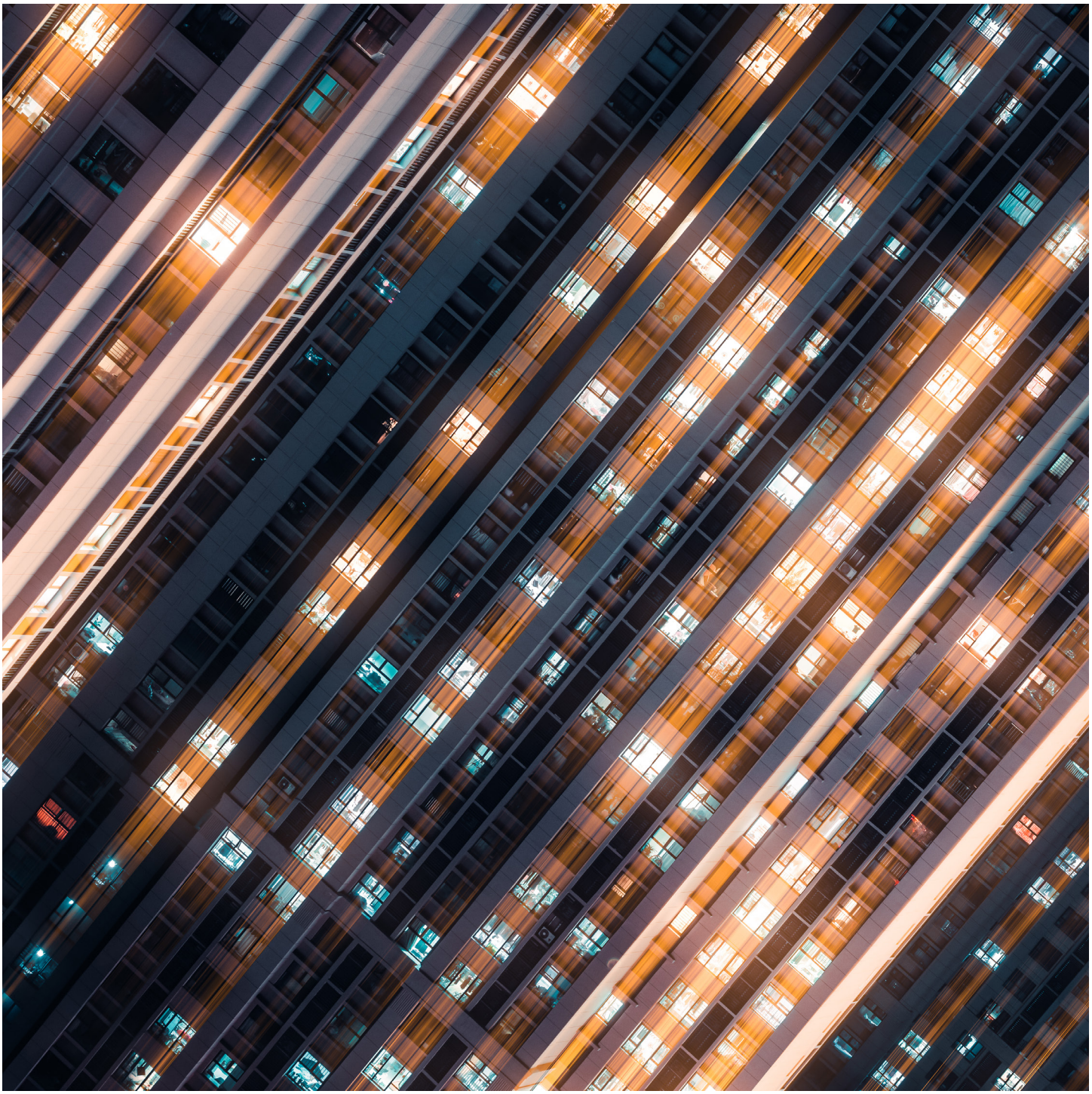


Engineering and R&D Report 2023

BAIN & COMPANY

Contents

The Innovation Race: Winners Are Investing Now

As costs rise, engineering and R&D leaders are finding new ways to ensure a strong return on investment.

By Daniel Suter, Bill Radzevych, Neil Malik, Sudheer Narayan, and Jessica Port

At a Glance

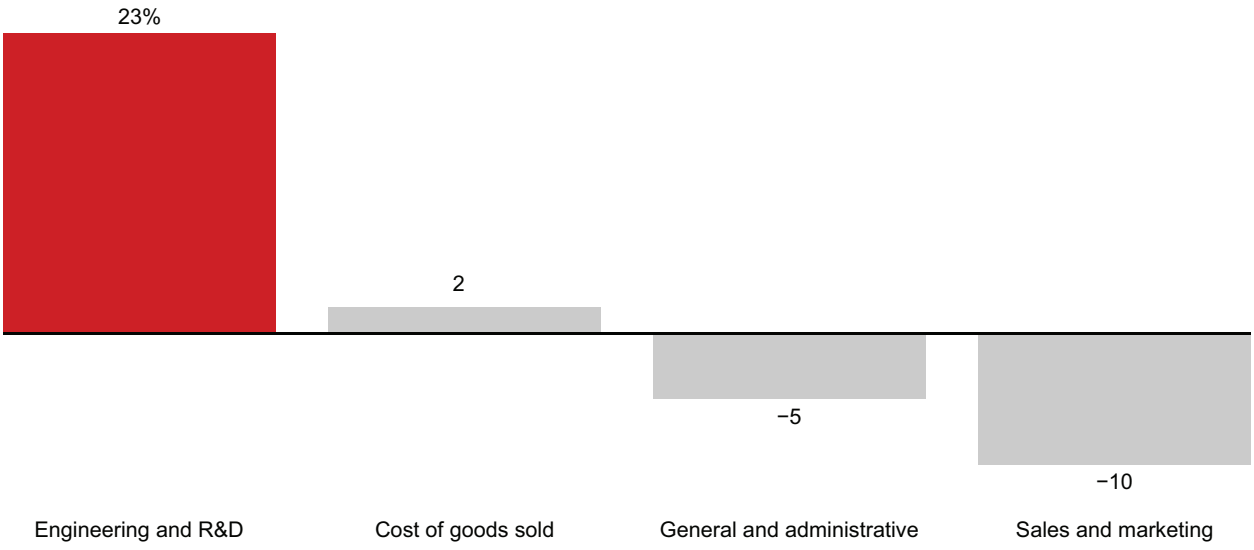
- Executives forecast a 10% compound annual growth rate for engineering and R&D spending through 2026, fueled by investments in digital engineering.
- Investing in engineering and R&D during a recession can help companies pull ahead in the innovation race.
- During past downturns, growth in engineering and R&D spending was more resilient than GDP growth.

The innovation race has become more costly than ever. Investment in engineering and R&D (ER&D) as a percentage of revenue has increased significantly since 2016 *(see Figure 1)*. And despite a looming recession, executives expect the growth in ER&D spending to continue rising, according to a recent Bain & Company survey of more than 500 senior executives *(see Figure 2)*.

ER&D is a core function for many large companies. Historically, these firms have focused on making products better and cheaper. Today, a growing number see ER&D as a strategic capability that will determine their future success and shape new business models. Investments in ER&D not only improve products but also increasingly reinvent or disrupt parts of the business.

Figure 1: The share of engineering and R&D spending has risen sharply compared with other expense categories

Change in spending as a percentage of revenue, 2016–2021

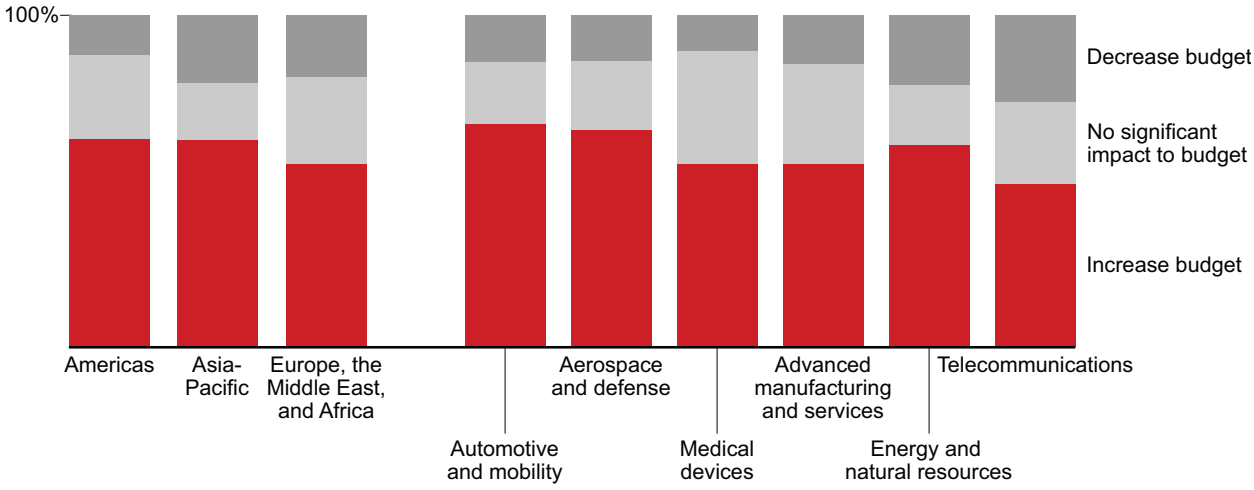


Sources: S&P Capital IQ; Bain analysis

Figure 2: Executives plan to increase engineering and R&D spending despite the uncertain economic outlook

How do you expect the current economic crisis and inflationary environment to impact engineering and R&D budgets? (single choice)

Percentage of survey respondents



Source: Bain Engineering and R&D survey 2022 (overall n=505; Americas n=177; Asia-Pacific n=109; Europe, the Middle East, and Africa n=217; automotive and mobility n=92; aerospace and defense n=95; medical devices n=47; advanced manufacturing and services n=123; energy and natural resources n=77; telecommunications n=69)

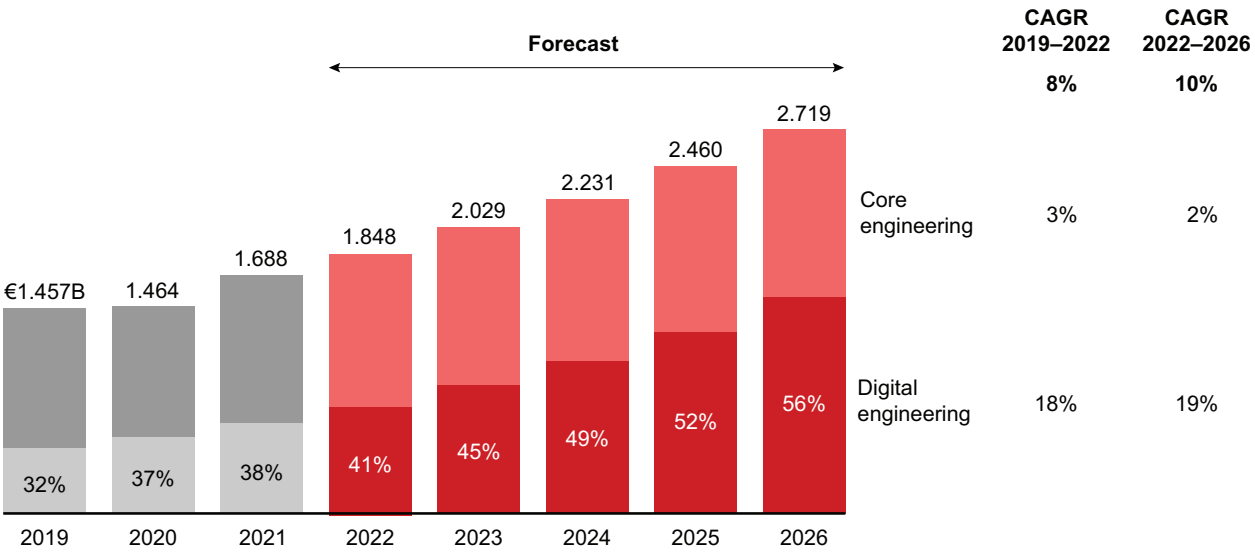
ER&D costs are rising, in part because disrupting markets (or responding to disruption) is more difficult than improving an existing product—even with greater availability of data and computing power. A good example is Moore's Law. The number of researchers required in 2017 to achieve the famous doubling every two years of the density of computer chips required 18 times greater the number of researchers that a company needed in 1971, according to a report by the National Bureau of Economic Research.

Overall, spending on ER&D is set to rise at a compound annual growth rate (CAGR) of 10% between 2022 and 2026 *(see Figure 3)*. As spending soars, leadership teams are redoubling their efforts to achieve a solid return. For the purposes of our analysis, we define ER&D as the wide array of activities aimed at developing new products and services and improving existing ones. These activities include early foundational research, the design testing and verification of products as well as developing infrastructure such as a manufacturing plant, and post-production support.

A key factor fueling higher ER&D spending is digital engineering, the discipline of developing new, connected, and digitally enabled products and services using technologies such as artificial intelligence (AI), machine learning, and cloud computing. Examples of digitally engineered products include autonomous vehicles and production plants wired for Industry 4.0. Executives expect investments in digital engineering capabilities to rise even faster—with a CAGR of 19% between 2022 and 2026 nearly double the pace of overall ER&D spending.

Figure 3: The compound annual growth rate for engineering and R&D spending is forecast at 10% through 2026

Engineering and R&D spending, 2019–2026 (in billions of euros)



Sources: S&P Capital IQ; Zinnov; expert interviews; Bain analysis

In fact, investing in ER&D during a downturn can help companies pull ahead in the innovation race. During past recessions such as the 2008–2009 global financial crisis, ER&D spending was more resilient than GDP growth, according to Bain research. And between 2014 and 2021, global ER&D spending grew nearly four times faster than GDP. One explanation is that a large body of engineering and R&D work typically spans longer time horizons and thus tends to be less fungible than other types of spending. The most successful companies even use recession years to outinnovate competitors by acquiring companies at lower multiples, poaching critical talent, and investing in intellectual property and R&D; downturns that trigger large-scale layoffs in the technology sector also offer ER&D companies an opportunity to hire much-needed talent.

During past recessions such as the 2008–2009 global financial crisis, ER&D spending was more resilient than GDP growth, according to Bain research.

Our research shows that five major challenges for ER&D-focused companies are fueling the innovation race—namely, shortening time to market; making new technologies more affordable; embedding digital capabilities into hardware-centric engineering teams; exploring new frontiers of value creation; and reengineering for environmental, social, and corporate governance (ESG) strategies.

1. Shortening time to market

Engineering companies face growing pressure to bring new products to market faster and to incorporate cutting-edge technologies into the R&D process to generate a stronger return on investment (ROI). For example, powerful chipsets and microprocessors are enabling products and solutions based on AI. That shift supports differentiation, increases revenue and profits, and speeds time to market. But it also requires new capabilities.

The lengthy and complex process of drug discovery illustrates the challenge. A new Massachusetts Institute of Technology deep learning model designed to identify drug candidate molecules performs that task 1,200 times faster than existing computational models. Advances in AI for drug discovery are likely to accelerate in the coming years, and pharmaceutical companies without in-house AI or deep learning capabilities will have to acquire that capability. Many are likely to partner with or acquire promising biotech start-ups rather than build their own technology from scratch.

2. Making new technologies more affordable

When companies shift to new technologies such as cloud-based software or electric cars, the immediate result is often higher costs since products need to be redesigned from scratch. Mass-market electric

cars are still more expensive than their combustion-engine equivalents, for example. But the firms that lead in bringing down the cost of new technologies gain a significant competitive edge. Automakers such as Hyundai and Tata Motors are investing heavily to build more affordable models. Hyundai is planning to build a small electric car that would cost less than $20,000, and Tata recently launched preorders for an electric car that will cost $10,000.

3. Embedding digital capabilities into hardware-centric engineering teams

Digital technologies underpin new business models. They also help organizations move from a cyclical, multiyear R&D process to a continuous one. One leading German engineering company has increased its digital training budget by 10 times over the past three years, a move that more than doubled the number of workers with next-generation digital skills.

4. Exploring new frontiers of value creation

For many industries, searching for new ways of creating value means redefining business models to focus on outcomes instead of products. Siemens Building Technologies, for instance, is shifting from selling building products to providing a building performance management system that combines its traditional products with cloud-based solutions and edge computing, which is a form of computing done on-site or near the source of data, thereby eliminating the need for remote processing.

Our research shows more than 70% of engineering and R&D companies report talent shortages, and many are losing engineers to tech competitors such as Alphabet and Meta.

5. Reengineering for ESG strategies

As governments and industries set targets to achieve net zero emissions, industrial companies are rethinking their use of resources in an effort to move toward sustainable inputs and circular supply chains. One leading European metals processing company is increasingly deploying digital twins and thermodynamic modeling across its operations to better calibrate equipment and significantly reduce energy consumption.

Addressing the five challenges above amid engineering talent shortages and high attrition is even harder. Our research shows more than 70% of engineering and R&D companies report talent shortages, and many are losing engineers to tech competitors such as Alphabet and Meta.

Best practices for maximizing ROI

As the cost of innovation rises, leadership teams are rethinking ER&D strategies and redoubling their efforts to make them as efficient as possible. Successful companies ensure the highest ROI by following a few best practices:

- **Redefine core vs. noncore capabilities.** Leaders regularly assess which engineering capabilities are core, or key, to differentiating the business and winning new customers. Some capabilities are becoming critical differentiators, such as Industry 4.0 technologies for machinery and equipment companies. For instance, a leading industrial equipment maker specializing in pumps, compressors, and turbines recently reevaluated its product portfolio and engineering activities as part of its ESG strategy, choosing to prioritize the development of components, which can dramatically reduce energy consumption in its compressors and vacuum pumps.

Ensure technological capabilities are available to the entire organization and not siloed inside one division.

- **Centralize and democratize access to strategic technologies.** Ensure technological capabilities are available to the entire organization and not siloed inside one division. One global medical technology company that previously had robotics and digital capabilities embedded in specific divisions has now created digital- and robotic-enabled healthcare platforms that combine the best capabilities in one place, accessible to all divisions. That allows the company to leverage those technologies for surgical equipment, orthopedics, and neurotechnology.

- **Organize for speed.** Deploy continuous development models. A leading European automaker is adopting a more Agile process to shorten its development cycles and innovate faster. In a first step, the automaker will shift to continuous software development for each car model. Over time, it will do the same for other parts of the development process. To prepare for that change, it is retraining thousands of engineers. The full migration represents a paradigm shift: Instead of completing a product cycle and starting a new one, original equipment manufacturers will continuously improve each car model and use software updates to keep digital features current. For automakers, the shift to continuous development means greater flexibility and faster time to market.

- **Become a talent magnet.** Rising attrition levels have made attracting and keeping engineering talent a top priority for many traditional ER&D companies. One solution is to develop what some companies call a technology hub in cities teeming with tech expertise. A second approach is to acquire software companies as cultural umbrellas that draw tech talent. Some companies embrace

a bigger shift, transforming the culture of their engineering and R&D departments to appeal to young engineers. To do that, they flatten hierarchies, offer permanent learning opportunities, focus teams on the most exciting problems, and allow remote work.

- **Play offense on innovation.** Collaborate with external partners, including start-ups and other innovation sources, to accelerate the pace. Acquire new capabilities and technologies through M&A. Verizon, for instance, has created a new business incubator to develop its product ecosystem, including 5G, and explore adjacent technologies such as location technology and sensor intelligence. Verizon's investments in these new business areas aim to further help the company innovate and outpace the competition.

Engineering-heavy companies face a once-in-a-generation strategic shift. Digital technologies offer the opportunity to reshape traditional ER&D businesses, but deploying them brings new challenges. Winners in the coming decade will be those that use those technologies to accelerate time to market, lower the cost of new products, and take a novel approach to value creation.

Bridging the Talent Gap in Engineering and R&D

How successful companies are transforming engineering roles to attract and retain top talent.

By Daniel Suter, Bill Radzevych, Junna Hashimoto, Parvathy Kailasam, and Jessica Port

At a Glance

- Nearly three-quarters of engineering and R&D-focused companies report talent gaps.
- Data engineering and analytics, cybersecurity, and the Internet of Things are among the most sought-after capabilities.
- Leading companies are offering better work benefits and unearthing new talent pools.

Every engineering chief technology officer is feeling the pain. Industrial firms are urgently seeking to expand their ranks of engineers to cope with new technologies and fast-changing markets while tech giants have been luring away some of their best engineers for years.

In fact, 73% of engineering- and R&D-focused (ER&D) companies report talent gaps, and that divide will widen as baby boomers retire more quickly than new graduates fill their shoes. Adding to the problem, midcareer engineers are transitioning to nonengineering roles. Globally, the percentage of engineers quitting their jobs at engineering companies has risen to between 16% and 17%, up by nearly 2 percentage points from three years ago.

The shortage of engineering talent is affecting all geographies and is likely to continue throughout the coming decade. Leading companies are realizing that in a tight talent market, it's as important to improve the attractiveness of engineering roles as it is to scour the market for new pockets of labor.

Employee demands are changing, and traditional engineering firms won't be able to attract talent to expand their roster of engineers without significantly transforming the value proposition they offer to potential employees. With the recent waves of tech layoffs, there is a rare opportunity to recruit some much-needed talent.

The engineering brain drain

As technologies in all industries grow increasingly integrated and complex, IT and engineering functions are converging in companies large and small. That means tech companies such as Alphabet, Amazon, and Microsoft are entering industrialized markets outside the software sector and competing for a slice of the business.

Fierce competition for talent means that attrition rates at ER&D companies are likely to increase over the next three years, according to Bain research. That trend will be exacerbated by the retiring baby boomer generation. The number of graduates in STEM disciplines grew at an average annual rate of 1.8% from 2016 to 2019 in OECD countries, while the population reaching retirement age (65 and older) during the same period grew at 6.2% each year.

About 40% of young engineering professionals globally say they are likely to change jobs within the next six months.

But young employees are also leaving engineering firms for more attractive jobs. About 40% of young engineering professionals globally say they are likely to change jobs within the next six months, according to a recent Bain survey. Many say they are frustrated by the low level of productivity at traditional engineering firms. For instance, aerospace and defense engineers say they spend only about half their time on active engineering work, of which more than 30% is spent on rework and more than 40% on lower-value tasks.

Attracting top talent

While all engineering firms are competing for talent, only a few succeed at consistently attracting the best people. Those winning this talent war follow a few key guidelines:

Provide career path transparency. In the competition for talent, it's important to determine what rates and packages other industries are offering for specific roles and candidate backgrounds. If it is tough to dramatically change compensation in low-margin industries, CEOs do have several other options to recruit and retain top talent. For one, they can reward top employees with promotions. Many engineers move to tech firms, where promotions to new roles are possible every year or two. By contrast, it may

take engineers five years to be promoted at traditional engineering or industrial firms. Shortening the promotion cycle will help secure young and midcareer employees. It also helps to make sure engineers understand what it takes to earn a promotion. At software company Miro, for example, managers share their 30-, 60-, and 90-day goals with new hires and help create a roadmap to achieve them.

Pay for skill, not for tenure. A Snowflake developer who is able to create state-of-the-art cloud-based analytics solutions is much rarer than a Java developer with the same tenure. Still, many companies would pay either of them the same wage if they had the same number of years as developers under their belts.

Leading ER&D companies are starting to classify employees' skills depending on whether they are more mainstream or premium. Those with more premium skills, such as fluency with Kafka (a framework used to store, read, and analyze streaming data), receive higher salaries than those with more standard skills.

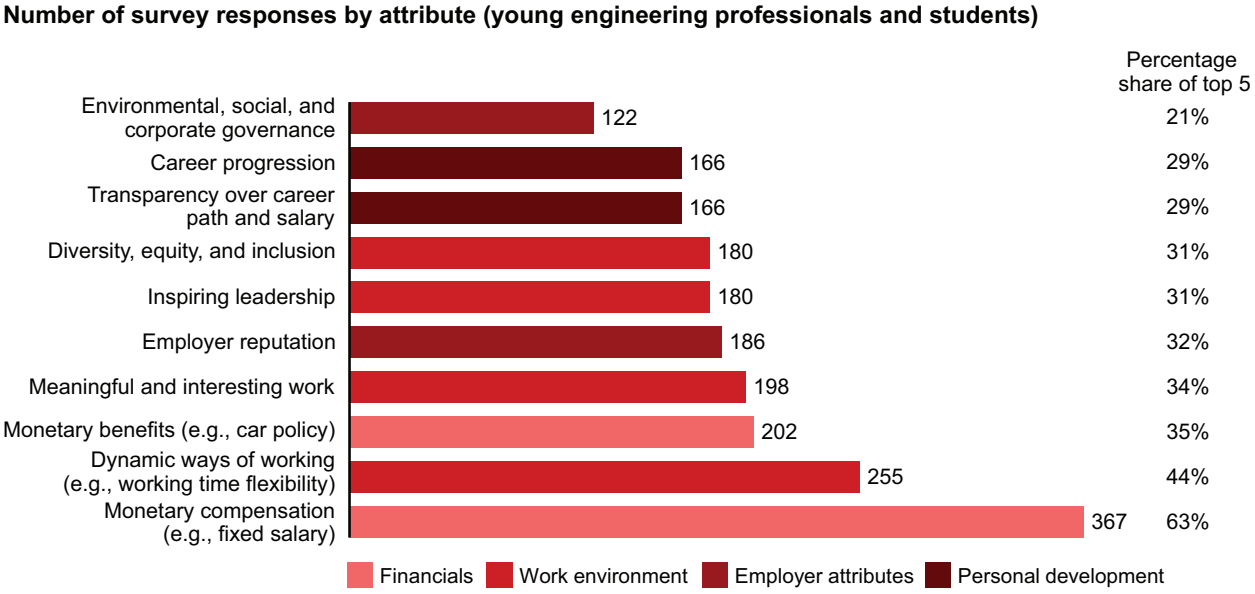
Foster employee development. Entice employees by providing learning opportunities including international assignments and new skills training. Audi, for example, announced a training budget of €500 million in 2022 to instill new digital skills necessary for the technical staff. Thousands of Audi employees every year take advantage of training in software development, data analytics, charging technology, and systems engineering. Amazon, on the other hand, offers employees self-directed online cloud-learning resources to earn additional credentials at no cost.

An attractive work environment also includes hybrid or flexible working models and programs to ensure emotional and psychological well-being.

Make work meaningful. One way to keep work interesting for employees is to improve efficiency and automate low-value work. Another option is to assign new employees to projects that allow them to see the impact of their work quickly. Netflix, for instance, assigns new hires to key projects that are close to completion to ensure they quickly feel a sense of satisfaction for the achievement and become motivated. An attractive work environment also includes hybrid or flexible working models *(see Figure 1)* and programs to ensure emotional and psychological well-being. In the wake of the Covid-19 pandemic, many employees consider such support a nonnegotiable benefit.

Engage and inspire. Build ecosystems that connect employees to the company's mission and provide exposure to new ideas. One approach is to create different cultures within an existing company. For example, some auto companies have acquired software or tech companies to create a unit with a start-up culture and office design. Others, such as Siemens, are adopting a "tech hub" model, in

Figure 1: What matters most to young engineering professionals and students when choosing jobs?



Notes: Question 1 to young engineering professionals asked, "What attributes are most important when considering switching to a new potential job? (rank up to 5)"; question 2 to engineering students asked, "Which attributes are currently most important to you when considering a job post-graduation? (rank up to 5)"; sum of participants that ranked category in top 5 divided over maximum potential sample size; excluded "other" (8 responses)
Source: Bain Young Engineering Professionals and Engineering Students survey (n=801)

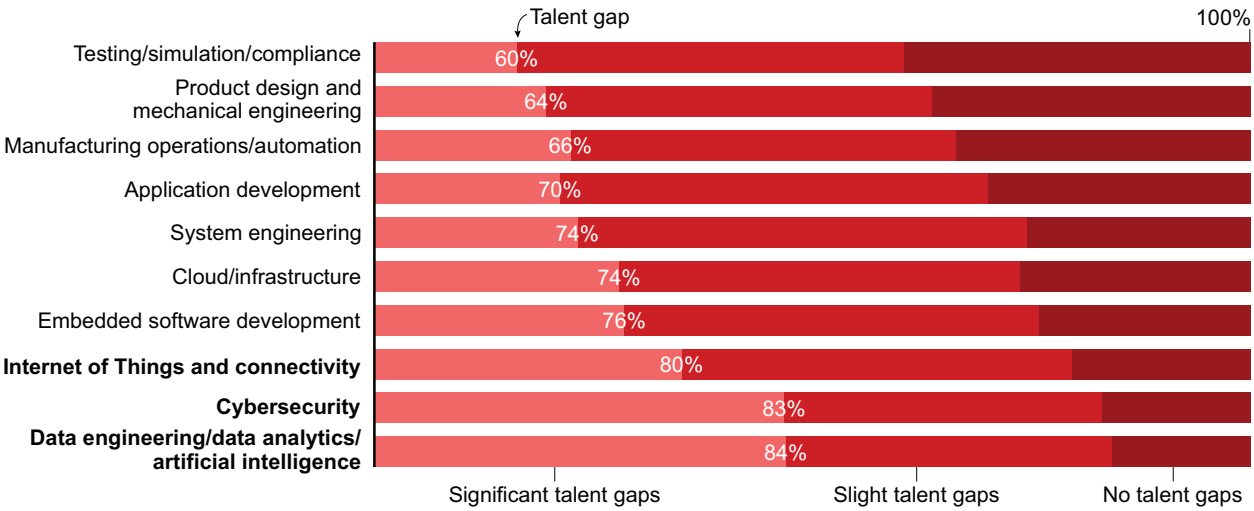
which the tech enterprise has its own campus and has perks typically seen at tech companies. Siemens' Lisbon tech hub, for instance, has a pool, a garden, game rooms, and gourmet food for employees. Others, such as Volkswagen, host open innovation challenges to gather ideas that could revolutionize the future of mobility.

Tailor jobs to what matters most. Identify the critical talent roles for the firm, and customize employment packages for each one. For instance, millennials and Gen Z are now already more than 40% of the workforce, and they have very different motivations than prior generations, according to a recent Bain survey. Companies that understand the different needs of their employees also regularly measure employee satisfaction. Indian telecommunications firm Airtel and payments company Paytm, for instance, use software from inFeedo to identify employees at risk of quitting, predict burnout, and reengage the workforce.

Tap into new talent pools. Company alumni may be particularly receptive to recruiting. In Bain surveys of young employees who have quit companies, more than 50% said they would be willing to return if they received a raise in salary, and 20% said they would consider returning if former employers significantly improved the work environment by offering flexible working time, for example, or programs to attract more diverse colleagues.

Figure 2: The talent shortage is most acute in data engineering and analytics, cybersecurity, and the Internet of Things

Percentage of survey respondents by capability



Notes: Decision makers were asked, "Do you expect talent gaps in the below capabilities over the next three years? (single choice by capability)"; results filtered for aerospace and defense; the formula for calculating talent gap percentage is first adding number of slight talent gaps together with the number of significant talent gaps and then dividing the sum by the total number of responses
Source: Bain Engineering and R&D survey 2022 (n=505)

Outsourcing and offshore hiring can help address shortages in digital engineering capabilities that are in highest demand, such as data engineering and analytics, cybersecurity, and the Internet of Things (IoT) *(see Figure 2)*. Companies facing high attrition rates are already 2.2 times more prone to accelerate offshore hiring for engineering activities vs. companies that have lower or decreasing attrition rates.

Leading companies also seek out young talent through partnerships with universities. The collaboration could include funding financial scholarships, student innovation competitions, or training for high-priority candidates. Volkswagen, for example, is considering financing programming schools in Mexico and Brazil to improve its access to software developers.

Finally, gig workers can help fill talent gaps, especially in IT and digital engineering roles. Tech companies such as Google, Salesforce, and Meta regularly employ contingent workers that allow them to quickly grow or shrink the workforce. Service companies including Wipro, TCS, and Cyient also are starting to use gig workers. Wipro, for instance, acquired Topcoder, a company with an open global community of developers, data scientists, and programmers that sells the community's services to business clients.

Chief technology officers of global engineering and R&D firms face a long-term battle for talent. Leaders are making gains by rethinking compensation packages, career paths, and the work environment. Above all, innovators are taking a lesson from other industries and mining new sources of talent.

Engineering and R&D: The Path to New Sources of Value

Leaders are using engineering and R&D to reimagine the business around customer outcomes and experiences.

By Daniel Suter, Peter Hanbury, Caitlin Sweeney, and Shintaro Okuno

At a Glance

- Artificial intelligence, machine learning, and other technologies allow companies to embed novel features in their products and enhance the customer experience.
- Engineering-heavy companies are also developing new sources of value by improving environmental, social, and corporate governance outcomes.
- Top engineering and research organizations build an ecosystem of partners to fuel innovation.

At global medtech giant Stryker, the leadership team's quest for new sources of value creation is transforming the business. Once focused mainly on medical products, the company has moved over the past decade into preoperative surgical planning, digital physician advisory, robotic surgery, and wearable devices to track rehabilitation. Digital sensors harvest data at each step in the patient journey to continually improve Stryker's products and ensure the best medical outcome.

Companies like Stryker are leading a vital shift in the way they wield technology and innovation in engineering and R&D (ER&D) as a source of value creation and competitive advantage. Historically, companies have viewed ER&D as a core function, but their primary focus was on making products better and cheaper. Today, an emerging group of leaders are investing in it as a strategic capability.

These companies put ER&D and new technologies at the center of their businesses and wield them in bold new ways to innovate and reinvent business models. Instead of concentrating largely on improving products, they are moving into outcome-based solutions that allow customers to pay based on negotiated results, such as machine uptime.

How does this work on the ground? CTOs and ER&D teams are developing software, hardware, and services to improve customer outcomes and experiences *(see Figure 1)*. For example, instead of selling a hip implant, Stryker's ambition is to ensure successful hip implant surgery and rapid recovery.

To reimagine the business around the concept of customer outcomes and experiences, leadership teams are accelerating their investments in several key areas. First, companies are embedding novel features in their products based on artificial intelligence, machine learning, cloud connectivity, and edge computing, which is a form of computing done on-site or near the source of the data, minimizing the need for remote data processing. Such features can transform unconnected products into smart devices.

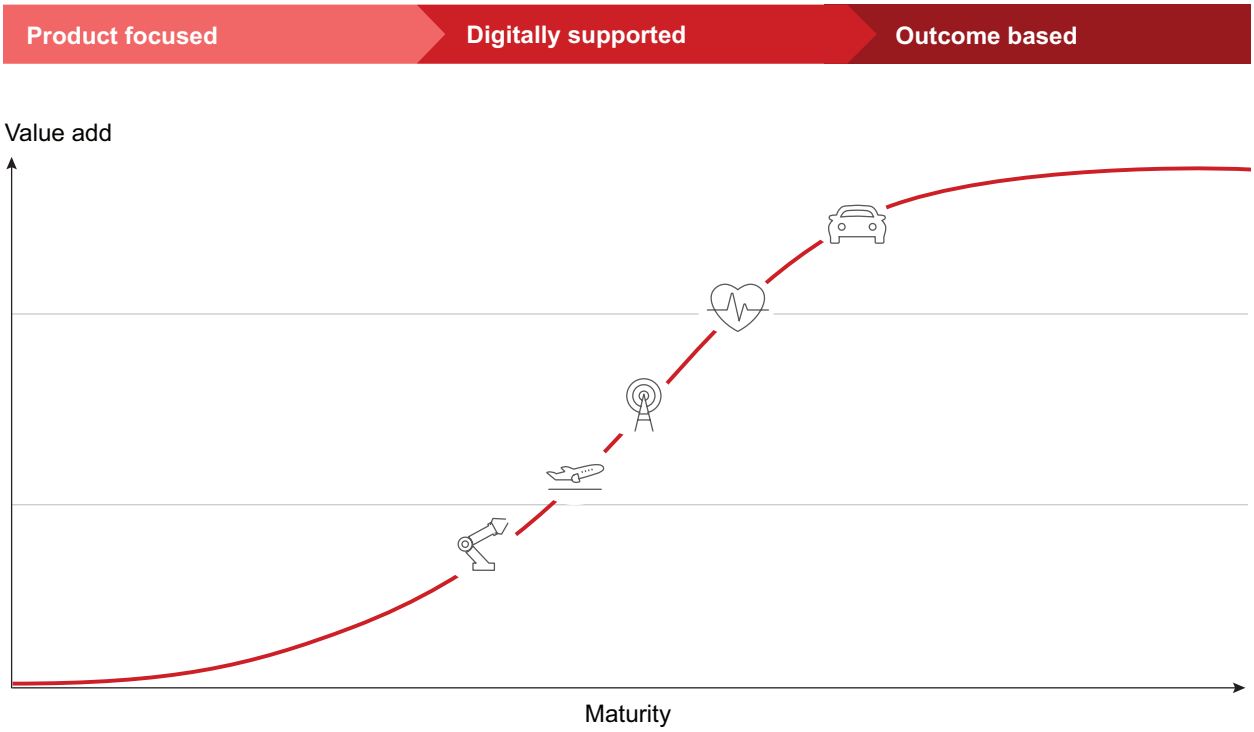
A second area of investment to enhance customer experience involves designing products for continual upgrades and new services. Digital technologies allow companies to send upgrades via software or over the air. The aim is to delight customers with new experiences and produce an ongoing stream of revenue as opposed to a one-time product sale.

Companies are also creating new sources of value by improving environmental, social, and corporate governance (ESG) outcomes. Many are investing in new technologies to lower the firm's carbon footprint and reduce the carbon emissions of their products. Leaders are designing goods for a circular economy by reusing materials, recycling, and remanufacturing products to extend their life. Circular design involves the use of modular components that are easy to replace or upgrade, enabling a longer life span. Remote monitoring technology can help firms better understand the value of a device in the field and its potential for refurbishment.

CTOs leading the race to find new sources of value creation are investing in all of these areas, often in combination. For example, Google Nest tapped artificial intelligence and machine learning to add innovative new features to standard thermostats. The result was a smart thermostat supported by cloud-enabled services that can learn a customer's schedule and program itself to save energy. The innovation transformed the customer experience and forged a new market segment. Smart thermostats are expected to capture 18% of the thermostat market by 2028.

The risk of technology-based disruption adds urgency to the search for new sources of value creation. Companies in ER&D-heavy industries that do not invest and innovate to improve the customer experience may find themselves rapidly sidelined by nimble rivals.

Figure 1: Strategic value creation in engineering is transitioning toward outcome-based solutions



Benchmarks at this stage

Product focused	Digitally supported	Outcome based
Automotive and mobility Better and more economical cars	**Automotive and mobility** Autonomous driving	**Automotive and mobility** Robo taxis
Medical devices Equipment for medical procedures (e.g., hip joint replacement)	**Medical devices** Personalization of medical products (e.g., 3D-printed hip joint)	**Medical devices** End-to-end patient outcomes throughout diagnostics, surgery, and rehabilitation
Telecommunications Faster communication infrastructure	**Telecommunications** Optimized network management and data-driven services (e.g., traffic forecasting)	**Telecommunications** New business models (e.g., vehicle monitoring)
Aerospace and defense Higher-performing and safer aircraft	**Aerospace and defense** Advanced route and fuel optimization	**Aerospace and defense** Aircraft as a service
Advanced manufacturing and services Equipment and services	**Advanced manufacturing and services** Remote equipment monitoring	**Advanced manufacturing and services** Machinery as a service—based on output

Sources: CTO discussions; Bain analysis

From product to service

The path to new sources of value creation differs by industry, but many first movers are reimagining their products as a service. Until recently, for example, automakers viewed their core business as producing vehicles. Now, many define their business as providing mobility. These leaders expect services to become a significant share of their business as they expand into new areas of mobility, including self-driving taxis, connectivity, and features that make driving easier, more pleasurable, and more productive.

Volkswagen, for example, sells electric vehicles (EVs), but also provides a charging service on multiple continents with one convenient wireless identification card. To ensure a seamless customer experience, it has teamed up with infrastructure providers to develop a simple and standard process that allows drivers to charge their cars at locations across the US, Europe, and China.

In aerospace, companies that once focused on selling planes increasingly are developing products and digital services that enhance the customer experience prior to the flight, in the air, and after landing. For example, Airbus and German authorities recently launched a research initiative on urban air mobility that will explore electric vehicle takeoff and landing for trips within cities and from one city to another.

Machinery companies are undergoing a similar shift. Instead of selling equipment with traditional service contracts, leaders are offering solutions that generate greater value for their clients. Such contracts may guarantee machine uptime, output rates, or other productivity metrics. Switzerland-based construction power tool company Hilti is expanding from hardware into construction software to improve construction productivity. It recently acquired Silicon Valley construction management software company Fieldwire, which is improving productivity on construction sites by optimizing coordination among owners, general contractors, architects, engineers, and other subcontractors.

Some companies and industries are further down the path than others in developing new sources of value based on enhanced customer experience. One early lesson: Success requires cross-functional collaboration. Leaders start by identifying the customer need. Next, the salesforce designs a proposition and pricing model. That ensures ER&D teams will create the right product.

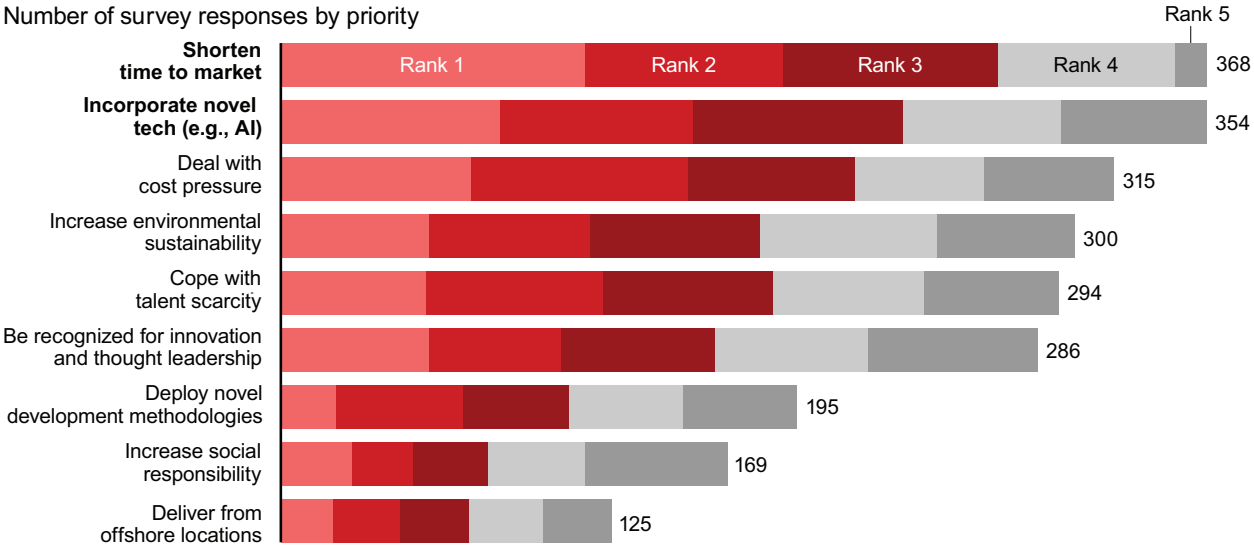
Outcome-focused engineering

What sounds easy in theory is extremely challenging in practice. Companies that take broader responsibility for outcomes need to deploy digital technologies that can dramatically reduce error rates and variable results. Take the case of self-driving cars or planes. To make autonomous vehicles safe, ER&D organizations must use fundamentally different technologies and develop new capabilities. Outcome-focused engineering requires big data and analytics capabilities, control over multiple value chain steps, and human-centric and personalized product design.

How are leading ER&D organizations supporting the transition to new business models? One important step is building a digital twin, or a virtual model of products out in the field. A digital twin can, for example, alert engineers to problems before they occur, chart energy use, and improve productivity. In designing a product, digital twins can be used to run simulations that help catch errors before the product trial phase, reducing time to market.

Figure 2: Top priorities in engineering and R&D are shortening the time to market and incorporating novel technologies

Which of the following engineering and R&D priorities are most critical for your company? (rank up to 5)



Notes: The share of top 5 is the sum of participants who ranked category in top 5 divided by maximum potential sample size; excludes "other" (6 responses)
Source: Bain Engineering and R&D survey 2022 (n=505)

Another vital step is building a talent pipeline for the necessary engineering and IT capabilities, including data science, including data science, Internet of Things (IoT), and cybersecurity expertise. Leaders also are expanding the engineering teams' scope of activity across the product life cycle. Nearly three-quarters of CTOs say shortening time to market is a top priority for engineering departments, while 70% say incorporating novel technologies into products and services is a key priority *(see Figure 2)*.

Organizational change

Successful CTOs have understood that redesigning the ER&D organization is critical to focusing more effectively on customer experience and outcomes. That means expanding the engineering team's scope of activity, modernizing the operating model, processes, and workflows, and developing an effective human capital strategy and culture *(see Figure 3)*.

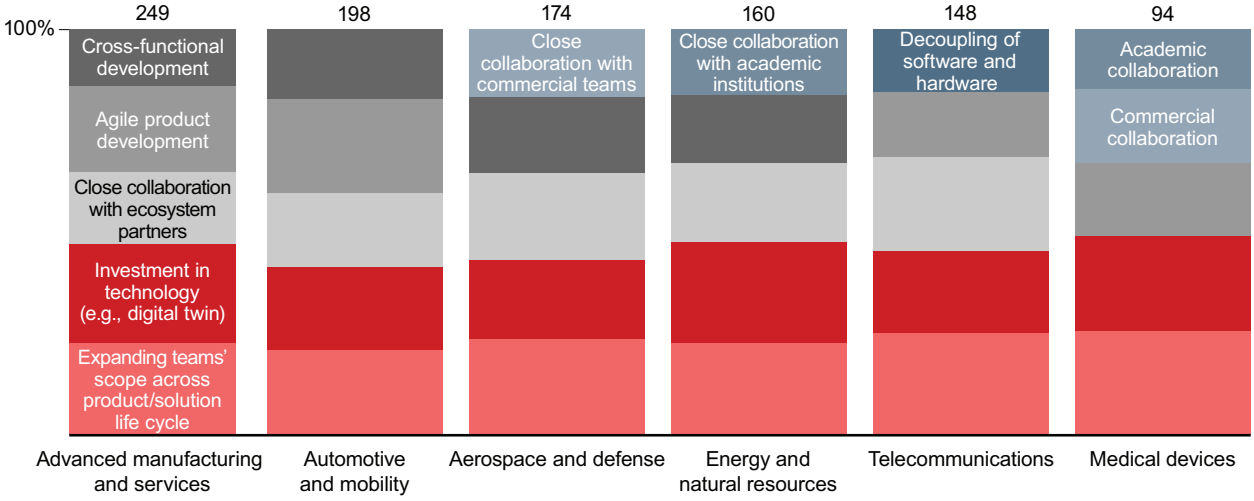
One important organizational change is the need for interdisciplinary teams that provide access to strategic assets such as technology expertise to all departments. For example, a European leader in building technologies has bundled its embedded software and hardware capabilities in a cross-functional team. That team now provides different internal units throughout the organization with a modular set of software and hardware building blocks that they can use to build products.

A second major organizational difference is the shift from cyclical product development toward continuous technology development. In the long run, an Agile approach shortens time to market

Figure 3: Leading companies are expanding the scope of engineering teams' activity

What approaches will contribute most to value creation in engineering and R&D over the next 10 years? (rank up to 3)

Top 5 approaches by industry



Note: Excludes "other" (9 responses)
Source: Bain Engineering and R&D survey 2022 (n=505)

and reduces unit costs. Software development leaders such as Amazon and Netflix highlight the power of continuous development by using software code to upgrade their products thousands of times a day. Cross-disciplinary teams are key to continuous development as they are more likely to develop efficient solutions. Instead of having different departments create electronic control units for various functions in a car, for instance, one cross-functional team can use its combined expertise to consolidate the customer experience functions in fewer chips.

Leading ER&D organizations also embrace open engineering. They build an ecosystem of partners to fuel innovation and broaden their capabilities. Siemens and Qualcomm Technologies, for instance, joined forces to develop 5G-enabled smart building networks. The goal of the building automation partnership is to improve energy efficiency, reduce the cost of building ownership, and enhance security.

To free up engineering talent for more critical tasks, top CTOs are investing in automation, technology, and artificial intelligence. That approach also increases engineering efficiency, generating cost savings to invest in upskilling and hiring.

In the coming decade, ER&D teams will be critical sources of competitive advantage. They will improve existing products, unearth new sources of value creation, and lay the foundation for entirely new business models. Leaders know that developing new sources of value takes time. Those that start down that path today will be best positioned to compete in a new era.

The Digital Shift Fuels Outsourcing in Engineering and R&D

Soaring demand for digital capabilities has research-dependent firms rethinking what needs to be done in-house and onshore.

By Daniel Suter, Sudheer Narayan, Neil Malik, and Bhanu Singh

At a Glance

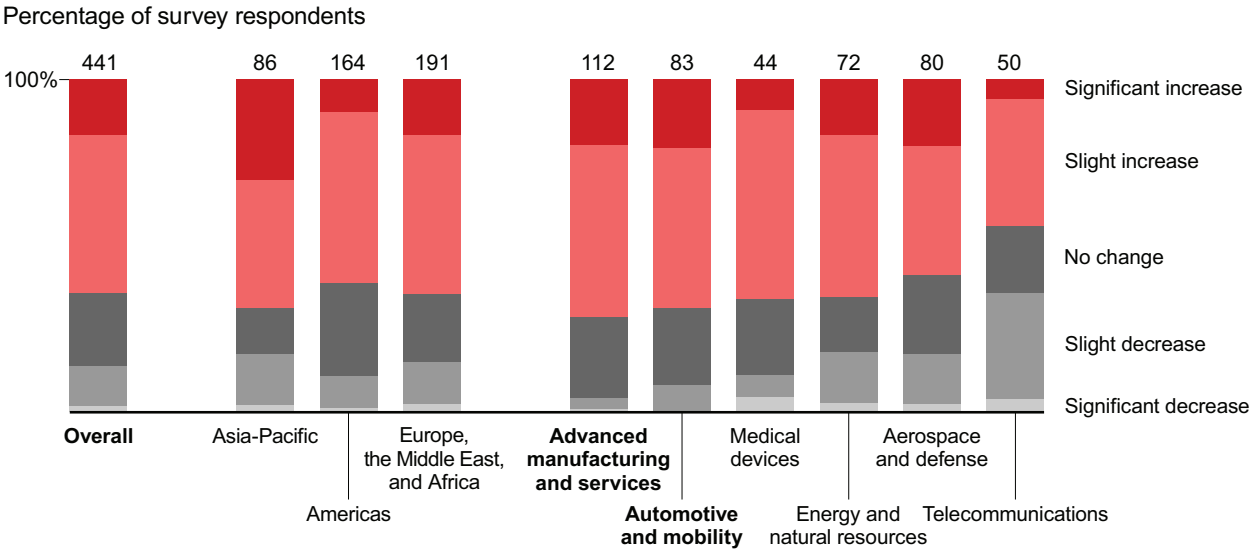
- Bain research shows 60% of engineering executives plan to increase outsourcing over the next three years.
- In a strategic shift, companies are outsourcing a wider scope of activities, including full programs, instead of augmenting staff.
- The most important factor in choosing an outsourcing partner is expertise, not cost, Bain survey results show.

As engineering and R&D (ER&D) organizations seek to innovate faster amid a talent shortage, many are opting to outsource and offshore an unprecedented proportion of work once done in-house. Leading companies are using outsourcing to overtake rivals in the innovation race by boosting value creation and accelerating time to market. Flexible labor pools help them respond faster to surges in demand, access missing capabilities, and free up in-house talent for more complex projects.

Signaling a strategic shift, 60% of companies plan to increase ER&D outsourcing over the next three years, according to a recent Bain survey of more than 500 senior engineering executives *(see Figure 1)*. Similarly, 60% of respondents said they plan to shift work offshore or nearshore in the same period. Historically, large engineering or research-dependent companies have outsourced about 18% of ER&D

Figure 1: More than 60% of senior executives expect to increase the engineering and R&D activities they outsource

Expected change in companies' share of outsourced engineering and R&D activities over the next 3 years



Source: Bain Engineering and R&D survey 2022 (n=505)

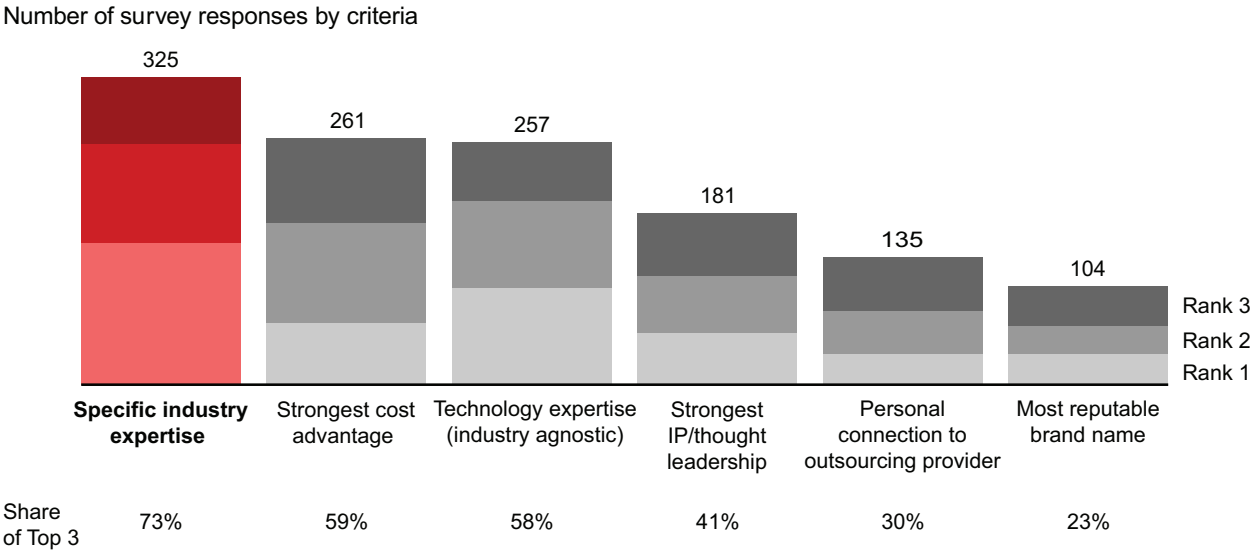
work by value. That level is far lower than that in the IT services sector, which went through a similar transformation in the 2000s and now outsources 46% of activities. The level of offshoring and near-shoring in ER&D is also significantly lower than it is in IT services.

What work does ER&D include? For our study, we define it as activities aimed at developing new products and services and improving existing ones. Traditionally, ER&D includes early foundational research, design testing and verification of products, infrastructure (for example, a manufacturing plant), and post-production support. An emerging group of leaders are also investing in ER&D as a strategic capability that can support innovation and reinvent business models. As part of that approach, many are reconfiguring their products as outcome-based services and solutions that allow customers to pay based on negotiated results, such as machine uptime.

In addition to accelerating innovation, outsourcing and offshoring also help leadership teams address chronic talent shortages and mounting cost pressure. More than 80% of the senior executives we surveyed report talent gaps in areas requiring digital expertise, including data engineering, data analytics, artificial intelligence, cybersecurity, the Internet of Things (IoT), and connectivity, but also in other crucial areas such as systems engineering. Underscoring that trend, 73% of respondents said industry or technology expertise is the most important factor in selecting an outsourcing partner. That compares with 59% of respondents who cited cost as the No. 1 factor *(see Figure 2)*.

Figure 2: Industry expertise is the most important factor for engineering and R&D executives when choosing an outsourcing provider

Top 3 criteria for selecting an engineering and R&D outsourcing provider



Notes: The share of top 3 is the sum of participants that ranked category in top 3 divided over maximum potential sample size; excluded "other" (14 responses)
Source: Bain Engineering and R&D survey 2022 (n=505)

Digital engineering

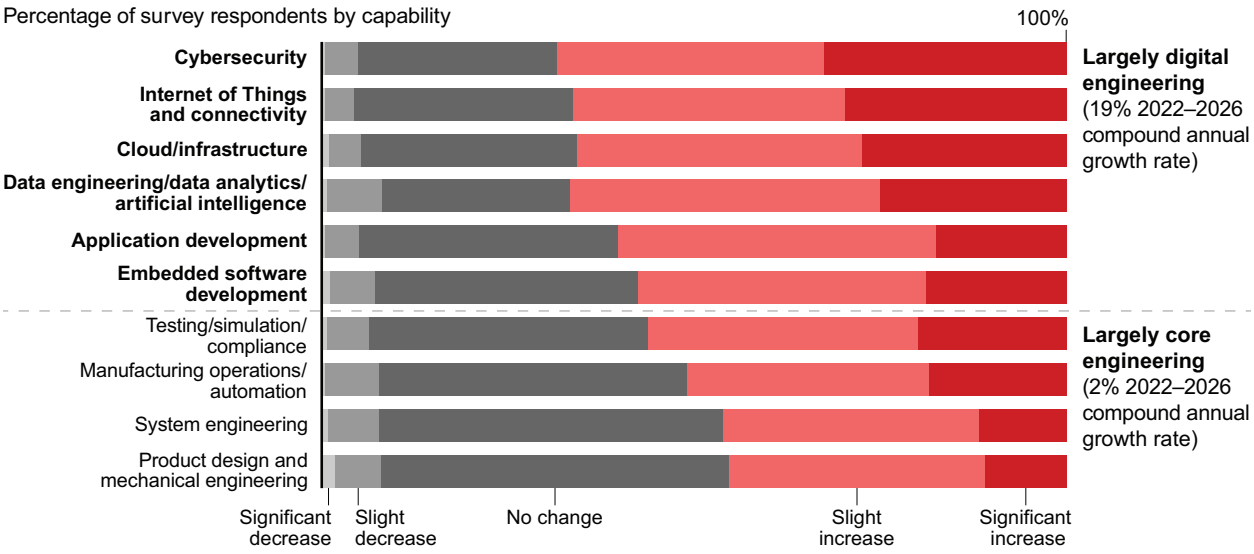
ER&D outsourcing is growing in all areas of expertise covered by the survey, and the type of outsourced work is changing. Companies are also seeking new capabilities from service providers. In the past, demand focused primarily on mechanical and core engineering skills. Today, executives plan to invest significantly in digital engineering capabilities, particularly cybersecurity, IoT, cloud, embedded software, and data engineering and analytics *(see Figure 3)*.

Software talent gaps fuel offshoring because global markets have deep pools of digital talent and software is easy to develop and deliver from remote locations. At the same time, companies are outsourcing legacy disciplines that are often less strategically relevant for original equipment manufacturers (OEMs). Many service providers have significantly optimized legacy operations such as mechanical engineering, testing, simulation, and compliance.

The use of ER&D service providers varies by industry. Our research shows the sectors most inclined to increase outsourcing over the next three years are advanced manufacturing and services, automotive and mobility, medical devices, energy and natural resources, and aerospace and defense.

Figure 3: Engineering and R&D leaders anticipate the sharpest outsourcing growth in cybersecurity, Internet of Things, and cloud activities

Expected change in share of outsourced engineering and R&D activities over the next 3 years



Source: Bain Engineering and R&D survey 2022 (n=505)

Finally, the types of projects are changing. Historically, large research organizations have mainly outsourced activities like testing, validation, and compliance while keeping core systems and products in-house. Now, the same companies are outsourcing a wider scope of activities, such as the end-to-end design of products or the development of key components such as combustion engines, traditionally a vital capability of automotive OEMs. While combustion engines still represent a large commercial market, OEMs are shifting their ER&D resources to next-generation electric power trains and new areas such as software-defined vehicles—including self-driving and connected cars—that can continually be upgraded. Many OEMs and Tier 1 suppliers are looking for partners to increase their software engineering capabilities.

Risk sharing

At the same time, ER&D-focused companies want outsourcers to take on more responsibility. Of companies already outsourcing, 60% of respondents said that they are increasingly switching from traditional staff augmentation ("body leasing") to engagement models, in which service providers assume a larger role managing the project and share risk.

Engagement contracts may include full work packages or products such as the complete development of a smart watch.

In a similar move, Rolls-Royce Holdings shifted part of the civil aerospace engineering work from its Bengaluru, India, operations to Infosys, which will provide high-end engineering and R&D services integrated with advanced digital capabilities. By outsourcing that work, Rolls-Royce aims to benefit from an influx of new capabilities while reducing its costs.

As companies adjusted working practices in response to Covid-19, many in-house teams began challenging the notion that service providers need to be in close proximity, increasing the opportunities for outsourcing.

In practice, the engagement model varies in scope. In more hardware-dominated engineering areas, upstream processes for engineering and R&D services, such as concept design and architecture, require a smaller staff but greater expertise and closer proximity to the client. Downstream processes, including detailed engineering and testing, require a larger staff but slightly less expertise, and the outsourcer does not need to be close to client sites. As companies adjusted working practices in response to Covid-19, many in-house teams began challenging the notion that service providers need to be in close proximity, increasing the opportunities for outsourcing.

Getting results

Engineering outsourcing and offshoring, once tactical solutions, are now strategic moves that help companies respond to innovation and cost pressures. Executives at leading ER&D-focused organizations follow a few important strategies to get the best results from outsourcing and offshoring:

Dare to outsource. Make a courageous decision about the activities that are not core to innovation and differentiation. Evaluate where the speed of closing capability gaps outweighs the importance of doing the work in-house. BMW, for instance, outsourced its next-generation charging electronics program to KPIT, a service provider specializing in vehicle electrification engineering and software. While the hardware and software that manage the battery and its use are core elements of the electric power train, outsourcing them can help BMW accelerate time to market. For companies lacking in-house capabilities, outsourcing components and modules can shorten development times by more than half.

Build an ecosystem of partners. Select three to five service providers with a strong partnership approach. Supplement this core group with smaller specialists in areas that require niche expertise. Reducing the total number of service providers helps both parties build higher-quality relationships. That, in turn, leads to greater efficiency and better pricing. It also opens the door to outsourcing larger projects.

Increase use of attractive outsourcing models. Companies that outsource entire engineering work packages, which include deliverables such as data, drawings, and models, often find that approach to be more economical than augmenting staff. For example, in workloads like technical documentation and aftermarket support, the dominant commercial model is based on the unit of work (fee per document, depending on complexity), as opposed to the number of engineers deployed. Outsourcing entire packages gives business leaders more predictable costs and allows service providers to deliver the benefits of standardization, automation, and an integrated global delivery model.

Coinvest with service providers for the long term. Jointly identify new outsourcing locations, both onshore or offshore, including centers of excellence. Investing together can help attract talent and rapidly build new capabilities. Coinvesting requires senior managers to commit to a strategic relationship. Leading companies ensure their teams have on-the-ground knowledge of local regulations, talent, logistics, and cultural issues. A good service partner can accelerate results and provide greater certainty of outcomes. One global tech service provider established a hub for Airbus in Bengaluru to support a platform-based approach in product development. That move gave Airbus access to new talent pools and reduced its costs.

A good service partner can accelerate results and provide greater certainty of outcomes.

For engineering and R&D service providers, the strategic shift toward outsourcing will provide huge opportunities in the coming decade. Leaders are likely to see annual revenue growth of 20% to 25% a year. However, meeting that surge in demand poses challenges. The emerging leaders have differentiated domain expertise, leading-edge engineering processes, and attractive employee value propositions. They also focus on a few strategic imperatives:

Become a talent magnet. Make employee experience a top priority. In a supply-constrained market, firms with the best track record in hiring and retaining talent have a significant advantage. Leaders ensure compensation packages reward those with scarce skills rather than just rewarding them based on tenure. They also create a flexible working environment and provide career path transparency and global mobility, which are increasingly important factors for young professionals.

Combine digital and domain expertise. Many firms offer generic digital services today, but few can combine sector-specific engineering domain and digital expertise. Our research shows that out of a company's total spending on digital engineering, more than 50% requires knowledge particular to an industry domain. For example, engineers need knowledge of aerospace engines to help build digital twins of those engines.

Develop a scalable operating model. Winning firms punch above their weight by combining cost and capability advantages. This requires large-scale offshore locations, an ecosystem of partners (e.g., semiconductor integrated device manufacturers, open-source consortia, and cloud service hyperscalers), and the ability to sell and deliver global projects. Engineering services firms that are still predominantly focusing on staff augmentation will need to build capabilities in project management, continuous performance improvement, and new pricing models.

Engineering and R&D in Aerospace and Defense

Leading aerospace and defense companies are increasing their investments in engineering and R&D and reimagining their business models and their approach to innovation.

By Bernard Birchler, Jim Harris, Hugo Parkinson, and Bill Radzevych

At a Glance

- Most aerospace and defense executives plan to increase their engineering and R&D budget over the next three years.
- Leading companies are investing in digital tools, modularity, and sustainability.
- While employment has still not yet recovered to 2019 levels, aircraft manufacturers expect a sharp increase in production.

Chief engineers in aerospace and defense (A&D) face mounting market pressures. The common denominator is speed—namely, whether to bring products to market more quickly, or to slash the costs of existing products, or to meet sustainability requirements by 2050 (if not earlier). And companies are racing to address these issues all while struggling to fill an expanding talent gap.

On top of this, chief engineers are navigating one of the largest transformations in decades as engineering and R&D (ER&D) expands from traditional disciplines such as mechanical and electrical to include digital ones such as software and cybersecurity.

There is also a shift in how executives view ER&D, a core function for many large companies, itself. Traditionally, the focus has been to make products better and cheaper. Today, many leaders also see ER&D as a strategic capability that will determine their future success and shape new business models.

As a result, the current tumult also opens opportunity for companies that are nimble enough to react quickly. Aerospace and defense leaders who are pulling ahead are responding to these seismic shifts by investing in new areas of ER&D and rethinking their approach to innovation and codevelopment. Finally, they realize that the large-scale layoffs in the tech sector present a rare opportunity to fill existing vacancies and hire the talent they need for the future.

Both commercial airline customers and the government want more for their money and faster. The demand for speed still, however, outstrips the reality of how quickly new planes can be made.

The demand for shorter development cycles and the race to zero emissions

Both commercial airline customers and the government want more for their money and faster. The demand for speed still, however, outstrips the reality of how quickly new platforms and systems can be made. In fact, many commercial and traditional defense programs launched within the past decade have not met their ambitious timelines.

In the defense sector, evolving global threats such as the conflict in Ukraine have increased pressure to hasten defense acquisitions. In 2015, the US Department of Defense (DoD) created a division called the Defense Innovation Unit (DIU) that uses advances in commercial technology to help the military deploy cutting-edge defense systems faster without the red tape of the traditional procurement system.

For instance, in 2022, the DIU turned 17 commercial prototypes into fully fielded military capabilities, up more than 50% from the prior year. One of the prototypes awaiting their launch is GigEagle, a platform that uses machine learning to find experts in the US National Guard and Army Reserve for specific missions. The algorithm scours for hidden skills that are not necessarily part of someone's military specialty but that are highly relevant to evolving military needs. This could be an infantryman who might also be a freelance developer for a tech giant, for instance, or a medic who is a champion-level esports player and could thus more easily learn to pilot drones.

On the sustainability side, pressure is increasing to make aircraft and air travel more sustainable. Airbus, Boeing, and the aviation industry groups have agreed to zero net emissions by 2050—a hugely ambitious goal. In the defense industry, the DoD has followed the lead of the private sector and introduced its own sustainability plan.

Increasing investment in ER&D

To compete in this new world, A&D companies are looking to shift spending and to accelerate ER&D investment. In fact, 59% of engineering executives in the sector expect budgets to grow slightly to significantly over the next three years as they ramp up production *(see Figure 1)*. In January 2023, Boeing, for example, announced hiring an additional 10,000 workers, and Airbus said it expects to add more than 13,000 workers in 2023 to increase production. Leading companies like these are investing in digital initiatives, modularity, and sustainability along the entire value chain.

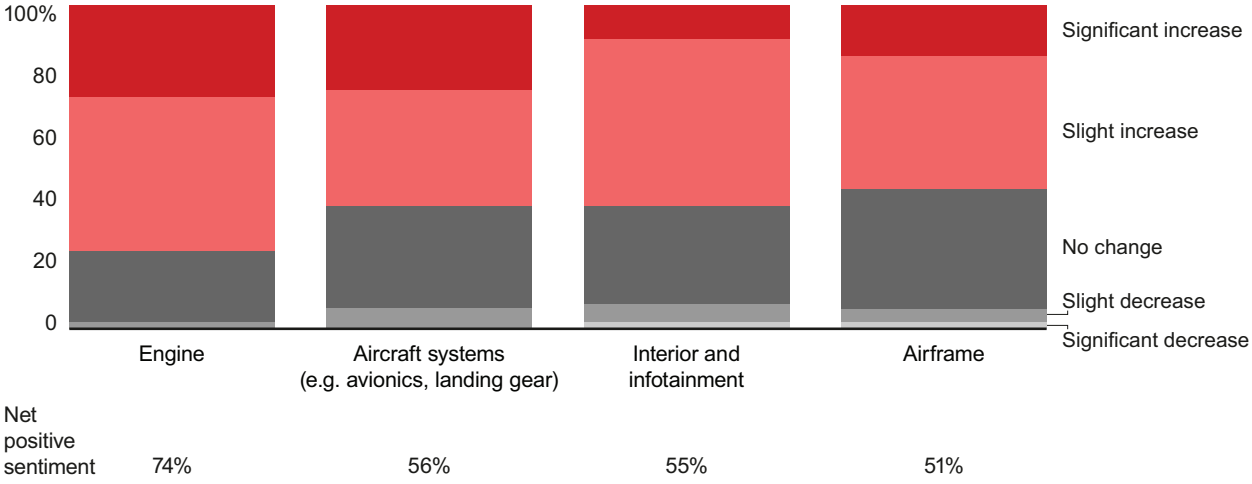
The Covid-19 pandemic accelerated most companies' digital transformation. Now, many are pursuing full digitalization of the engineering process from initial product concept to production. Many companies are developing digital twins—that is, virtual copies of real-world components—to bring products to market more quickly and save millions of dollars.

Digital twins can reduce aircraft downtime and streamline the transition from engineering new parts to manufacturing new parts. Digital twins allow engineers to perform virtual maintenance and model more potential scenarios than a typical physical engine would ever encounter. One such scenario is how an engine will perform in extreme weather.

Figure 1: Most aerospace and defense executives plan to increase engineering and R&D budgets, especially for engines

Question to decision maker: How do you expect engineering and R&D budgets for the respective capability to change (in relative terms) over the next three years? (single choice per component)

Percentage of survey respondents by aerospace and defense component



Note: Net positive sentiment is calculated by subtracting the number of decrease responses from the number of increase responses, and then dividing the difference by the total number of responses
Source: Bain Engineering and R&D survey 2022 (n=505)

Digital twins and augmented reality enable people who are located in different geographic locations to collaborate virtually. The digital twin functions as a single source of data about a given piece of machinery or equipment. Anyone wearing either an augmented reality or virtual reality headset can access information about the assets at all times. The technology allows engineers to interact with the equipment and with colleagues in order to adjust the design or conduct maintenance. Many of these digital tools allow companies to develop products faster and more efficiently, and they reduce recurring costs.

Many of these digital tools, such as digital twins and augmented reality, allow companies to develop products faster and more efficiently, and they reduce recurring costs.

Sustainability is another area in which A&D companies are ramping up investments. ER&D executives are exploring sustainable aviation fuels, hybrid and electric airplanes, as well as new types of engines that can reduce emissions. GE and Safran, for instance, are developing a new type of engine through their Revolutionary Innovation for Sustainable Engines, or RISE, program that aims to reduce emissions by more than 20%. And circular design using modular components that can be replaced and upgraded easily can increase the life span of aircraft.

In the defense industry, leaders approach sustainability differently. Defense capabilities remain the top priority in product design, but executives are addressing sustainability in operations, energy use, and other areas. Northrop Grumman, for instance, set a goal of net-zero emissions for its operations by 2035 and plans to source 50% of its electricity from renewable sources by 2030.

Investments alone, however, will not be enough to pull ahead of competitors. A&D companies also need to change how they approach ER&D. We have identified four success factors that leading A&D companies have on their radar—they include building products that can evolve, reimagining the business model, seeking smart alliances, and finding the right talent.

Build products that can evolve. Leaders are moving from the historical development approach of "build to last" to a new approach of "build to evolve." Consider, for instance, intelligence, surveillance, and reconnaissance satellites. Historically, these satellites cost hundreds of millions of dollars and took years to develop. Once launched, they typically lasted for a decade or longer. Now, new companies are creating smaller, lighter satellites at a fraction of the cost with software that can be updated over the air. These satellites are made out of commercially available technology, and parts can be created

and replaced much more quickly than in traditional satellites. They gather images that are in growing demand by companies and governments for applications in fields ranging from agriculture to finance to insurance.

For the defense industry, global threats are evolving rapidly, prompting companies to develop and deploy new weapons at a faster pace. The Ukraine conflict highlights the need to create immediate, on-the-spot defense solutions. As a result, leaders are evolving their models to keep pace with commercial off-the-shelf systems. Starlink and WhatsApp, for instance, have proved remarkably resilient and resistant to attack, and they provide near–real-time visibility across the battlespace in Ukraine.

For the defense industry, global threats are evolving rapidly, prompting companies to develop and deploy new weapons at a faster pace.

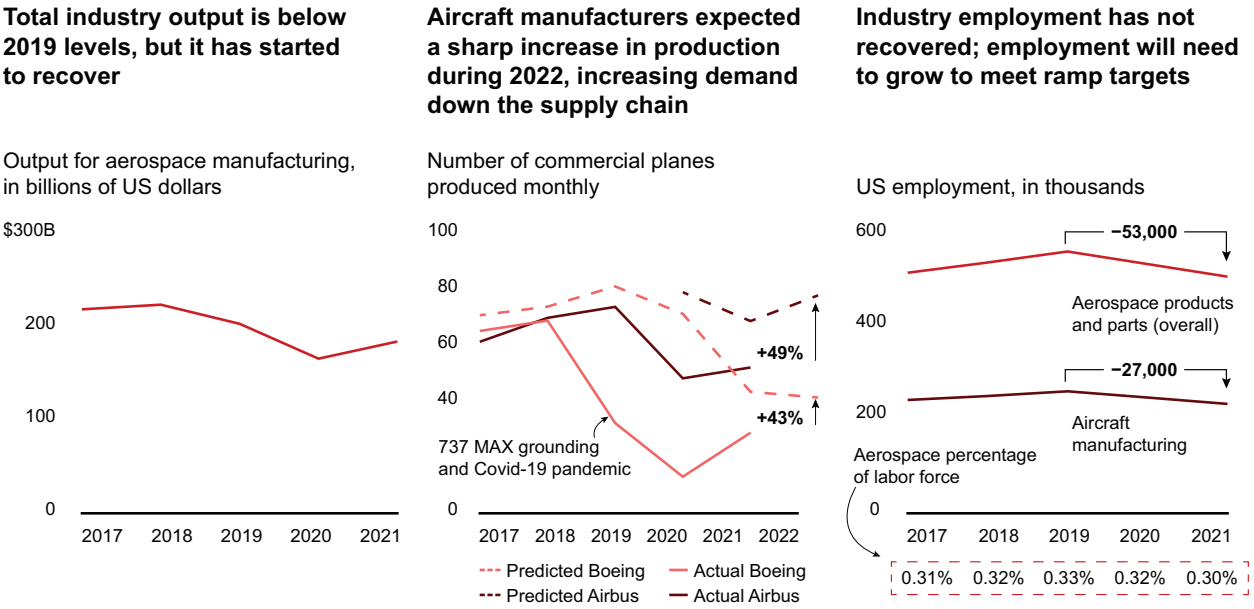
Reimagine the business model. Just as the electric car has ushered in a new era in the automotive industry, the A&D industry is entering a period of transformation. Zero-emissions aircraft will require different value chains and new systems—from engineering to operations and distribution. The adoption of hydrogen, electricity, and sustainable aviation fuels (SAFs) will further alter the value chain.

Airlines won't be able to finance the transformation alone. New companies will help build services in the airport to deliver hydrogen, electricity, and SAFs. Airbus, for example, has partnered with Linde, a global industrial gases and engineering company, to create hydrogen infrastructure in airports worldwide.

A&D companies are no longer solely focused on selling planes and platforms. Just as the auto industry has shifted from making cars to developing mobility services, A&D companies are developing an increasing number of ecosystems with both products and services. Many companies are creating modular-type programs in which the focus is on mission system capabilities rather than an individual product. The DoD, for example, recently awarded a contract to Anduril, a company that offers an anti-drone system powered by artificial intelligence (AI).

Seek smart alliances. Cooperate with innovative commercial companies to bundle resources and investments. With partnerships, there is the potential to benefit from increased data points while protecting intellectual property and getting access to new capabilities. In defense, companies have

Figure 2: Aerospace and defense production and demand are expected to increase sharply, but employment has not yet recovered to 2019 levels



Notes: Sectoral output is the current dollar value of output that has been adjusted for changes in inventory (gross output) and the removal of goods and services shipped among related establishments; predicted production represents predictions made during the previous year; actual production represents production rate reported at the end of the year; broader aerospace and defense industry includes companies in sectors outside of aerospace products and parts (e.g., shipbuilding)
Sources: US Federal Reserve Bank of St. Louis; Boeing annual reports; Airbus annual reports; Boeing Investors Commercial Airplanes Fact Sheet 2016–2022

been teaming up with one another for decades, but current partnerships see traditional companies collaborating with start-ups to leverage software, AI, blockchain, and other technologies for a variety of purposes (e.g., improving the management of unmanned aircraft systems).

Find the right talent. Talent has arguably never been trickier to secure. Aircraft manufacturers such as Boeing and Airbus expect a sharp increase in production while A&D employment still has not yet recovered to 2019 levels *(see Figure 2)*. To meet this growing demand, leaders ensure that employees are tackling the appropriate scope of work and that they are allocating work to the appropriate resources. Above all, they are implementing new productivity tools and finding ways to attract the right talent for the future.

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