacturers face technical and non-technical challenges. Companies must understand these challenges in-depth so that they can address them early on—before the challenges impede the project's longer-term success.

The top three technical challenges

Respondents said that their main technical challenges are developing new applications (49%), securing OT networks (43%), and interfacing with enterprise applications such as ERP or MES (42%) (Exhibit 5.1).

Exhibit 5.1: Technical challenges inhibit scaling

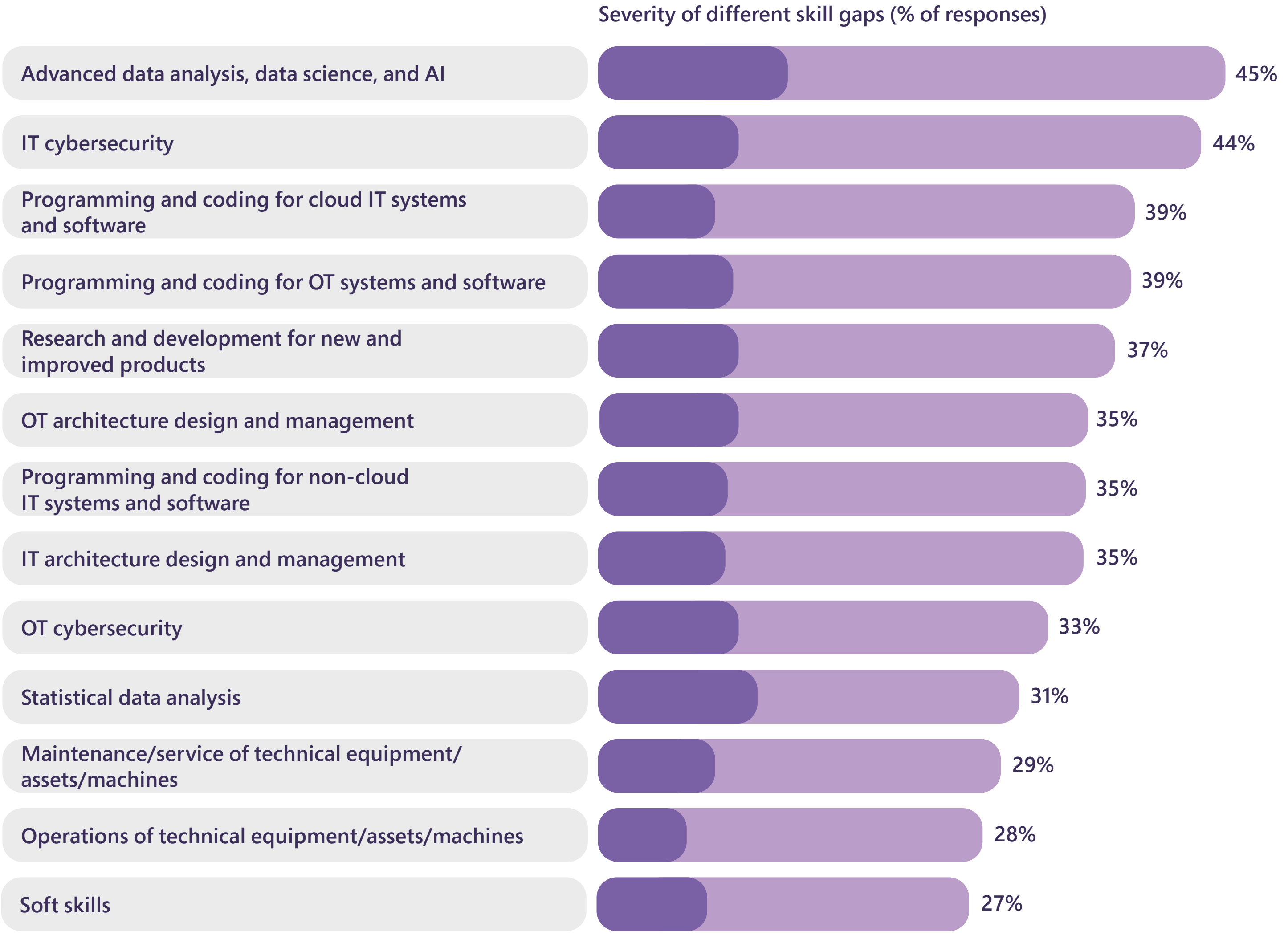


OT = Operational Technology.
N=500. Question: How much are each of the following technical challenges inhibiting you from scaling your smart factory projects?

The top three skill gaps

Eight out of 10 of the respondents reported having at least one very important skill gap. Respondents said that their biggest skill gaps related to advanced data analysis (45%), IT cybersecurity (44%), and cloud IT system coding (39%) (Exhibit 5.2).

Exhibit 5.2: Data analysis and cybersecurity are the biggest skill gaps



OT = Operational Technology; soft skills (e.g., communication, creativity, complex problem-solving).
N= 358. Question: How severe is the skill gap of your organization in each of the following areas?

To make Smart Factories a success, many manufacturers realize that they need to embrace a digital-first culture that empowers employees to design and use innovative technology applications. But too many companies fail to capture the benefits. One reason is that they do not enable their workers to use digital tools. Another is that they tell workers which digital tools to adopt. The top-down approach means that workers (somewhat reluctantly) implement orders from management rather than implementing tools that are the result of their own ideas.

Practitioners’ perspectives: Why it is tough to develop the right skills

A former VP of manufacturing at a global automaker explained the skills challenge this way:
“Many people think that technology runs the Smart Factory, but this couldn’t be further from the truth. The work-force must make the decisions. To transition to a Smart Factory, you need to develop skills on all levels, which is super difficult because you haven’t implemented one before. We have found it really tough to get good automation engineers and data analysts who have some knowledge of our industry.”

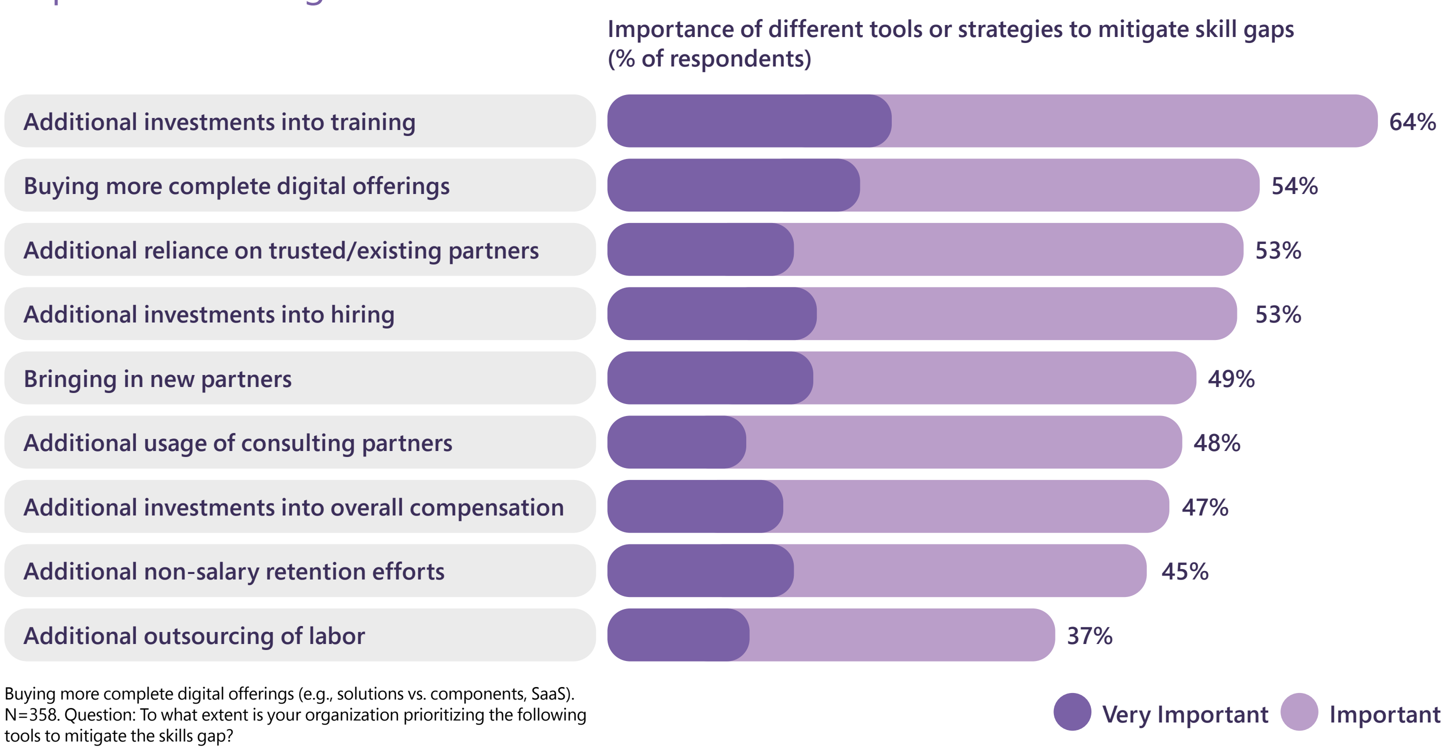
An operations IT director at an aircraft supplier highlighted the importance of enabling people when scaling Smart Factory applications: “The big challenge is that the job is not done when a nice app is available and working in a pilot area in one factory. The job is done when we have managed to scale it to the entire network, and people in entire factories are enabled to use those tools. This is much more challenging than I imagined. For example, machine operators now need to understand the basics of a self-service analytics tool.”

A senior VP at a leading industrial automation vendor emphasized the need for skills convergence:
“To perform future shop-floor roles, workers will need to be flexible and have strong digital skills. This doesn’t mean the jobs are moving away from OT. Rather, there will be a convergence of OT and IT skills.”

The top three ways to close the gaps

In seeking to mitigate the skill gaps, respondents gave the greatest importance to training (64%), buying more complete digital offerings (54%), and additional reliance on existing partners (53%) (Exhibit 5.3).

Exhibit 5.3: Tools and strategies to mitigate skill gaps —companies emphasize training



Buying more complete digital offerings (e.g., solutions vs. components, SaaS).
N=358. Question: To what extent is your organization prioritizing the following tools to mitigate the skills gap?

Practitioner’s perspective: How to organize for better training

A deputy manager at an oil refinery emphasized the importance of training to digitalize at scale: “To promote digitalization, which is different from traditional IT, we created a Digital Academy. We have organized various training programs at the Digital Academy to improve our colleagues’ digital thinking reflexes—that is, to expand their digital thinking ability.”

Respondents ranked hiring fourth as a skill mitigation tool. Manufacturers cite two reasons why hiring is not the most effective strategy in many cases. First, today’s near-record low unemployment and labor shortage have made finding highly skilled digital talent immensely difficult for manufacturers—many of which are located in rural areas. Second, because many manufacturers are launching their first digital or Smart Factory initiative, it is very difficult to precisely articulate the skills they are looking for.

Practitioner’s perspective: Why hiring is a challenging strategy to mitigate the skills gap

A former VP of manufacturing at a Tier I automotive manufacturer broke down the challenge of defining skills gaps: “On all levels, you need to clearly map what set of skills you have in-house and what you will need in Smart Factory. Defining that is super difficult. Because companies haven’t developed a Smart Factory before, they don’t understand what it takes.”

How challenges have changed over time

These challenges are a testament to the progress companies have made in implementing digital technologies in manufacturing. Initial challenges such as data collection and aggregation from legacy machines, interfacing with local servers, and architecting the cloud are no longer major barriers. To tackle the emerging challenges, companies need new skill sets. Factory-level skills are evolving from OT-focused to those that require a combination of IT–OT talent.

To standardize or not?
Some respondents said that they align their Smart Factory initiatives with leading standardization bodies and consortia (Exhibit 5.4). The most important organizations are ISO, IEEE, and Standardization Council Industrie 4.0. However, none of the standardization bodies or consortia stands out as the most widely used, and even the most used framework has been adopted by only one of four manufacturers. As a result, we continue to see many siloed architectures throughout the manufacturing sector.

Exhibit 5.4: The prevalence of smart factory frameworks and consortia

Framework/consortium	Share of companies that say a core part of their smart factory strategy (e.g., technology architecture) is aligned with various frameworks/consortia (% of respondents)
IEEE Smart Manufacturing Standards	27%
ISO/IEC TR 30166:2020 – Industrial IoT	26%
ISO/IEC TR 63306-1:2020 Smart Manufacturing Standards	25%
Standardization Council Industrie 4.0	22%
MESA Smart Manufacturing	19%
ISO/IEC 21823-2:2020 – interoperability for IoT systems	19%
Industrial Internet/Industry IoT Consortium	18%
Digital Twin Consortium	18%
Acatech Industrie 4.0 maturity index	18%
Plattform Industrie 4.0 asset administration shell	17%
Plattform Industrie 4.0 reference architecture (RAMI 4.0 - DIN SPEC 91345)	16%
ANSI/ISA-95 (International Society of Automation)	16%
ISO/IEC TR 30164:2020 – edge computing	16%
Alliance for Internet of Things Innovation	15%
US National Institute of Standards and Technology – Digital Thread for Manufacturing	14%
W3C Smart Manufacturing Committee	13%
OPC Foundation specifications	13%
European Factories of the Future Research Association	13%
IEC/TC 65/WG 23 Smart Manufacturing Framework and System Architecture	13%
IEC 61131-3 – open international standard for PLCs	13%
Industrial Data Space Association	11%
Open Manufacturing Platform (Linux Foundation)	8%

N=404. Question: How much is your smart factory strategy aligned with the following frameworks/architectures/consortia (regardless of whether your employer is a member of this organization)?

A manufacturer's choice of IT–OT technologies and architectures provides the foundation for scaling Smart Factory solutions. Next, we discuss what respondents told us about the current state of their technologies and architectures and their plans for the future.

6. Technologies and architectures

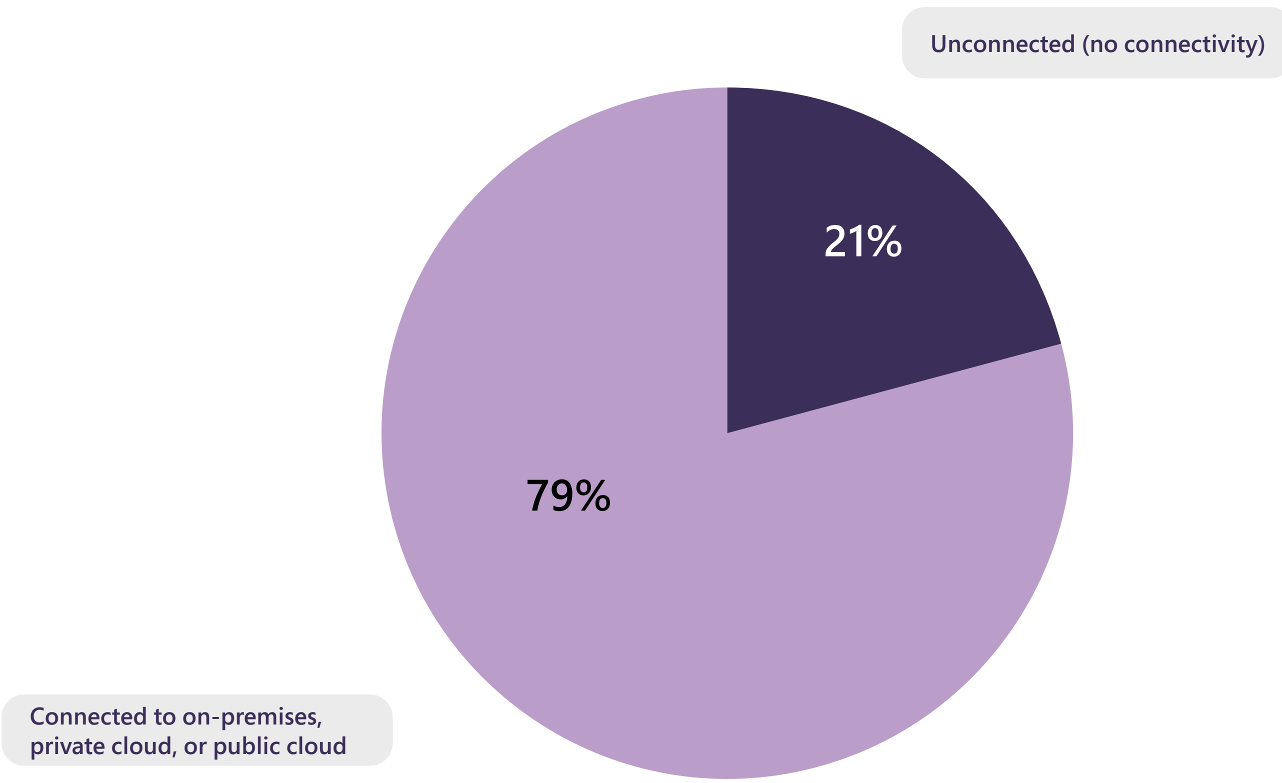
Manufacturers will increasingly move workloads to the cloud, containerize software, adopt software as a service (SaaS) and focus on their security strategy.

To make factories agile and modular, manufacturers need a strong understanding of how to best navigate the convergence of IT and OT. Trends in software and hardware are bringing major changes to manufacturing technology architectures. Our survey found a range of implications for connected assets, the migration of workloads to the cloud, and the role of SaaS.

Most factory assets are connected

More than three-quarters (79%) of the factory assets—that is, machinery and systems with controllers—are connected to an on-premise network today (Exhibit 6.1). Only about one-quarter (24%) can also connect to the public cloud.

Exhibit 6.1: More than three-fourths of factory assets are connected

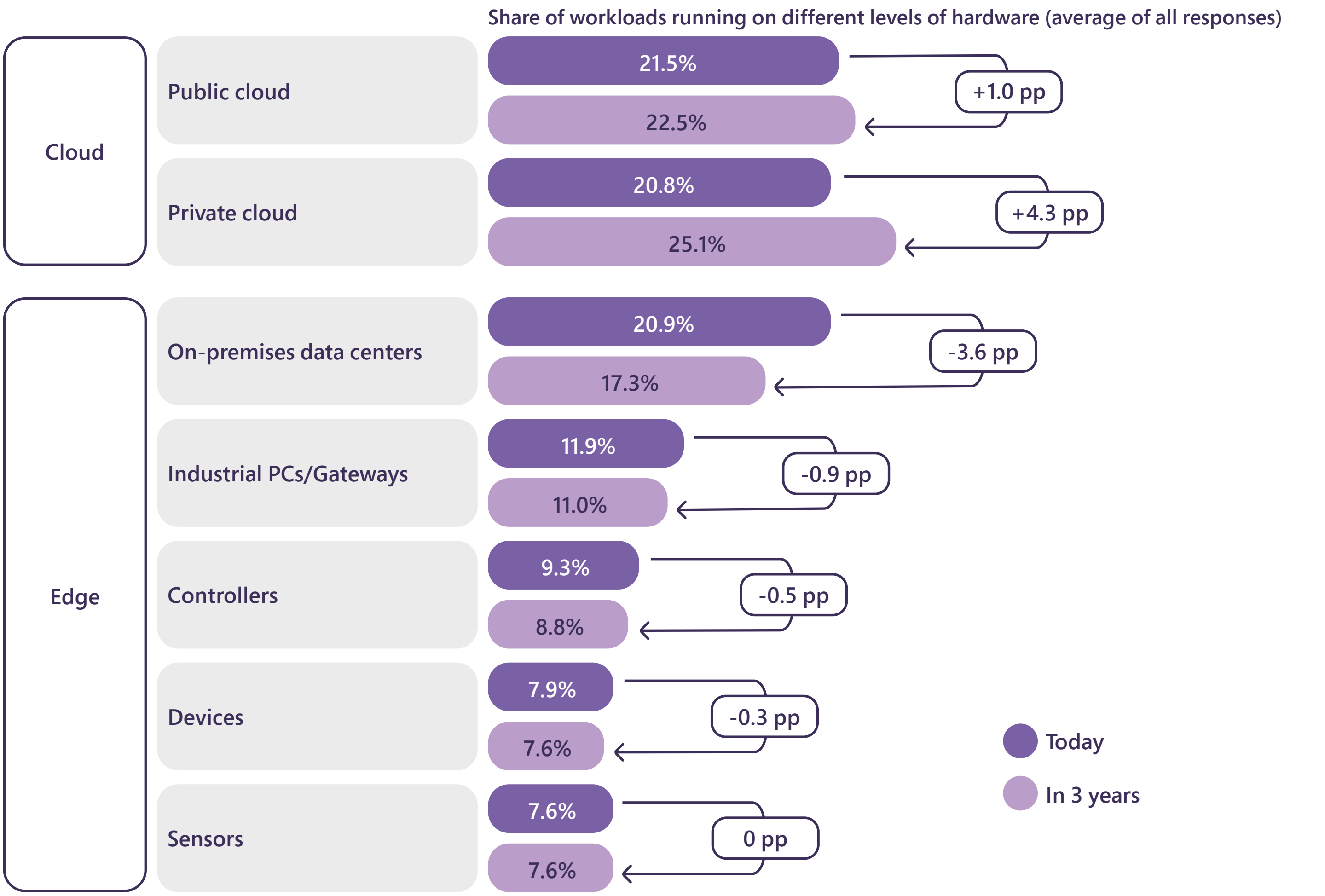


N= 225 Question: What percentage of your connectable operational technology (OT) assets (i.e., machinery/systems with controllers) fall into the following categories?

The private cloud is playing an increasingly important role

Most major enterprise applications run on either on-premises data centers or public or private cloud infrastructure. So, it is not surprising that nearly two-thirds (64%) of manufacturing workloads are performed on one of those three assets. The growing role of software throughout organizations makes it likely that the total amount of workloads run by a manufacturer will increase in the coming years on all levels of the stack. However, there is an important relative shift from on-premises data centers to off-premises private cloud data centers. The share of workloads running on the private cloud will increase from 21% today to 25% in the next three years. During the same period, the share of workloads running on on-premises data centers will decrease from 21% to 17% (Exhibit 6.2).

Exhibit 6.2: Workloads are shifting to the cloud

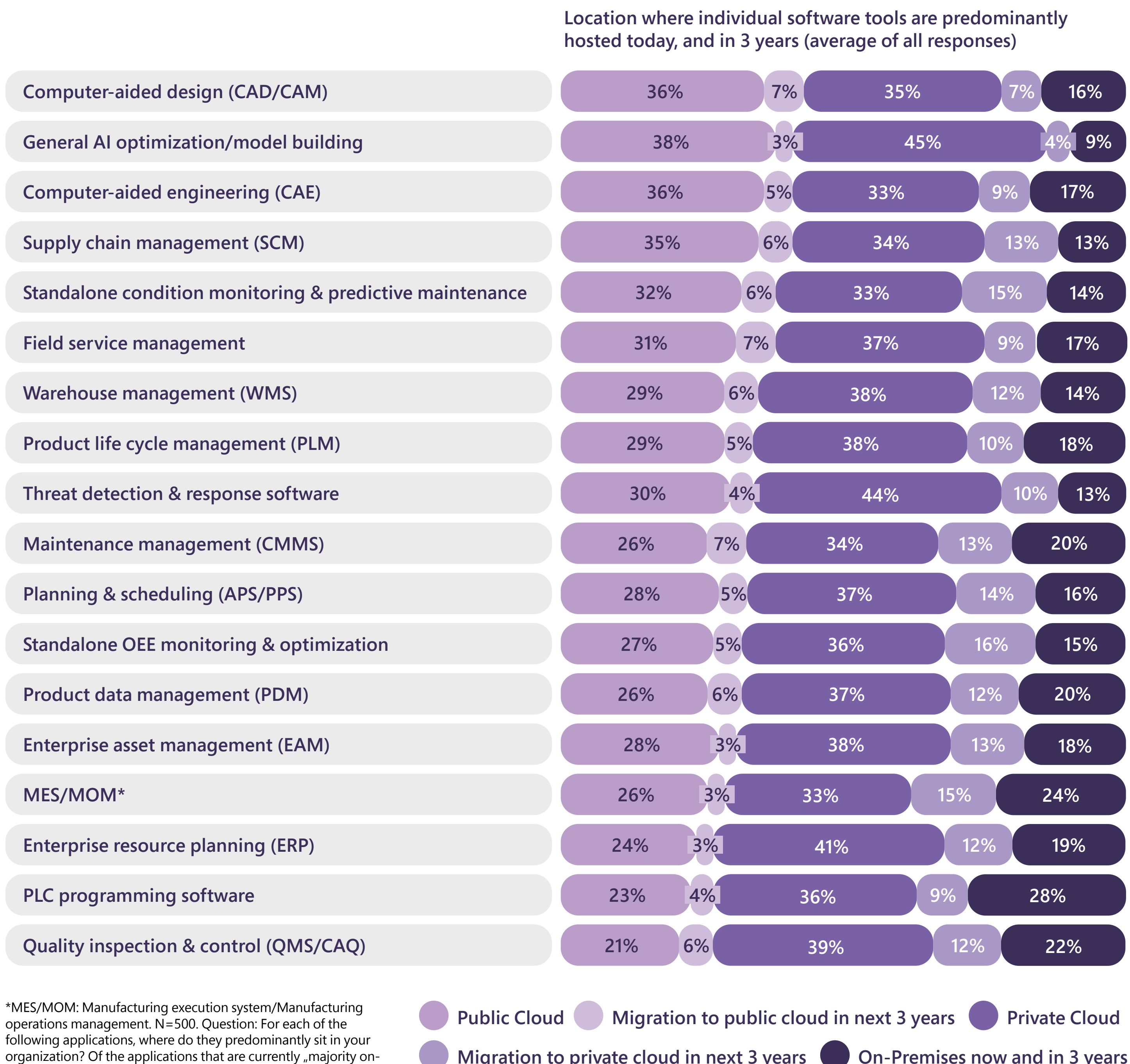


Public Cloud: Off-premises/remote public data centers; Private cloud: Off-premises/remote private data centers; On-premises data centers: Highly available computers on same LAN as OT hardware; Industrial PCs/Gateways: Linux or Windows-based computers outside of data centers; Controllers: PLCs, RTUs, and DCs; Devices: HMI/MMIs, VFDS, remote/distributed I/O, and cameras); Sensors: Valves, actuators, temperature sensors, and proximity sensors. N=500. Questions: For each of the following applications, where do they predominantly sit in your organization? Of the applications that are currently „majority on-premises," which ones do you expect will move to being majority in the cloud until mid-2025? And in which type of setup?

Manufacturing enterprise applications are migrating to the cloud

The migration of various enterprise applications to either a public cloud or private cloud environment is clearly driving the shift in workloads. Although 83% of AI model-building is already happening in the public or private cloud today, the shift for other types of software is more profound. Respondents are planning to migrate 20% of their maintenance management systems (CMMS) along with 21% of their on-premises condition monitoring, predictive maintenance, and OEE monitoring solutions to the cloud (Exhibit 6.3).

Exhibit 6.3: Companies are moving enterprise software to the cloud



*MES/MOM: Manufacturing execution system/Manufacturing operations management. N=500. Question: For each of the following applications, where do they predominantly sit in your organization? Of the applications that are currently „majority on-premises“, which ones do you expect will move to being majority in the cloud until mid-2025? And in which type of setup?

Practitioners' perspectives: The advantages of moving to the cloud

The CIO of a machinery and equipment company in India emphasized reliable up-time: "We've moved applications from on on-premises bare metal servers to an in-house private cloud setup. The availability of applications is now better because planned downtime occurrences are minimal."

The VP of an automotive company in China highlighted the value of using the public cloud: "Our local high-performance computing is not enough for large data processing. To give you an example: An entire vehicle development project requires at least 2,000 cores for calculation including safety, NVH, CFD, and more. As we have two completed vehicle projects now and some retrofit projects, the CPU gap is about 4,000 cores, which is why we introduced a large Chinese public cloud vendor."

The VP of a food and beverage company in the Philippines stressed the benefits of confidentiality: "The cloud helps us to safeguard confidentiality. We store confidential product formulations used in quality assurance and R&D, as well as other proprietary data, in the cloud. We give the access code to only a few people involved in the day-to-day operations."

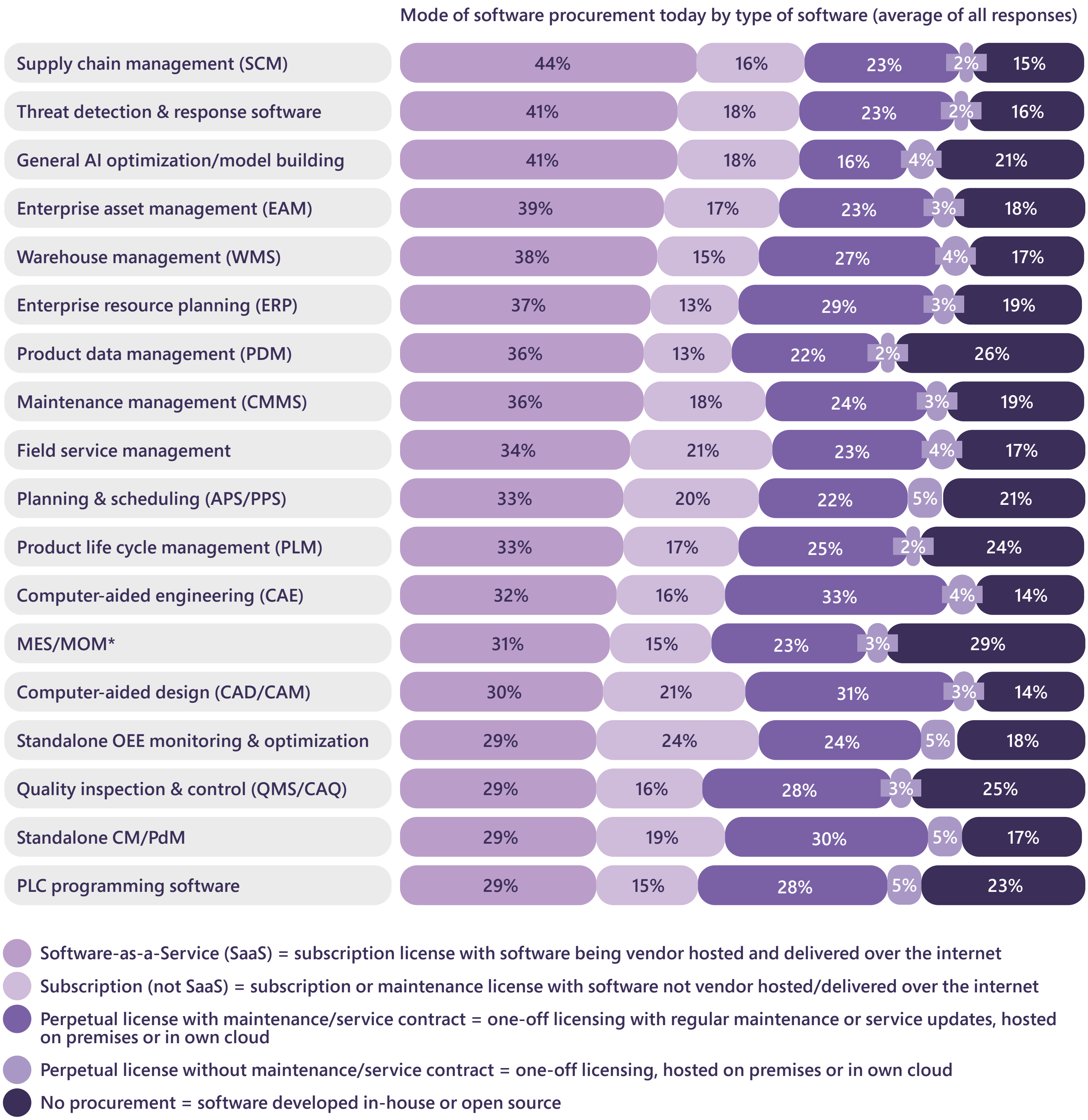
Manufacturers are moving towards procuring SaaS

Today, procuring SaaS increasingly dominates as the way to procure manufacturing software for several applications: supply chain management (44% of respondents), threat detection and response (41%), general AI optimization (41%), and enterprise asset management (39%) (Exhibit 6.4).

By 2025, respondents plan to increase their share of SaaS procurement, particularly for quality inspection and control (11% increase), condition monitoring and predictive maintenance (11% increase), product lifecycle management (10% increase), and planning and scheduling software (10% increase) (Exhibit 6.5).

The shift to SaaS promises flexibility, ease of setup, and better scalability. However, we see some resistance to moving to this model for two main reasons. First, manufacturers fear they may temporarily lose access to a business-critical application (such as when a bill has inadvertently not been paid). Second, they are concerned that the total cost of ownership in a SaaS model is higher because providers sell small but important add-ons on the go.

Exhibit 6.4: SaaS increasingly dominates procurement



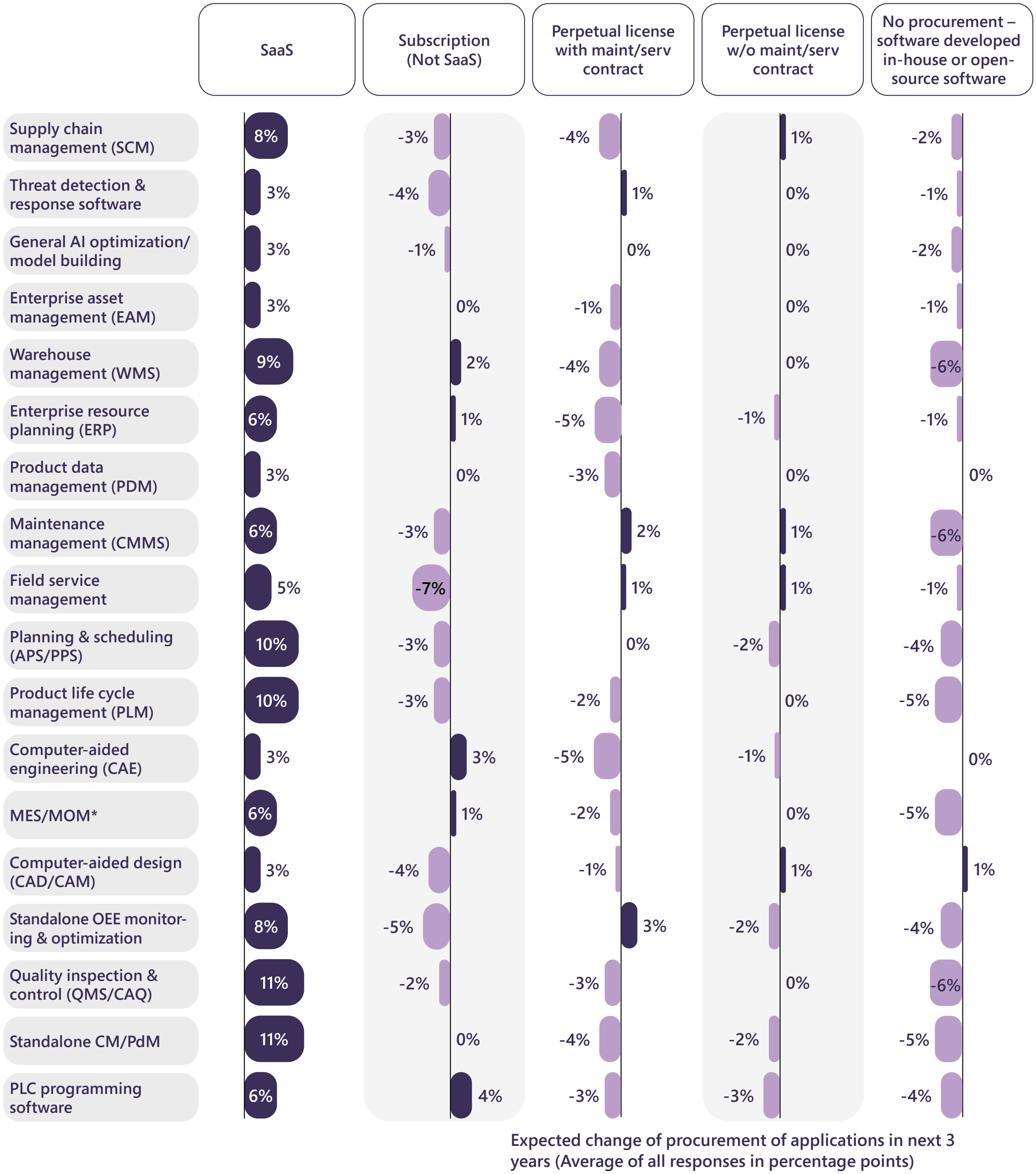
*MES/MOM: Manufacturing execution system/Manufacturing operations management.
N=500. Content: For the applications that are currently in use, how does your organization mainly procure each of them?

Although some companies are shifting from perpetual licenses to SaaS, it is even more common to see companies that had previously built their own software moving to SaaS for the benefits of ease and flexibility. For example, one-third of companies that currently use their own proprietary warehouse management system and one-quarter of those that currently use their own proprietary quality control software said that they plan to buy software for these purposes in the next three years.

Practitioner's perspective: SaaS makes the most sense for next-generation systems

The IT Director at a Tier I automotive supplier emphasized that new applications will drive SaaS adoption. "SaaS is particularly interesting because it doesn't require any upfront data center infrastructure investments. Being a large company, however, we have set aside money for specific long-term investments in our own data centers. Our ERP system, as a result, runs predominantly on our on-premises servers. For such enterprise applications, the ROI for SaaS is too low. However, for the new next-generation systems, such as cybersecurity endpoint protection tools, SaaS makes a lot of sense because we haven't previously allocated any hardware investments for it. The other aspect is how core the application is to the business. We are also moving applications to a SaaS model in which we do not want to be the experts and can afford to lose ownership—such as for wide area network management or for specific IT cloud management services."

Exhibit 6.5: The shift to SaaS will continue over the next three years



*MES/MOM: Manufacturing execution system/Manufacturing operations management.
N=500. Content: For the applications that are currently in use, how does your organization mainly procure each of them? For the applications that are in use today, how do you expect your organization to procure each of them mid-2025?

Next, we focus on two technology areas that have become critical to Smart Factory success: edge computing and security.

6.1. Deep dive: Edge computing

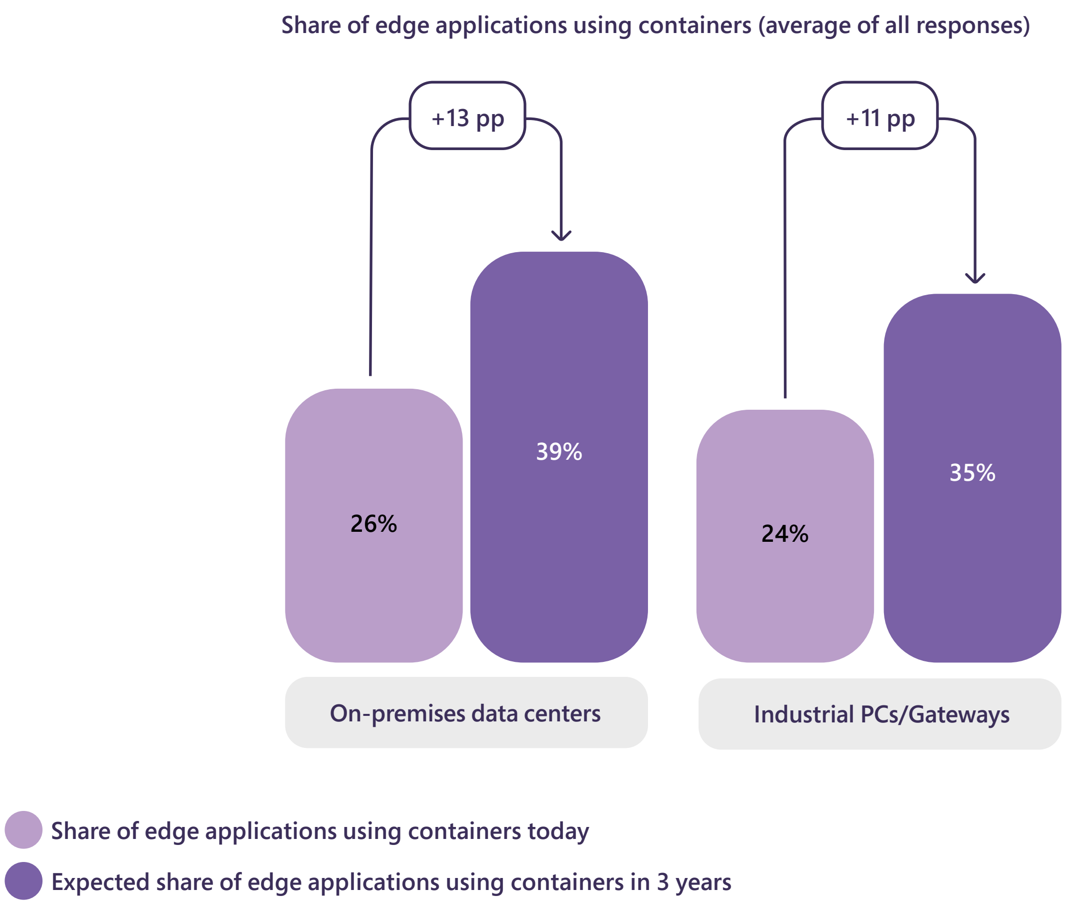
Manufacturers increasingly deploy edge applications on containers and prefer pre-certified edge hardware.

As many of the workloads become increasingly distributed throughout the tech stack, two trends play an important role: containerization of software and precertification of hardware.

Manufacturers are deploying edge applications in containers

Respondents said that they are using containers for 26% of applications running on on-premises data centers today. They expected this to increase to 39% in the next three years as they modernize their software stack (Exhibit 6.6).

Exhibit 6.6: The share of containerized applications is growing



On-premises data centers: Highly available computers on same LAN as OT hardware; Industrial PCs/Gateways: Linux or Windows-based computers outside of data centers.
N= 196. Question: What percentage of your applications at the edge is currently deployed in containerized environments (e.g., Docker), and how do you expect this percentage to change in 3 years?

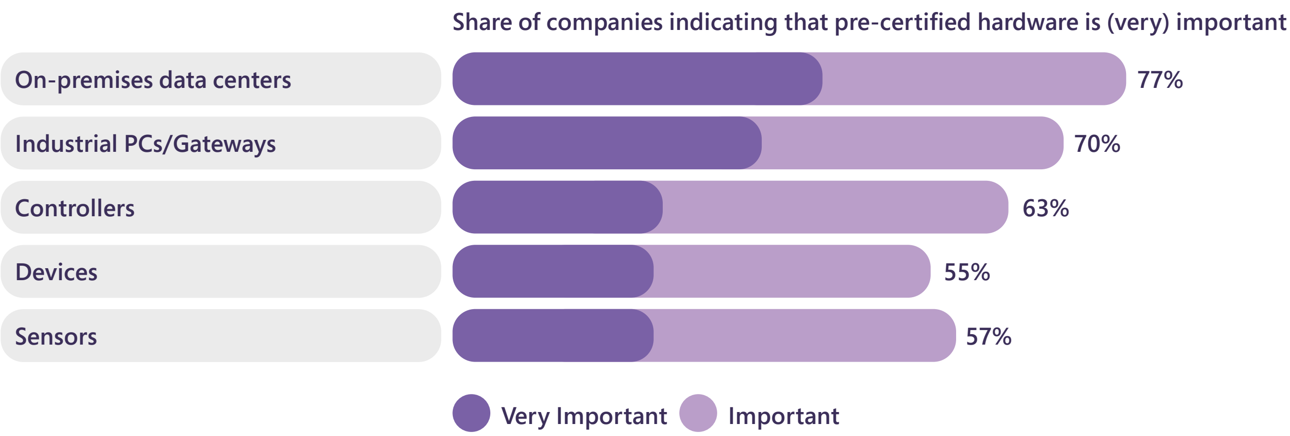
Virtualization and containerization infrastructure and management software (for example, Kubernetes, Docker Swarm, and Apache Mesos) enable end users and integrators to scale their edge software deployments from PoC testing to a global rollout much more seamlessly.

Practitioner's perspective: Containerization enables real-time transactions
A systems integrator for an automotive OEM explained the benefits of containerization for running a management execution system (MES): "We just developed a containerized version of the MES of a large automotive OEM. Because it is containerized, the various modules of the MES are deployed on an on-premises edge server and simultaneously in the cloud. All latency-critical, real-time transactions happen at the edge, while the cloud is used as a fallback or failsafe option."

Pre-certification of edge computing hardware is gaining importance

As workloads become more independent from hardware and are shifted to the cloud, it is becoming increasingly important to manufacturers to ensure the hardware is pre-certified to run with the software and the cloud. 77% of respondents said it is important that their on-premises data centers are pre-certified to work with their preferred cloud/IoT platform vendor. 70% want pre-certification for industrial PCs or gateways and 63% for controllers (Exhibit 6.7).

Exhibit 6.7: Companies want pre-certified edge computing hardware



Off-premises/remote private data centers; On-premises data centers: Highly available computers on same LAN as OT hardware; Industrial PCs/Gateways: Linux or Windows-based computers outside of data centers; Controllers: PLCs, RTUs, and DCs; Devices: HMI/MMIs, VFDS, remote/distributed I/O, and cameras; Sensors: Valves, actuators, temperature sensors, and proximity sensors. N=230. Question: How important is it that the following edge computing hardware be pre-certified to work with your selected cloud IIoT platform cloud vendor?

6.2.Deep dive: Security

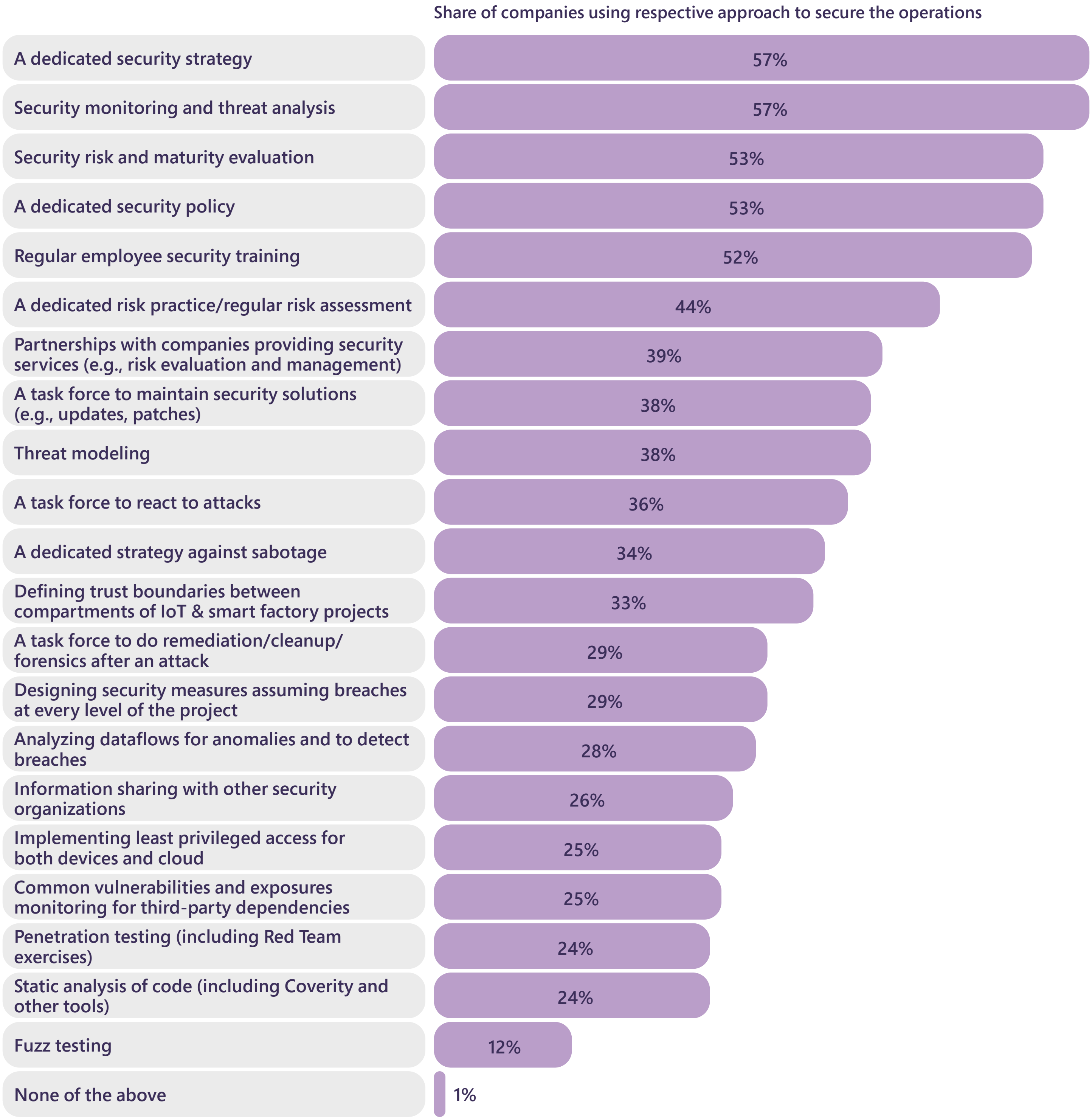
Manufacturers are emphasizing a dedicated stratgy and threat monitoring to secure Smart Factory operations.

Respondents have a variety of priorities for operations security, with some notable variations at the regional level.

Top priorities for security

Respondents said that their highest priorities for securing operations at smart factories are a dedicated security strategy (57%) and security monitoring and threat analysis (57%). They also gave high importance to security risk and maturity evaluations (53%), a dedicated security policy (53%), and regular employee security training (52%) (Exhibit 6.8).

Exhibit 6.8: The priorities for operations security



N= 300. What elements are part of your approach to secure the operations (e.g., shopfloor, warehouse, production process) and the infrastructure to run them?

Approaches differ slightly at the regional level

Manufacturers in Asia-Pacific give much more importance to security risk and maturity evaluations than manufacturers in North America (65% versus 44%). North American manufacturers give much more importance to partnerships with companies that provide security services than their European counterparts (46% versus 30%). European companies put a much higher emphasis on regular employee security training than their North American counterparts (64% versus 39%) (Exhibit 6.9)

Exhibit 6.9: The regional priorities for operations security

Share of companies using respective approach to secure the operations

	North America	Europe	APAC
A dedicated security strategy	53.0%	64.3%	53.5%
Security monitoring and threat analysis	60.7%	58%	47.9%
Security risk and maturity evaluation	44.4%	54.5%	64.8%
A dedicated security policy	42.7%	61.6%	54.9%
Regular employee security training	38.5%	64.3%	54.9%
A dedicated risk practice/regular risk assessment	34.2%	44.6%	57.7%
Partnerships with companies providing security services (e.g., risk evaluation and management)	46.2%	30.4%	40.8%
A task force to maintain security solutions (e.g., updates, patches)	42.7%	28.6%	45.1%
Threat modeling	35%	43.8%	33.8%
A task force to react to attacks	36.8%	37.5%	31%
A dedicated strategy against sabotage	33%	37.4%	32.4%
Defining trust boundaries between compartments of IoT & smart factory projects	35%	28.6%	38%
A task force to do remediation/cleanup/forensics after an attack	29.9%	23.2%	38%
Designing security measures assuming breaches at every level of the project	29.1%	26.8%	33.8%
Analyzing dataflows for anomalies and to detect breaches	28.2%	26.8%	31%
Information sharing with other security organizations	24.8%	24.1%	32.4%
Implementing least privileged access for both devices and cloud	21.4%	20.5%	39.4%
Common vulnerabilities and exposures monitoring for third-party dependencies	29.9%	21.4%	23.9%
Penetration testing (including Red Team exercises)	23.9%	23.2%	26.8%
Static analysis of code (including Coverity and other tools)	26.5%	22.3%	23.9%
Fuzz testing	12%	11.6%	14.1%
None of the above	1.7%	0%	0%

N=.300. What elements are part of your approach to secure the operations (e.g., shopfloor, warehouse, production process) and the infrastructure to run them?

Practitioner's perspective: A variety of ways to secure operations

The project manager of a machinery and equipment company in Germany stressed the need for external penetration testing: "A key element of our strategy is penetration tests on our own products."

The project manager at a metals processing company in Canada highlighted the importance of a cybersecurity team: "Our company built a strong in-house cybersecurity team after being hacked in 2016. For every project that I deployed thereafter, I had to work closely with the cybersecurity team to design the network solution."

An engineer at an automotive company in China emphasized protecting confidentiality: "Our main goal is to ensure the confidentiality of the company's working documents and the normal conduct of work. For example, we want to avoid the intrusion of a ransomware virus."

Leading manufacturers are using advanced digital technologies to transform not only their operations but also their products. In the final chapter, we look at the top features and future priorities for smart connected products.

7. Smart-connected products

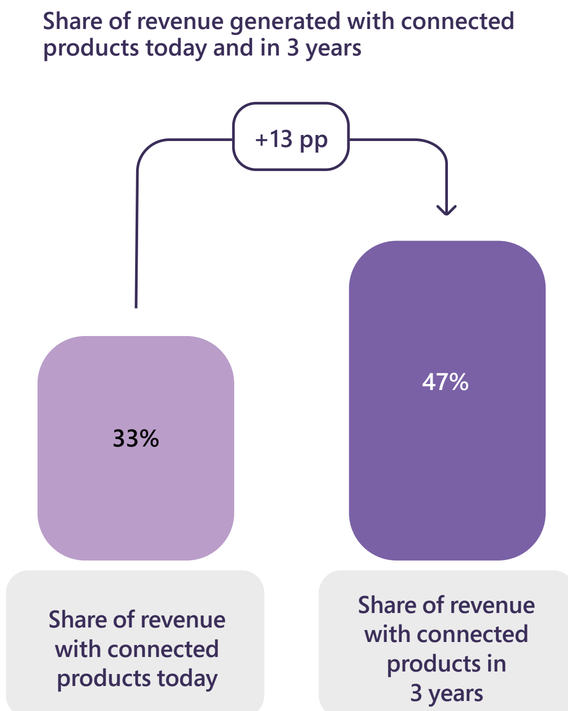
Smart-connected IoT products will play a more important role going forward for many manufacturers.

Smart-connected IoT products are becoming more common – whether they are consumer electronics, appliances, communication equipment, automotive components, or entire machines. Manufacturers are offering new, IoT-based software and services along with their physical products to add customer value and generate additional revenue. We asked a subset of the manufacturers who participated in the survey about the current performance, connected features, and plans of their smart product portfolio.

The increasing importance of smart products

Respondents said that 33% of their product revenue today is generated from products that can be classified as "smart"—that is, the company collects operational data from the products. They expect the penetration of smart products to rise to 47% in three years (Exhibit 7.1). The data suggest that smart products are successful in adding value for both the customer and the manufacturer.

Exhibit 7.1: Share of smart products expected to grow

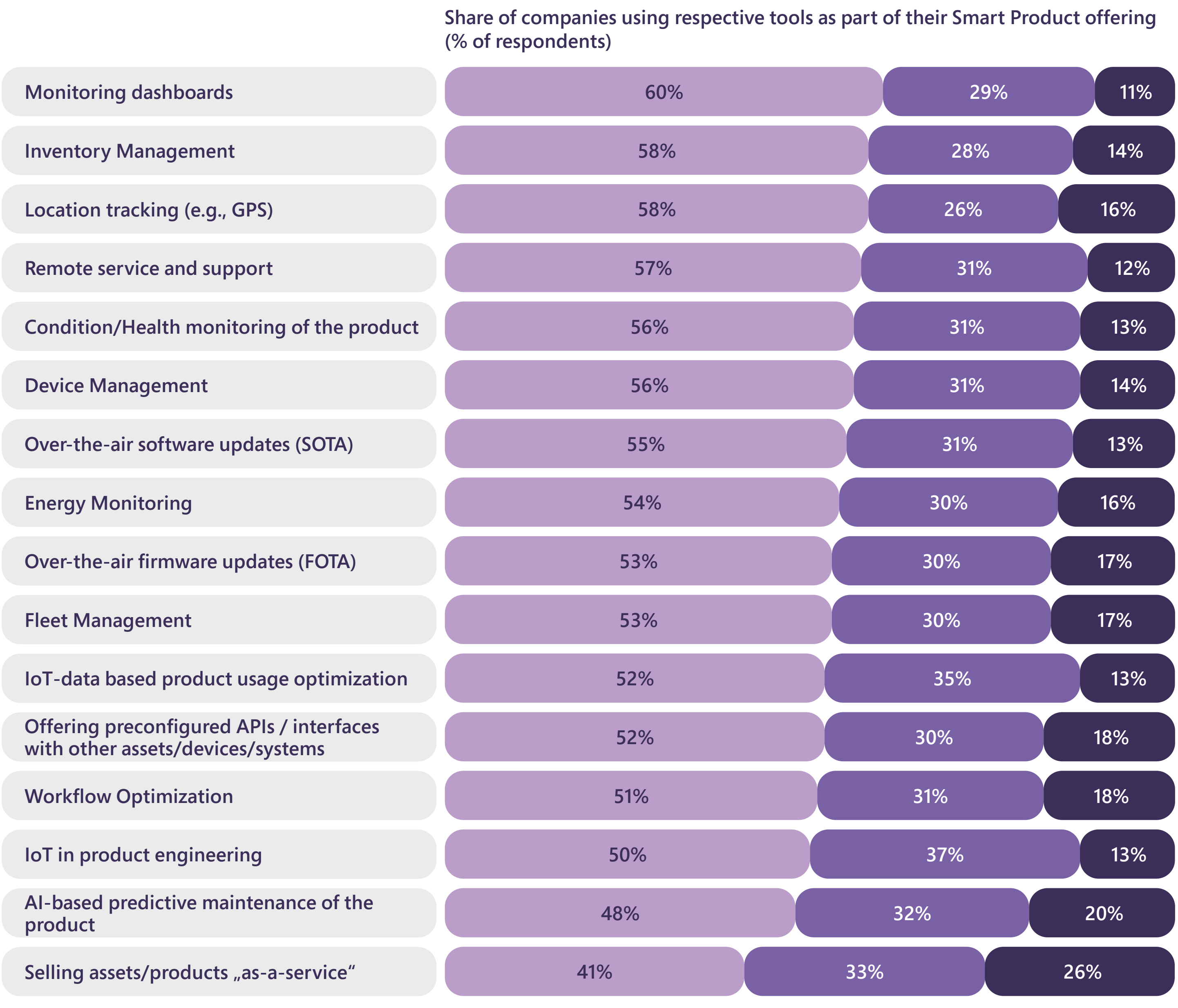


N= 200. Question: Looking at your entire portfolio of physically manufactured products, what share of product revenue is generated with products that are connected (i.e., have the ability to send data back from the customer premises)? How do you expect it to change in the next 3 years?

The top three smart product features

Among the leading features of smart products, respondents said that they have partially or fully deployed monitoring dashboards that customers can access as they use the equipment (60%), inventory management software (58%), and location tracking (58%) (Exhibit 7.2).

Exhibit 7.2: Monitoring, inventory management, and tracking are the top smart product applications



N= 200, Question: Looking at the products you sell to your customer, which of these smart product use cases have you rolled out?

The priorities for the next three years

AI-based predictive maintenance is the top smart product use case going forward, with companies planning to boost investments by 43% (Exhibit 7.3). They plan to invest 42% more in remote service and support and condition/health monitoring use cases. Respondents expect to increase investment in device management by 40% and in monitoring dashboards by 39%.

Exhibit 7.3: Predictive maintenance and remote service are the top investment priorities

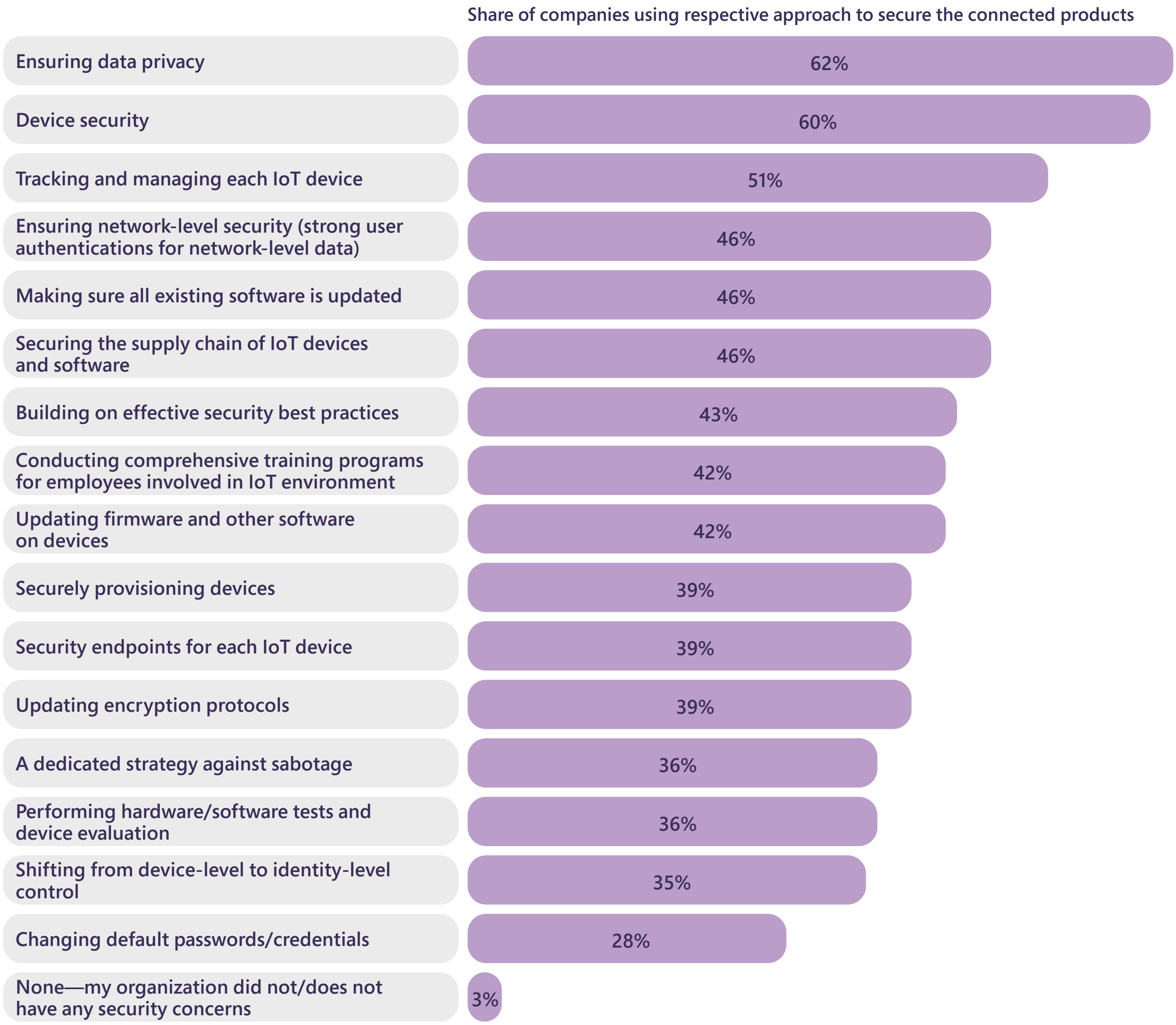
	Average investment increase (in % compared to today) for smart product use cases in the next 3 years
AI-based predictive maintenance of the product	+43%
Remote service and support	+42%
Condition/Health monitoring of the product	+42%
Device Management	+40%
Monitoring dashboards	+39%
Selling assets/products „as-a-service“	+39%
IoT-data based product usage optimization	+39%
IoT in product engineering	+36%
Energy Monitoring	+36%
Over-the-air software updates (SOTA)	+36%
Offering preconfigured APIs / interfaces with other assets/devices/systems	+35%
Location tracking (e.g., GPS)	+35%
Fleet Management	+35%
Workflow Optimization	+34%
Over-the-air firmware updates (FOTA)	+33%

N= 172, Question: Looking at the products you sell to your customer, how much is your organization planning to invest in each of these use cases in the next 3 years compared to today?

The leading security strategies

Given that security is among manufacturers' top concerns (see chapter 6), a sound security strategy is essential for connected products. Very often, privacy (an adjacent topic) is part of the security strategy. Privacy is particularly important for connected products in the field because their operational data can reveal important competitive insights. Such a privacy breach can cause substantial harm or make customers vulnerable to cyber attacks, which can also be very damaging. Against this backdrop, it is not surprising that 62% of respondents said that they have strict data privacy policies and 60% have adopted device-based security for securing the connected products sold to customers (Exhibit 7.4).

Exhibit 7.4: Data privacy and device security are the top security considerations for connected products



N=200. Question: Which of the following elements are part of your approach to secure the connected products sold to customers?

Examples: Smart products in action

Two examples highlight how smart products create value:

Example 1: A US instrumentation company developed and deployed a remote condition and health monitoring solution for its product (thermocouples). The solution gives customers real-time visibility into the product's performance and alerts them when abnormal operations occur. The company likewise gains the ability to track product performance in real time.

Example 2: A Sweden-based bearing and seal manufacturer added value-based features to help customers extend product lifetimes. Lubricators allow bearings to run smoothly. In a pilot phase, the company added a connectivity layer on the bearings and offered a dashboard to monitor the lubrication of machines with little human interaction. It identified four distinct features that create customer value: active information about the current grease level, active information about alarms, remote adjustment of lubrication, and a dashboard with additional insights.

Practitioner's perspective: The benefits of smart connected products

The VP of strategy for a Swiss machinery manufacturer highlighted three benefits of deploying a smart product solution for condition and health monitoring: "First, it creates customer value and thereby enhances the value of the prime product. Second, it helps us to optimize the cost of the service contracts on the equipment. Third, it helps in keeping the customers in the channel beyond the warranty period."

8. Conclusion

Putting the insights into action

Our study confirmed that manufacturers recognize the imperative to use digital technology to transform their operations and products. For many, the question now is how to accelerate their efforts.

In developing their ambitions and implementation plans, manufacturers must navigate a highly dynamic environment. For the Smart Factory, key considerations include prioritizing the right investments, identifying and closing skill gaps, and promoting the convergence of IT and OT. For Smart Products, it will be crucial to gain experience with the connected technologies that enable value-added services.

To assess their current efforts and test the robustness of their planning, the following 10 questions, which are tied to the survey results, can act as a starting point:

1. Have we integrated the four key themes of agility, resiliency, a digital workforce, and sustainable operations adequately into our digital transformation strategy?

2. Are we looking at the most suitable technologies for our goals? Especially in the fields of industrial automation, quality, and maintenance?

3. Are major digital transformation decisions taken centrally also allowing enough autonomy for the factory to actively drive and implement the many smaller initiatives?

4. What is our digital twin strategy?

5. How well are we working with our equipment suppliers to digitize our shop floor?

6. How will we master the challenge of bringing sustainability considerations to the shop floor?

7. Have we given enough attention to our workforce-enablement strategy?

8. Have we considered using the IEEE, ISO, or other smart manufacturing frameworks?

9. Do we have clear strategies for our deployments of cloud, SaaS, and containerization capabilities?

10. Have we developed a clear feature roadmap for our smart connected products?

For many manufacturers, the answers will point to the need to redesign at least some aspects of their approach to digital transformation. Given the highly competitive and dynamic environment, now is the time for action.