Report overview

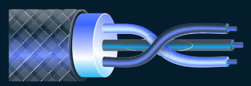
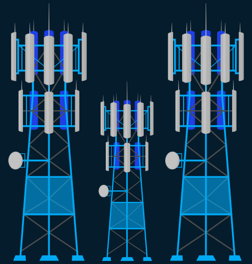
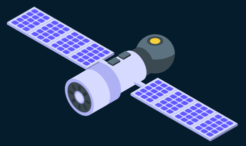
McKinsey & Company

Advanced connectivity

August 2022

What is the trend about, and what are the most noteworthy technologies?

The latest generation of protocols and connectivity technologies has helped networks increase geographic coverage, reduce latency, reduce energy consumption, increase data throughput, and increase spectrum efficiency. This has led to higher-quality network access for consumers and unlocked new use cases for industrial players

	Fixed	Terrestrial wireless			Non-terrestrial wireless
					
Connectivity technology	**Optical fiber**	**LPWA[1] networks**	**Wi-Fi 6**	**5G/6G cellular**	**LEO[2] satellite constellations**
Description	Most reliable high-throughput, low-latency connectivity provided through physical wire	Wireless low-power networks with wide-area coverage supporting a high number of connected devices (eg, NB-IoT[3], LTE-M, LoRa, Sigfox)	Next-generation Wi-Fi (also called "industrial Wi-Fi") with higher throughput, more controllable quality of service, and almost "cellular like" level of security	Next-generation cellular technologies with higher-spectrum efficiency, providing high-bandwidth, low-latency services for consumers and industrial verticals	Wide-area coverage with significantly reduced latency vs existing satellite offerings, due to lower-orbit constellations

[1]Low-power wide-area.
[2]Low-Earth orbit.
[3]Narrow-bandwidth Internet of Things

Source: McKinsey analysis

Why should leaders pay attention?

As advanced connectivity becomes broadly available, industries will find innovative use cases

Monetization opportunities for technology and telecom companies

Uplift in B2B revenues for telecom companies

10–20%

Overall revenue increase from developing 5G-enabled premium connectivity and B2B use cases

Exponentially growing need for network capacity

20–25%

Annual rate of global data creation, which necessitates access to higher-bandwidth networks

Rapid increase in number of connected devices

~51.9 billion

Total number of connected devices expected in 2025, up from 43 billion in 2020

New capabilities for industrial companies and consumers

Impact from industrial use cases

$2 trillion

Estimated global GDP impact, driven by operational enhancements resulting from advanced connectivity in just 4 major industries

Closing the digital divide and enhancing existing connections

~200 million

Number of **individuals accessing the internet for the first time** in 2021, due to new connectivity technologies

Connectivity as an enabler

Enhanced connectivity is an enabler for new and upcoming technologies

- **IoT applications** will increase the need for 5G, Wi-Fi 6, and LPWAN
- **Mobile AR/VR[1] and cloud gaming** are examples of consumer technologies dependent on low-latency, high-throughput wireless networks
- **Edge and cloud computing** technologies, coupled with advanced connectivity, will unlock full benefits of next-gen computing for consumers and industrial verticals

[1]Augmented reality/virtual reality.

Source: DataSphere Forecast, 2020–2025, IDC; “Connected world: An evolution in connectivity beyond the 5G revolution,” McKinsey, Feb 2020; Simon Kemp, “Digital 2022: Global Overview Report,” Datareportal, Jan 26, 2022; Worldwide Global DataSphere IoT Device and Data Forecast, 2021–2025, IDC

Why are advanced connectivity technologies interesting compared with what already exists?

We compared the current generation of advanced connectivity technologies with their predecessors

	Summary	Previous generation	Next/current generation
Optical fiber	Rapid growth has connected millions of people to high-speed internet	Widely used copper had lower throughput and higher cost for an operator	Modern optic fiber brought an exponential increase in **throughput**, much **lower latency,** and lower maintenance costs for telecom companies
LPWAN	Standards designed from the ground up aim to optimize for IoT devices	Relatively costly standard cellular connectivity and low-range tech such as Wi-Fi/Bluetooth drove most IoT applications	Purpose-built LPWAN connectivity standards enable more devices, **higher energy efficiency**, extended **coverage**, and lower connectivity **cost**
Wi-Fi 6	Significantly higher industry readiness has been enabled by improvements in security and connection quality	Wi-Fi 5 brought a marked improvement in indoor wireless connectivity and a major improvement in speed over Wi-Fi 4	Wi-Fi 6 improves upon previous standards in **speed, range,** and **security,** making it more suitable for **industrial applications**
5G/6G cellular wireless	Advanced cellular technology standards are replacing 4G networks, bringing new features and access to new spectrum	4G cellular technology with moderate speed provided true mobile broadband access for the first time	5G/6G offers much higher throughput, device density, **spectrum efficiency, quality of service,** and **security guarantees with** very **low latency** for improved user experiences
LEO satellite constella-tions	These satellite constellations ensure that the most remote locations on earth have high-quality connectivity	Satellite connectivity was for military and industrial applications, with limited consumer usage for internet or communication	LEO satellites aspire to reduce the cost of hardware and increase accessibility to **satellite internet connectivity** by providing enhanced proximity to users

Source: McKinsey analysis

What are examples of disruption that advanced connectivity could cause?

Advanced connectivity will catalyze the adoption of technologies to create disruptions in many industries

$1.2T–$2.0T

Estimated global GDP impact from disruption in just 4 major industries

Automotive

Connectivity could enable **preventive maintenance, improved navigation, prevent collisions**, enable various levels of **vehicle autonomy and carpooling** services, and provide **personalized infotainment** offerings

Healthcare

Low-latency networks and high density of connected devices and sensors make it possible to **monitor patients at home in real time**, which could be a major boon in the treatment of chronic diseases

Manufacturing

Features such as **automated guided vehicles and computer-vision-enhanced quality control** require the kind of speeds and ultralow latency that high-band 5G networks provide

Retail

Connectivity allows retailers to **manage inventory, improve warehouse operations, coordinate supply chains, eliminate checkout activities,** and add **augmented reality** for better product information

Bridging the digital divide

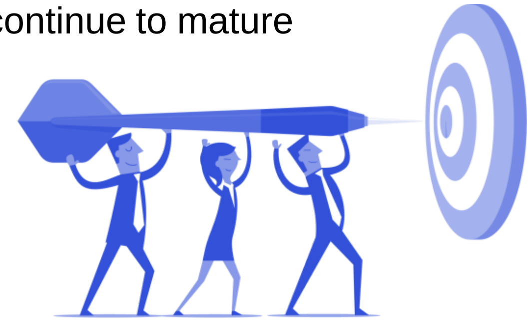
With broader 5G, optic fiber, and satellite internet coverage, the **digital divide for the next billion internet users is being bridged**

Current users will also see their experiences improve significantly as network speeds and latency improve, enabling use cases previously considered unfeasible

Source: "Connected world: An evolution in connectivity beyond the 5G revolution," McKinsey, Feb 2020

What should a leader consider when engaging with the technologies?

Advanced connectivity will be a huge catalyst for change as the value chain and ecosystem continue to mature



Benefits

Enabler: Connectivity is a key enabler of revolutionary capabilities of digital transformations, driving efficiency through automation and enabling technologies reliant on high-quality connectivity such as cloud computing and IoT

Experience: Average consumers’ experiences are enhanced with ubiquitous connectivity and significantly higher quality of service, enabling individuals to work remotely, access bandwidth-heavy services, stream higher-quality content, etc

Global aspirations: Advanced connectivity technologies are aspiring to have a global footprint, as countries from the global south and north stand to benefit significantly in the future, even if the rate of adoption is uneven

Risks and uncertainties

Ecosystem maturity: The ecosystems for cutting-edge technologies such as LPWAN and LEO are maturing, but so far, few players provide solutions and services in limited markets

Business model: Commoditization of connectivity has meant that only a few telecom companies have been able to monetize 5G well enough to get a good ROI; telecom companies and service providers in the value chain must focus on customer-centric services and solutions that leverage these new technologies

Scalability: Despite global ambitions, only a few users in select locations are currently benefiting from high-band 5G and LEO, partly because of hesitancy in allocating the high capital expenditures required to scale these networks and moderate enthusiasm from customers as service differentiation from previous-generation technologies remains a challenge

Source: McKinsey analysis

What are some implications of advanced connectivity across industries?

Connectivity technologies are relatively mature with several examples of industries successfully using them to create impact in their operations and services

Cellular wireless, optic fiber, and LPWAN technologies are leading catalysts of change in these industries; applications include ubiquitous connectivity for consumers, industrial automation, and IoT applications such as smart meters

Industry affected	Implications from technology trend
Telecom	Telecom companies are using advanced connectivity to introduce new B2C and B2B service offerings, such as improved cellular services for retail customers and private 5G solutions for enterprise customers
Automotive	Innovative automotive players of the future will introduce self-driving, connected vehicles packed with features that depend on high-quality network access even in remote locations
Logistics	LPWA wireless technology lets logistics providers track and trace products and provide data to help customers optimize supply chains, improving overall operational efficiency
Manufacturing	Private 5G, industrial Wi-Fi, and LPWA networks support Industry 4.0 solutions that lift productivity, lower energy consumption, and reduce costs in factories
Healthcare	Connectivity will be a major boon in the treatment of chronic diseases, as AI-powered diagnostics can be conducted using data from patients while they are monitored at home using connected medical devices; this will improve patient access to healthcare while improving the overall digitization of healthcare services

Source: McKinsey analysis

Who has succeeded in driving impact through leveraging advanced connectivity?

Leading players across industries have already leveraged advanced connectivity to optimize their operations

Manufacturing

Michelin utilized LPWAN to enable real-time inventory management in 2019. Using Sigfox standards, Michelin was able to gain up to a 10% reduction of the on-sea inventory and a 40% increase in estimated time of arrival (ETA) accuracy while reducing inventory ruptures caused by exceptional events like critical weather conditions

Bosch equipped their first factory with a 5G private network in 2020. The network enables a range of advanced use cases such as autonomous transport systems at scale, an automation platform connecting hundreds of end points, and robots cooperating with human factory workers by adjusting movements in real time

Automotive

Volkswagen has implemented 5G private networks in their factory in Dresden. VW replaced wired connections between machinery, updates finished cars with over-the-air updates, and connects unmanned vehicles with edge-cloud servers

Telecom

Verizon deployed 5G private networks in NFL stadiums to enhance spectators' experience. These networks allow fans to access real-time stats and data in augmented reality and to access a feed of up to 7 camera angles simultaneously via the 5G multiview offering

What are some notable topics of debate?

Despite relative maturity, advanced connectivity technologies still spark a certain amount of debate regarding their implementation and perceived vs realized benefits

1 Industry-ready 5G

Is now the right time to rapidly increase investments in 5G for industrial companies (ie, private 5G networks)?

- Private 5G networks are a **proven technology, with many players already reaping their benefits**
- Other technologies, such as **IoT and automated guided vehicles,** perform much better when using high-quality networks enabled by private 5G
- However, **private 5G may not be cost-effective for all players;** this would depend on a player's technological aspirations and planned use cases

2 Extraterrestrial networking

Are satellite constellations the future of connectivity?

- A few players are already **piloting internet services;** there are signs that consumer devices with LEO connectivity are on the horizon
- However, due to high capital expenditures and user costs, the **business model and pricing will be a challenge** for scaling up networks, nor can **LEO connectivity fully serve as a substitute for terrestrial networks** for all use cases that rely on cost-efficiency, energy consumption, or overall performance

3 Choosing LPWA standards

What to consider while choosing an LPWA standard?

- Depending on availability of traditional LTE networks, a player might choose **between licensed or unlicensed cellular LPWA standards**; this choice may also be critical when dealing with **stationary and mobile devices**
- LPWA standards vary in terms of **bandwidth, cost, power consumption, range** and other features; depending on the final use case for the player, some standards might be more appropriate than others

Source: Expert interviews; McKinsey analysis

Additional resources

McKinsey Center for Advanced Connectivity

Connected world: An evolution in connectivity beyond the 5G revolution

Interview : Laying the foundation to accelerate the enterprise IoT journey

Unlocking the value of 5G in the B2C marketplace

Reliably connecting the workforce of the future (which is now)

Breaking through the hype: The real-world benefits of 5G connectivity

How tapping connectivity in oil and gas can fuel higher performance

Agriculture’s connected future: How technology can yield new growth

How our latest work helps leaders get ready for the 5G revolution

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Applied AI

August 2022

What is the trend about?

Applied AI brings **intelligent applications that automate and augment real-world business use cases.** As AI technologies rapidly push new frontiers of innovation, **business adoption** continues to **grow across use cases**

Selected AI technologies[1]
Foundational methods of AI

Machine learning (ML)

- Computer vision
- Natural-language processing (NLP)
- Deep reinforcement learning
- Knowledge graphs

Selected use cases[2]
Applications of AI at work

Risk management

Service operations optimization

Product and/or service development

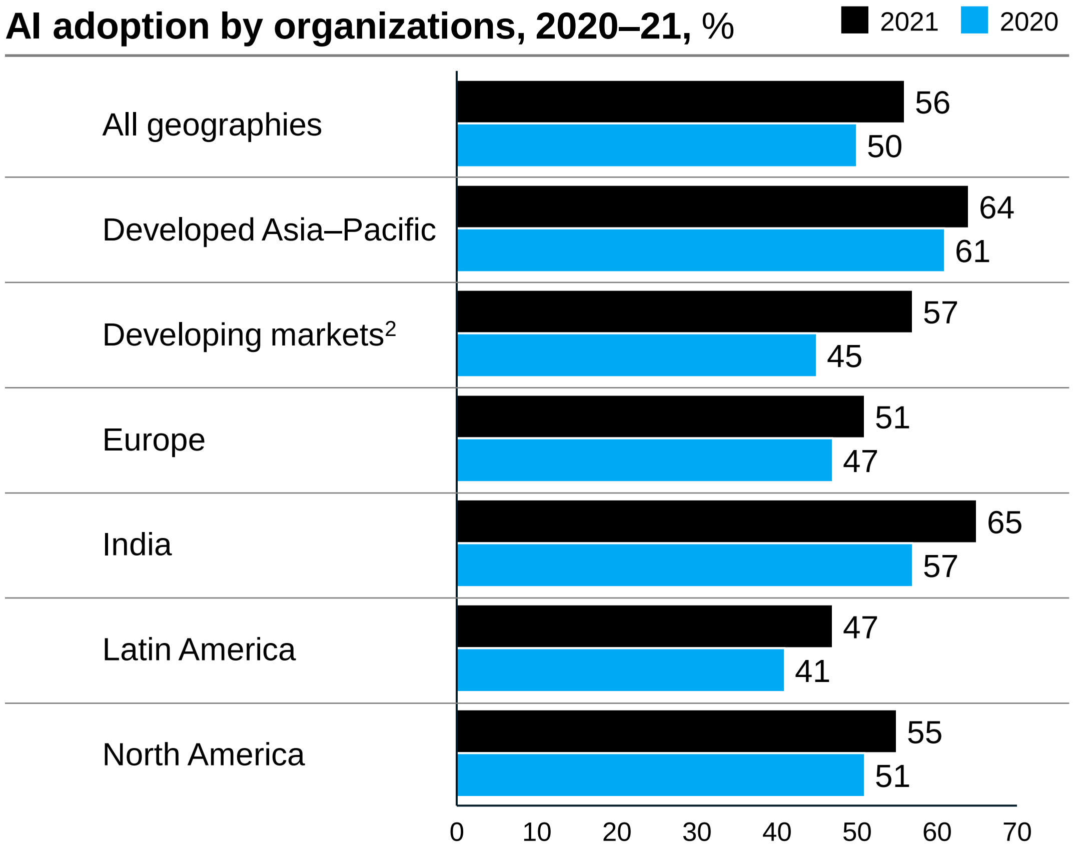
[1]Technologies are nonexhaustive and examples that are at the frontier of innovation and used across industries.
[2]Use cases are nonexhaustive and industry agnostic examples that are leading in business adoption.

Source: McKinsey analysis

Why should leaders pay attention?

AI adoption has continually increased, enabled by its financial investment and development for easier access[1]

AI adoption by organizations, 2020–21, %



[1]For details about easing ML development and integration, see "Industrializing machine learning", The top technology trends of 2022, McKinsey August 2022. [2]Including China, Middle East, and North Africa.

Source: Daniel Zhang et al., *The AI Index 2022 annual report*, Stanford University, Mar 2022; "The state of AI in 2021," McKinsey, Dec 8, 2021

Global expansion of AI

56%

Share of respondents to a 2021 global survey who said their organizations were adopting AI (up 50% from 2020)

Easier and more affordable AI implementation

94.4%

Improvement in training speed for AI models since 2018

Rapidly growing innovation

30x

Relative number of patents filed in 2021 vs 2015 (compound annual growth rate of 76.9%)

Investment growth and intensified efforts

$93.5 billion

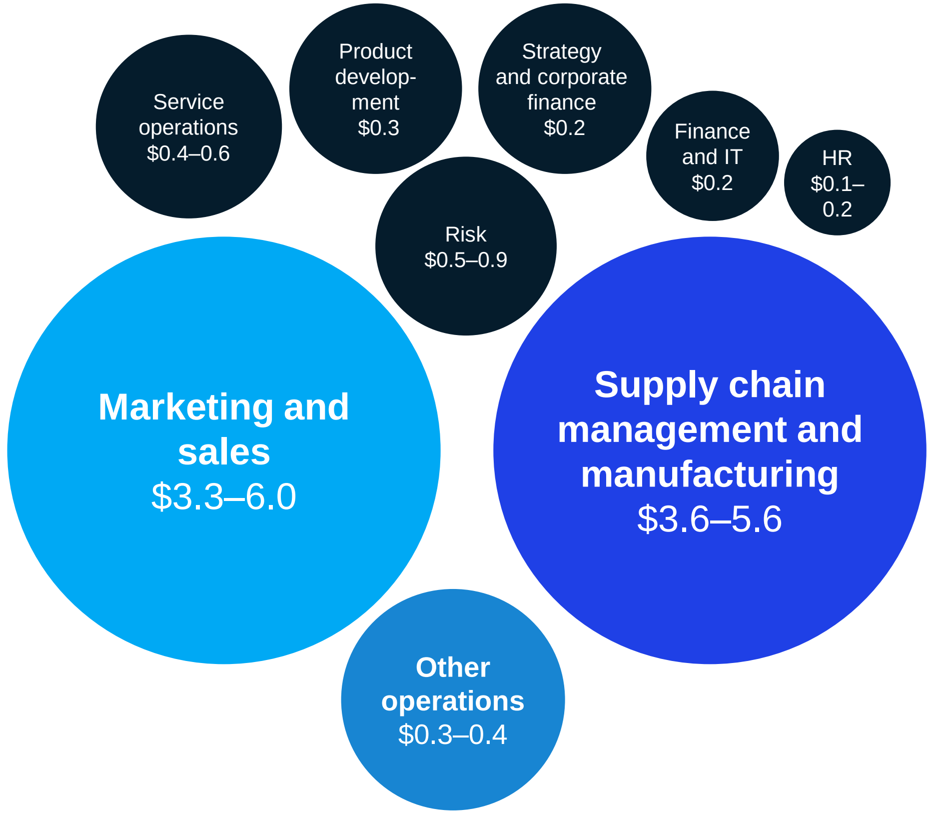
Private investment in AI-related companies in 2021, accompanied by higher concentration of efforts (doubling vs 2020)

Why should leaders pay attention? (continued)

The potential impact from AI is $10 to $15 trillion of annual revenue by 2030 ...

Global annual impact potential, forecast for 2030

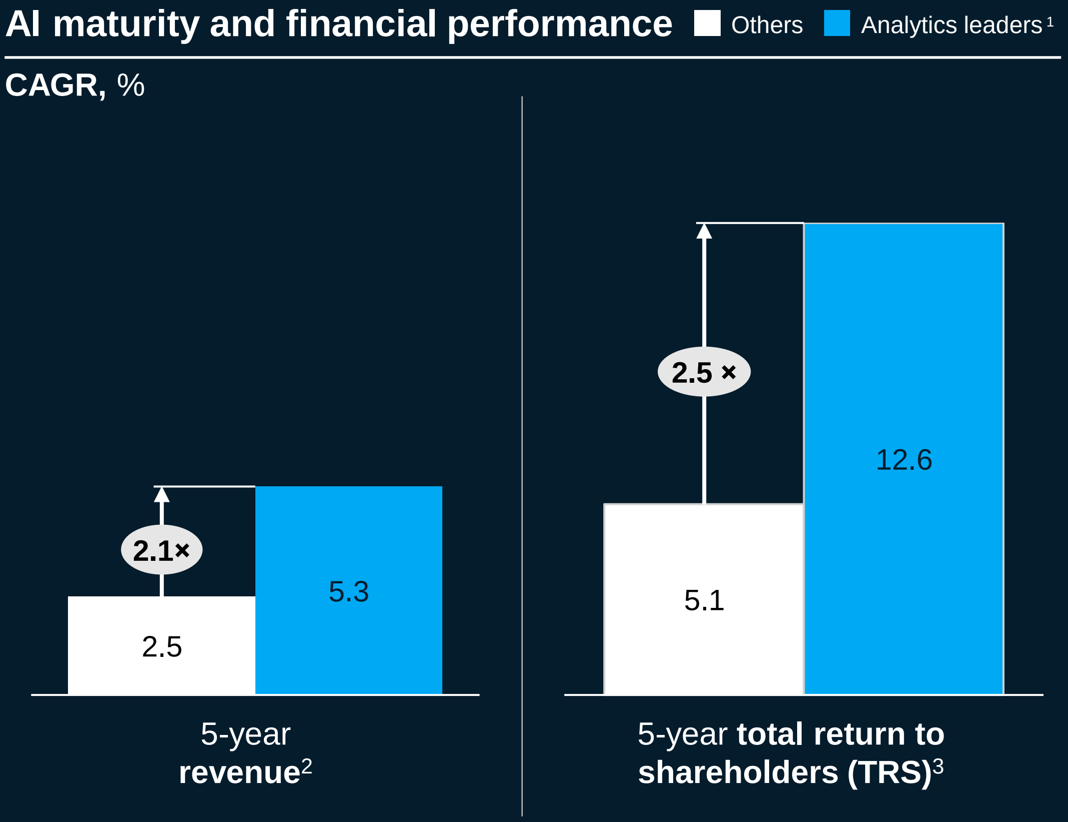
Revenue, $ trillion



… and leaders adopting AI exhibit stronger financial performance

AI maturity and financial performance

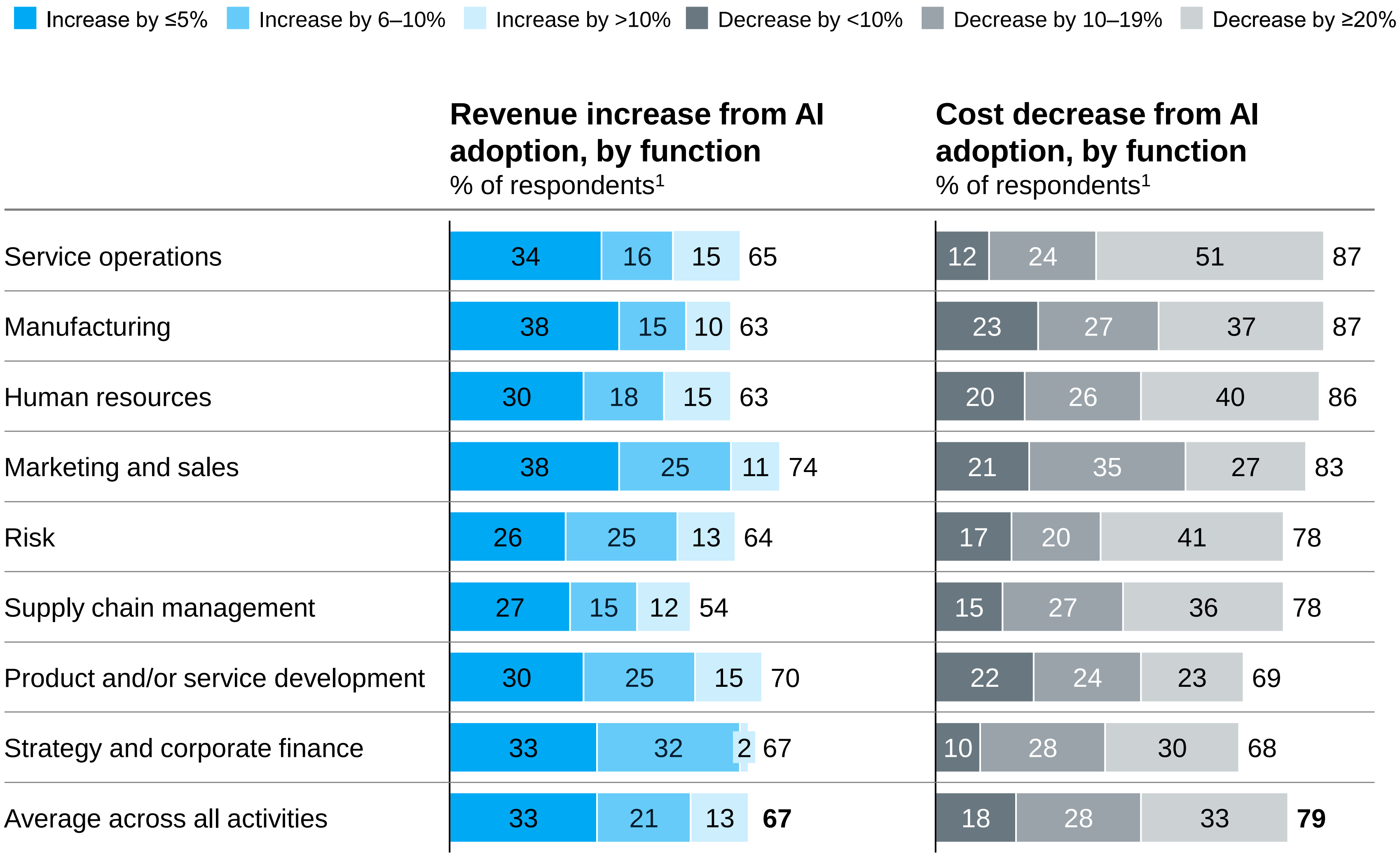
CAGR, %



[1]AI leaders are defined as the top quintile of companies that have that taken the McKinsey Analytics Quotient (AQ) assessment. [2]Includes revenue through fiscal year 2019; during this time, the 5-year revenue CAGR of the S&P 500 index was 4.1%.[3]Includes TSR through FY 2019; during this time, the 5-year TSR CAGR of the S&P 500 index was 11.7%.

Source: S&P Global, Oct 2020; McKinsey Analytics Quotient data set

Why should leaders pay attention? (continued)



[1]Earnings before interest and taxes.

Source: “The state of AI in 2021,” McKinsey, Dec 8, 2021 (for FY 2020)

Across business functions, AI has already made notable financial impact

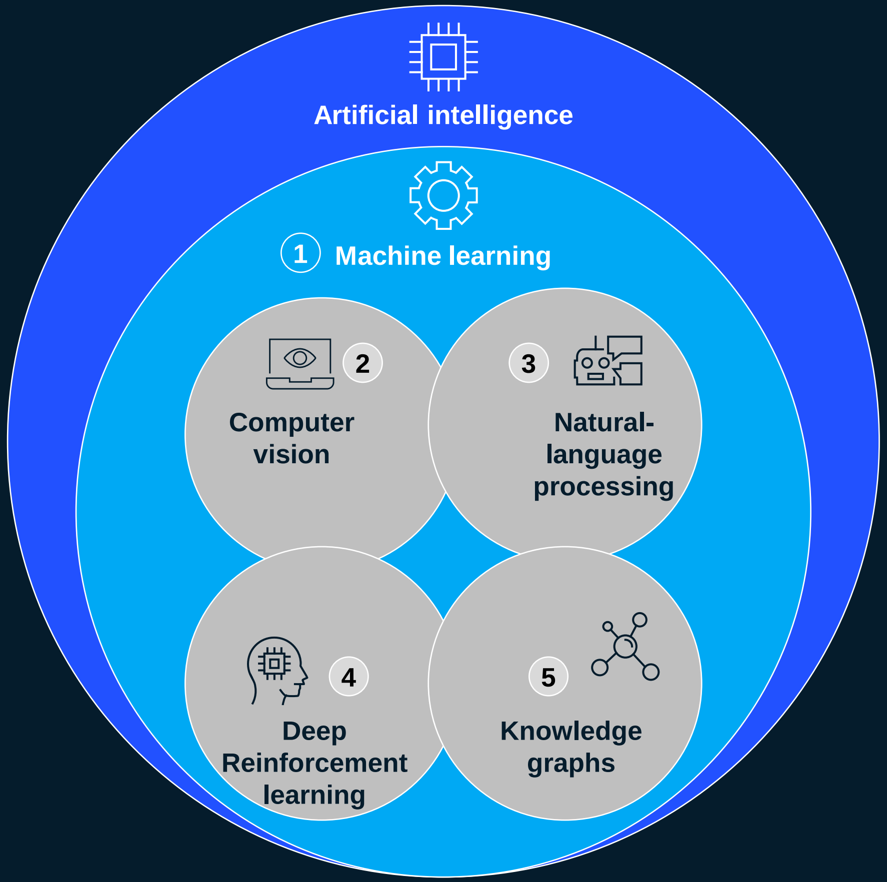
27%
Share of respondents who report at least 5% of EBIT[1] being attributable to AI

67%
Average share of respondents reporting a revenue increase via AI adoption

79%
Average share of respondents reporting a cost decrease via AI adoption

What technologies are driving AI applications?

AI involves machines exhibiting intelligence,[1] encompassing various interconnected fields of technology[2]



	Description	Example use case
1	**ML:** Subfield of AI that uses statistical methods to learn from data	Schedule optimization
2	**Computer vision:** Subfield of ML using visual data, such as images, videos, and 3-D signals, extracting complex information and gaining rich interpretations	Facial recognition as biometrics
3	**NLP:** Subfield of ML that involves processing, generating, and understanding language-based data, such as written text and spoken word	Speech recognition in a virtual voice assistant
4	**Deep reinforcement learning:** Combination of deep learning and reinforcement learning, in which an agent makes decisions within an uncertain environment using complex algorithms inspired by brain neural networks	Planning robotic-arm motion for the manufacturing line
5	**Knowledge graphs:** Collection of data points structured into a network to show complex relationships among themselves	Social-network analysis

[1]AI is nonprogrammatic intelligence exhibited by machines, in which they perform cognitive functions often associated with human minds. Cognitive functions include all aspects of perceiving, reasoning, learning, and problem solving.
[2]Technologies are nonexhaustive and are examples that are at the frontiers of innovation and cut across industries.

Source: Expert input; McKinsey analysis

What industries and functions are leading adoption of AI applications?

AI adoption by industry and function, 2021
% of respondents

Industry	Human resources	Manu-facturing	Marketing and sales	Product or service development	Risk	Service operations	Strategy and corporate finance	Supply chain management
All industries	9	12	20	23	13	25	9	13
Business, legal, and professional	11	26	20	15	4	18	6	17
Consumer goods/retail	14	8	28	15	13	26	8	13
Financial services	2	18	22	17	1	15	4	18
Healthcare systems	10	4	24	20	32	40	13	8
Pharma and medical products	9	11	14	29	13	17	12	9
High tech/ telecom	12	11	28	45	16	34	10	16

Source: AI index report, McKinsey in collaboration with Stanford Unversity Human-Centered Artificial Intelligence (HAI), Mar 2022

Technology-centric industries are leading adoption by businesses

Product and service development, service operations, and marketing and sales are the business functions leading adoption of AI

What is the notable potential impact of applied AI across industries?

AI has potential to impact **all industries**, but **technology-centric industries** are leading wide-scale adoption, with widespread implications that overlap those of other trending technologies

Industry affected

Technology and telecommunications

Subindustries

- **Software** (productivity, cloud, social media)
- **Computer hardware**
- **Telecommunications** (network service providers)
- **Electronic devices**
- **Sensors**

Impact from technology

- Numerous AI efforts are on the rise both for **new cross-industry applications** (see next page) and for **improving the technical stack**[1]
- **Automation across the software development life cycle** to ease developer workloads and improve efficiency for reduced costs[2]
- **Shift in value chain through AI adoption across all business functions,** such as digital marketing and sales strategies focusing on hyper-personalization
- **Faster product development** through automated testing, AI-enabled simulations, and AI-generative tooling
- **Increased need to advance cybersecurity,** due to a surge of advanced AI-enabled cyberattacks
- **Rapidly evolving regulations** and advancing need for cross-disciplinary development of responsible AI, including ethics

[1] See "Industrializing machine learning," The top technology trends of 2022, McKinsey, Aug 2022.
[2] See "Next-generation software development," The top technology trends of 2022, McKinsey, Aug 2022.

Source: Expert input; McKinsey analysis

What are additional implications across industries?

A **diverse set of stakeholders** across all industries are experiencing implications from applied AI, which can include **disruption in value chain, better financial outcomes**, and **improved operations**

Industry affected[1]	Implications from technology trend
 **Healthcare and pharmaceuticals**	**Shift in value chains** for patient care and pharmaceutical development to improve efficiency and efficacy of patient care life cycle (ie, screening, testing, diagnosis, treatment), alleviate workload for healthcare providers, and expedite development of new treatments Increased emphasis on reliable data collection and bias mitigation
 **Finance**	**New and/or enriched revenue streams through predictive insights** (eg, risk assessment for loans, algorithmic trading) to improve service offerings and automate service operations
 **Retail and consumer goods**	**Shift toward hyper-personalization and advanced analytics** in product development and sales and marketing (leveraging social media and user activity) Increased automation in customer service, leading to increased revenue and decreased costs
 **Manufacturing**	**Reduction in long-term costs** through advanced analytics for predictive maintenance and automation of manufacturing processes, such as robotic process automation and multimodal sensor fusion Potential shift and disruption of workforce on manufacturing lines
 **Education**	**Wider, more inclusive learning** for students through personalization and teaching aids; **improved efficiency** for teachers
 **Transportation**	**Enablement of autonomy, electrification, smart mobility, and connected-vehicle** technologies[2]

[1]Nonexhaustive and focused on industries where AI has widespread applications with mature adoption.
[2]See “Future of mobility,” The top technology trends of 2022, McKinsey, Aug 2022.

Source: Expert input; McKinsey analysis

What are notable use cases in production?

Innovation led | Gaining business adoption

Use case[1]	Technology[2]	Function	Relevant industries[3]	Description	Benefits[4]
Generate 3-D models	Computer vision; ML *Optional:* NLP	Product development	Technology; manufacturing; consumer goods; retail	Apply generative techniques that synthesize 3-D visuals based on singular or multimodal instructions. *Examples:* Models for animation, furniture models, and apparel re-creations	Decrease cost with improved efficiency through quickly generated 3-D models
Prioritize dynamically changing tasks	ML; deep reinforce-ment learning *Optional:* Computer vision; NLP	Service operations	Any	Optimize changing workflow through multitask learning to prioritize most relevant tasks. *Examples:* Schedule-planning and project management tools	Decrease cost with improved productivity
Fuse multi-modal sensors	Deep reinforcement learning; ML; computer vision. *Optional:* NLP	Product development	Transportation; retail; healthcare	Utilize various sensor inputs to perform tasks. *Examples:* Sales checkout for retail; vehicle sensing for autonomous driving	Decrease cost by automating systems requiring sensor input
Recommend products to purchase	ML *Optional:* Knowledge graphs; NLP; computer vision	Product development	Technology; retail finance; healthcare	Predict and suggest potential products relevant to a customer's interests based on prior customer data (individuals or groups). *Examples:* Online suggestions of products to purchase; movie recommendations	Improve revenue through increased sales via personalized recommendations
Detect fraud	ML *Optional:* Knowledge graphs; NLP	Risk management	Any	Detect fraudulent behaviors to reduce incidents of loss. *Examples:* Detection of fraudulent credit card purchases and account log-in	Reduce losses through stronger detection of risky behaviors

[1]List of use cases is nonexhaustive and highlights those that are at the frontier of innovation and/or rapidly gaining adoption across organizations.
[2]Technologies typically used to implement the use case. Optional technologies can be applied but depend on the specific task for the use case.
[3]Relevant industries are nonexhaustive and highlight industries with visible adoption of the use case.
[4]Nonexhaustive benefits, focusing on major benefits to businesses.

Source: Expert input; McKinsey analysis

What should a leader consider when engaging with AI technologies?

Benefits

- **Cost savings:** Up to 90% of survey respondents cited cost decreases in 2020
- **Overall revenue increase:** Up to 75% of survey respondents cited revenue increases in 2020[1]
- **New use cases:** New use cases will unlock new business capabilities and opportunities across automation and acceleration
- **Increased access to AI and ease of implementation:** New technologies and practices, such as ML operations and software automation, should make AI more readily available

Risks and uncertainties

- **High up-front investment in talent and resources:** This creates a high barrier to entry related to developing AI and ML workflows for production[1]
- **Cybersecurity and privacy concerns:** Data risks and vulnerabilities are occurring across the technical AI workflow; 55% of survey respondents cite cybersecurity as a leading risk in their business in 2021 and are actively taking steps to mitigate it
- **Increasing regulation and compliance:** New legislation will affect the development of AI's direction
- **AI ethics:** Issues include responsibility, equity, fairness, and explainability

[1]For more development of ML systems and tools, see "Industrializing machine learning, *The top technology trends of 2022,"* McKinsey, Aug 2022.

Source: "The state of AI in 2021," McKinsey, Dec 8, 2021; Stanford HAI; McKinsey analysis

What are notable topics of debate?

1 Trustworthiness

What does it mean to apply trustworthy and responsible AI?

- Potential risks and concerns increase as AI use cases expand
- According to the EU Commission High-Level Expert Group on AI, responsible and trustworthy AI can be defined by abiding laws, incorporating ethics, and implementing technical and social robustness to mitigate potential harm
- The commission has developed 7 requirements for AI responsibility and trust: human agency and oversight; societal and environmental well-being; technical robustness and safety; privacy and data governance; transparency; accountability; and diversity, nondiscrimination, and fairness

2 Explainability

When is AI explainability needed?

- AI explainability looks at how well we can understand an AI model. Interest in this field is rising as models are growing increasingly complex and high-risk use cases (eg, disease diagnosis) are being explored
- According to Stanford University Human-Centered Artificial Intelligence (HAI), there are three types of AI: engineers' explainability (technically explains how the AI model works), causal explainability (explains why a model input leads to its output), and trust-inducing explainability (information that people need to trust and deploy a model)
- AI explainability depends on the situation, where it may use one, a combination, or all types of explainability depending on the situation (eg, disease risk evaluation looks at all three types)

3 Other risks

What are other areas of risk that are relevant?

- According to Stanford HAI, leading areas of risk for organizations include cybersecurity, regulatory compliance, explainability, individual privacy, organizational reputation, and equity and fairness
- While customers, shareholders, and regulators are calling for increased scrutiny on these topics, subjective topics (eg, privacy, equity, and fairness) are not high strategic priorities within organizations, as they lack resources and capabilities to fully understand and address these concerns

Source: European Commission High-Level Expert Group on Artificial Intelligence; expert interviews; Stanford HAI; McKinsey analysis

Additional resources

[QuantumBlack, AI by McKinsey]

[The state of AI in 2021]

[The AI Index Report: Measuring trends in artificial intelligence]

[It's time for businesses to chart a course for reinforcement learning]

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Cloud and edge computing

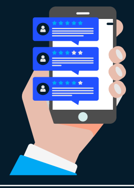
August 2022

What is the trend about, and what are the most noteworthy technologies?

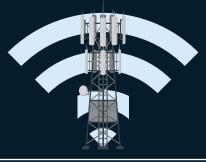
Networks of the future consist of traditional cloud data centers and a variety of computational resources located at network edge nodes closer to end users to reap the benefits of traditional cloud computing while gaining advantages such as better data latency and increased data autonomy

Tomorrow's networks will consist of devices at many locations computing simultaneously

Edge networks closer to the user (Device edge, Remote edge, Branch edge, Enterprise edge, Telecom/MEC[1] edge) | **Hybrid cloud** (Cloud)








	Device edge	Remote edge	Branch edge	Enterprise edge	Telecom/MEC[1] edge	Cloud
Compute location	Smartphone Camera Wearable tech	Connected vehicle Resource extraction site Remote filming locations	Branch Retail outlets Restaurants	Factories Hospitals Airports	Network aggregation points Network access points	Regional data centers Co-location data centers Hyperscale data centers
Use cases	Remote patient monitoring Real-time fleet tracking Worker safety monitoring	Remote asset management Remote content rendering	Building energy management Real-time personal promotions Immersive-content experiences	Smart construction and manufacturing Passenger analytics at airports Proactive equipment maintenance	Smart city infrastructure Air quality monitoring Media/content delivery	Streaming media delivery Real-time multiplayer gaming Local content exchange

[1]Multi-access edge computing.

Source: McKinsey analysis

Why should leaders pay attention?

Cloud has already effected change across industries and will remain an important tech disruption

Cloud computing is a huge opportunity for all organizations

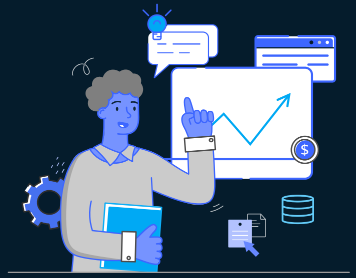
$1 trillion

Opportunity in run-rate EBITDA[1] across Fortune 500 companies in 2030 through cloud cost optimization levers and value-oriented business use cases

Cloud is no longer public or private but is increasingly hybrid

~90%

Share of **cloud users** who **have a multi-cloud strategy**, with over 80% having a hybrid mix of private and public cloud



The market for public cloud continues to grow rapidly

~$300 billion

Worldwide public cloud services market in 2020, growing at a CAGR of ~25%, driven by growth in IaaS, PaaS, and SaaS[2]

Security and access in the cloud remain a top concern for users

~75%

Share of enterprises where cloud security issues are a top concern, with the top challenges being infrastructure configuration, access, and insecure APIs

[1]Earnings before interest, taxes, depreciation, and amortization.
[2]Infrastructure as a service, platform as a service, and software as a service.

Source: "Cloud's trillion-dollar prize is up for grabs," McKinsey, Feb 2021; Flexera 2022 state of the cloud report, Flexera, Mar 2022; Worldwide Semiannual Public Cloud Services Tracker, IDC, May 2021; 2022 cloud security report, Check Point

Why should leaders pay attention? (continued)

Edge computing might soon become an operational necessity for many organizations

Data regulation is taking center stage around the world

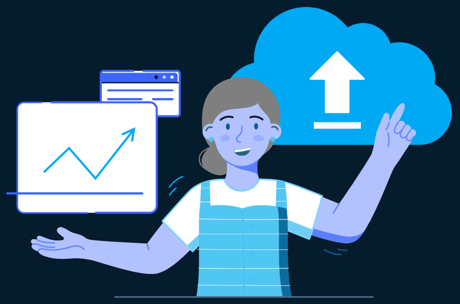
>60

Number of countries reporting data protection localization requirements in 2021; requirements can be fulfilled by adoption of edge storage and computing

Enterprise edge computing spend is growing rapidly

~$250 billion

Projected worldwide spending on edge computing in 2025, growing at a CAGR of ~10%



Data volume and velocity are growing at an unprecedented pace

<20%

Share of data generated by enterprises that is ultimately used, due to challenges with latency and costs of moving data across environments

Distributed computing is getting more popular, unlocking real-time insights

26%

Forecast **share of servers** shipped in 2024 that will be **deployed at the edge**—up from 20% in 2019

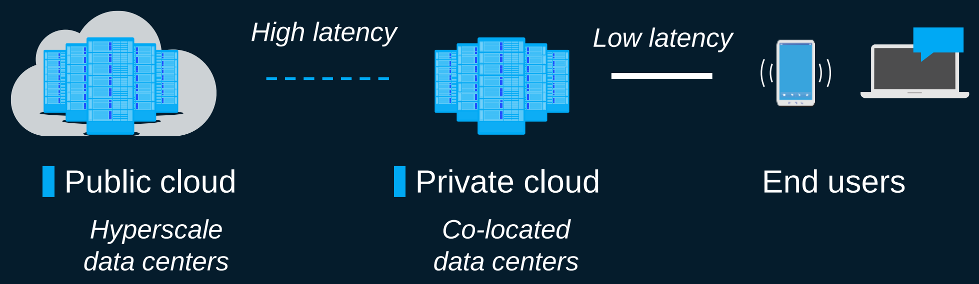
Edge computing provides flexibility for organizations to achieve **greater data sovereignty, greater autonomy, better security, and better latency** while unlocking a variety of use cases that rely on real-time data processing

Source: IDC; Omdia

What differentiates edge computing from traditional cloud?

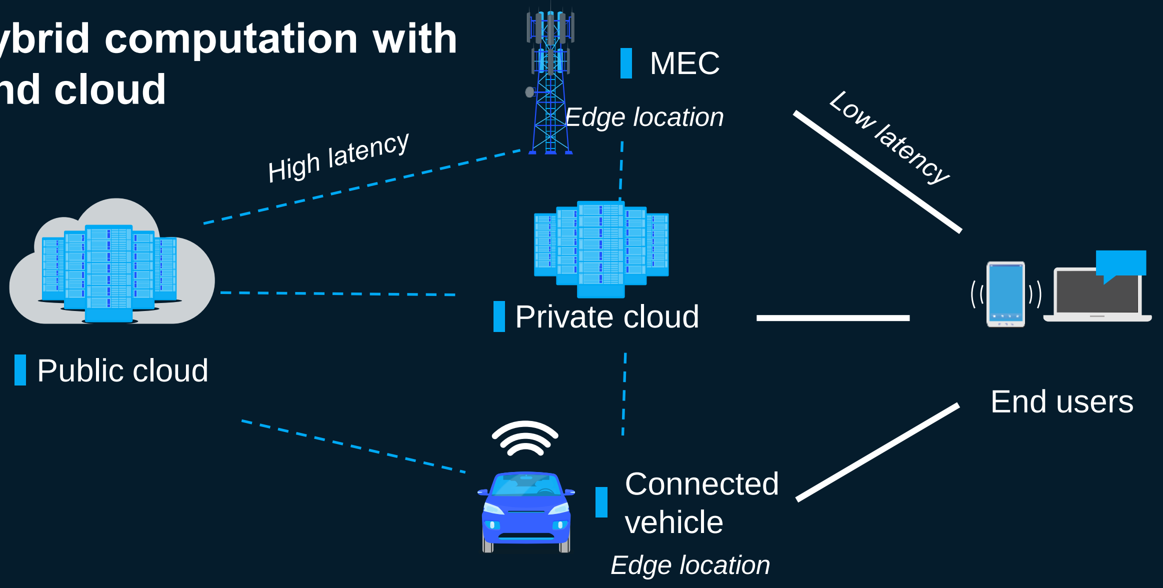
Computational resources

From multi-cloud-based centralized computation …



Fully **centralized core** with **computation and storage** done **in the cloud**, leading to high latency and network congestion

… to hybrid computation with edge and cloud



Selected **core functions moved toward the edge**, where **computing infrastructure** is deployed to run latency-intensive apps

Edge computing will leverage many types of networking technology to connect end users to a decentralized core of **computing infrastructure located closer to the end user**

Reduced distance to end users will **shrink data transmission delays and costs,** as well as provide **faster access** to a smaller, more relevant set of data, which helps companies **comply with data residency laws**

Traditional public cloud will continue to play a critical role in the networks of the future by **performing non-time-sensitive computing use cases** at better **economies of scale** at a distance from the end user

Source: McKinsey analysis

What are some examples of disruption that edge computing could cause?

Disruptions from edge computing will have impact on almost all industries and functions

The impact can be described in terms of 2 broad categories:

Network service improvements

Improvements in the **performance of the network** and in the **quality of experience** for users

Content/CDN[1] caching

Mobile backhaul optimization

Media delivery optimization

New services unlocked by improved quality of experience

B2B services that usually do not benefit the end user directly

Active-device location tracking

Real-time personal promotions

Drones/smart robots

Connected cars

B2C services that generally benefit the end user directly

Cloud gaming

Remote desktop applications

Cognitive assistance

Augmented and assisted reality

[1]Content delivery network.

Source: McKinsey analysis

What should a leader consider when engaging with cloud and edge?

Benefits

Data latency: Edge will enable use cases that had been challenging to implement effectively, due to data latency (eg, cloud gaming, smart factories, autonomous vehicles)

Data residency compliance: Edge will ensure compliance with local data residency laws necessary to experience the benefits of both cloud and edge

Data autonomy: Edge will ensure much more granular control over individual and enterprise data by limiting reliance on public cloud

Data security: Edge provides a security advantage over public cloud infrastructure, which is often susceptible to breaches enabled by the infrastructure-sharing model and misconfigurations

Risks and uncertainties

Business model: Telcom companies and IT service providers need to figure out partnership, services, and infrastructure management approaches to unlock cost-efficiency and avoid major cost increases resulting from greater technical complexity

Technical challenges: Cloud and edge involve managing resources over networks that require interoperability among a wide variety of devices and sensors to deliver value

Scaling hurdles: The growing number of edge nodes and devices will be challenging, since edge doesn’t benefit from the same economies of scale as traditional cloud computing

Source: McKinsey analysis

What are some implications of cloud and edge computing across industries?

Edge computing is **quickly approaching maturity;** several players have successfully used it to create impact in their operations and services

Synergetic technologies (**5G, MEC, SD-WAN,**[1] and other advancements in networking) are **driving adoption for edge** to create major impact across many industries

Industry affected	Implications of technology trend
Telecom	Increase in revenue streams from technologies such as multi-access edge computing (MEC), given the telecom company role as the primary owner of the networking infrastructure required for distributed computing
Automotive and logistics	Increase in overall efficiency of transportation routes through schedule management, route optimization, etc Reduced reliance of connected/autonomous vehicles on large, distant data centers for access to compute
Energy and utilities; materials	Increase in employee safety and efficiency at work sites through real-time tracking and optimization Improvements in equipment efficiency through condition monitoring, real-time data processing, and predictive maintenance
Manufacturing	Improvements in networking and data latency, increasing effectiveness of other Industry 4.0 technologies, leading to better overall productivity
Finance	Sensors and monitors in vehicles, helping insurance players reduce collision and theft
Retail	Improvements in advanced analytics use cases (eg, personalization, staff allocation, theft detection)
Healthcare	Improvements in most digital use cases (eg, remote diagnostics, active drug tracking, fitness trackers)
Public sector	Smart cities with improved infrastructure (eg, emergency services, weather monitoring, waste management) Ability of governments to enforce data residency laws

[1]Software-defined wide-area network.

Source: McKinsey analysis

Who has managed to successfully drive impact through leveraging cloud and edge computing?

Industry	Case example
 **Entertainment**	**Hulu** is using edge networking services to deliver content and improve viewer experience by taking advantage of locally cached data at network edges to extend its content delivery network and reduce infrastructural load
 **Telecom**	**AT&T** has created a new service line providing customers with multi-access edge computing by partnering with system integrators to connect customers’ enterprise data centers with LTE and 5G infrastructure
 **Automotive and logistics**	**Tesla**’s vehicles are powered by homegrown full self-driving (FSD) processors that act as edge nodes to run machine learning algorithms trained in the cloud to unlock self-driving capabilities
 **Retail**	**Walmart** is planning to use edge computing not only to improve its own Internet of things(IoT), real-time analytics, and customer experiences but also to leverage its nationwide coverage of supercenters to provide edge computing services to customers near these locations

What are some notable topics of debate?

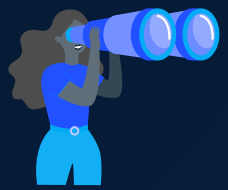
Cloud and edge computing will undoubtedly be a huge driver of change, but experts are still debating several key questions

1 Impact of edge computing

Will edge truly be more disruptive than cloud?

- Edge is **extremely flexible** and supports a **wide array of devices** while lying in a **business and regulatory sweet spot**
- However, traditional cloud enables economies of scale that would **be impossible for edge computing** networks that require a **high level of interoperability and commonality of standards** currently absent in networking

2 Outlook



Will hyperscale cloud providers win the edge race?

- Public cloud providers have already **created services and partnership ecosystems** to provide seamless edge and cloud connectivity to their customers
- **Telcom companies with 5G-enabled MEC** can choose to either contend or partner with hyperscalers
- **OEMs and networking and edge service providers** will be important as edge networks scale up and customers require custom solutions

3 Security vulnerabilities

Will the increase in number of storage and processing units lead to security vulnerabilities?

- Keeping **sensitive data at edge locations** away from centralized servers helps restrict access and minimize risks in the event of a major attack
- However, increasing the number of edge locations increases the **attack vectors for malicious actors;** if proper precautions aren't taken, security vulnerabilities may arise

4 Energy consumption

How will cloud and edge evolve in line with the sustainable IT paradigm?

- Data centers are increasingly relying on green IT measures such as **sustainably sourced energy** and **energy-efficient cooling systems**
- Edge computing further reduces overall energy requirements, as **less data is transmitted across the network** and more is processed and stored locally
- However, as networks expand, the amount of critical infrastructure and number of devices, data centers, and **related energy requirements will continue to increase**

Source: Expert interviews; McKinsey analysis

Additional resources

Knowledge center

Cloud Insights

Related reading

New demand, new markets: What edge computing means for hardware companies

Cloud foundations: Ten commandments for faster—and more profitable—cloud migrations

The cloud transformation engine

McKinsey & Company

McKinsey & Company

Immersive-reality technologies

August 2022

What is this trend about?

The immersive-reality space has 4 key components

Technology	**Blending technology into the world** …	to see the **world differently …**		… or see a **different world**
				
	Spatial computing Software enabling interaction	**Mixed reality (MR)** Graphics linked to reality	**Augmented reality (AR)** Information not linked to reality	**Virtual reality (VR)** 100% computer graphics
Description	Interprets physical space and introduces virtual 3-D objects, allowing users to **interact with environments that feature virtual elements**	**Modifies the real world** through a device, augmenting or diminishing the user's view of the world	**Interacts directly with** and **overlays** onto the dynamic **external reality** (eg, AR glasses with live translation; runs **interactively in 3-D** and real time	**Replaces the real world** (eg, via headsets) by **placing** the **user in** an **entirely digital experience** that uses external cameras/ sensors to render movements in virtual worlds
Experience	N/A	**Merging of reality and MR:** User's sense of being immersed is gone	**Partly immersive:** User holds a sense of presence in the real world with digital overlay	**Fully immersive:** User's visual sensation is controlled by the system inside the virtual world

Immersive-reality technologies will have a significant role to play in the metaverse

Source: McKinsey analysis

What is this trend about? (continued)

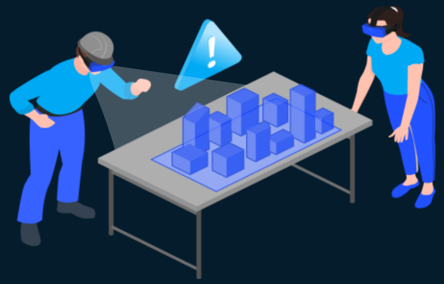
Most mature immersive-reality solutions fall under a few key themes

Nonexhaustive

Learning and assessment

Learning and training: Hands-on skills and procedures training—especially useful for simulating unusual or dangerous edge cases that are difficult to simulate safely in real life, thus building muscle memory

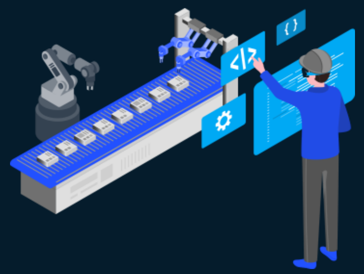
Assessment: Use of the same infrastructure (eg, 3-D models, procedure rules) to stress test the workforce knowledge, skill, and capability in safety and efficiency and target further avoid widow?



Product design and development

Product design: Creation of digital twins to enable virtual walk-throughs of a physical environment (eg, construction site) or a physical product (eg, new space satellite), enabling more efficient product prototyping and test simulations

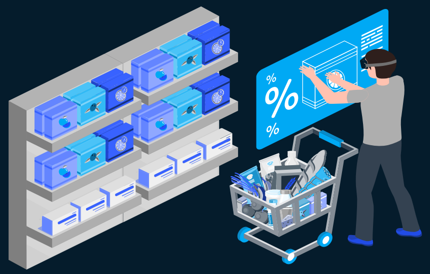
Development: Simulation of process design, such as a software engineer "grabbing" blocks of code overlayed virtually onto factory equipment to redesign the process flow, then pushing the equipment back into production



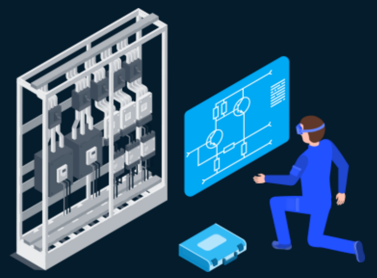
Enhanced situational awareness

Overlay of data visualization enables more productive assessment of situations

Retail example: Store manager observes store while wearing AR glasses that display sales data overlaid on sections and products



Manufacturing example: Lead engineer conducts factory operations and maintenance remotely; VR tech enables a virtual walk-through with visualized data and pop-up decision options for areas requiring avoid widow?



B2C use cases (eg, entertainment, retail)

Live events: Participation in virtual events mimicking real-life experiences such as concerts, conferences, sports games, and fashion shows

Virtual showroom: Shopping by virtually walking through stores, trying on new products, etc

Source: McKinsey analysis

Why should leaders pay attention?

Overall trends

~$1.2 trillion GDP boost by 2035

Global immersive-reality market size is expected to grow at a CAGR of ~24% until 2035, facilitated by several factors, including increased use of smartphones and connected devices and rising adoption of 5G networks

Increasing innovation

2× growth in immersive-reality patents from 2018 to 2021

Growing venture capital investments

~$3.9 billion of venture capital investments made into VR/AR start-ups in 2021, the second-best year historically (after ~$4.4 billion in 2018) as venture capital interest recovers from COVID-19 pandemic

2.2× growth in average ticket size from 2020 to 2021; 1.3× growth from 2018

Growing B2B adoption

~66% CAGR in enterprise adoption of AR through 2026

Need for more collaboration platforms (eg., Virbela, VRtuoso) triggered by COVID-19 pandemic to enable remote work

Increasing functionality across industries

Product and service enablement

Rapid prototyping (eg, driven by early-stage amendments and powerful visualization) shortens time to market and **reduces costs drastically**

New services unlocked by engaging consumers in new ways

Development and training scalability

Scalability of training expands across all sectors, particularly for non-desk workers (eg, situational/ emergency training without risking users), while ensuring standardization in quality of training

Process improvement

Faster and more efficient processes possible via early-warning detection mechanisms, risk management, improved quality assurance, reduced assembly/ construction efforts, and reduced guesswork in manual labor

Source: McKinsey analysis; "Demand for augmented reality in enterprise and consumer markets to create US $175 billion AR market by 2026," ABI Research, June 2021; "VR/AR investments increase just as metaverse talk heats up—but that may not be the only reason," Crunchbase News, January 2022; "Extended reality market size, share, trends, by type," Emergen Research, February 2021; McKinsey analysis

What are the most noteworthy technologies?

AR and VR technologies still have a way to go from current state to what's needed

Nonexhaustive

Capability		VR Current	VR What's needed	AR Current	AR What's needed
Computation	**Hardware acceleration**	Moderate-performance GPU[1] can render low-detail worlds or tether to console	Specialized hard-ware acceleration per computation type	Moderate-performance GPU can render low-detail worlds	Specialized hardware acceleration-off device tethered to AR display
Network	**Bandwidth**	~42 Mbps[2]; cannot stream fully realistic worlds	250 Mbps–1 Gbps[3]	~20–40 Mbps; cannot stream fully realistic worlds	250 Mbps–1 Gbps
	Latency	~10–300+ ms; doesn't allow for instant communication across large distances	Consistently <50 ms, but ideal is 10–20 ms	~50–350+ ms; ~40–50 ms of 5G latency adds to underlying network transit time	10–20 ms[4] total latency; massive reduction in latency to edge node needed
Display	**Resolution,** pixels	4K; pixels are visible	8K	2K–4K	8K
	Refresh rate	90 Hz; choppiness induces nausea	120 Hz	60 Hz	120 Hz
	Field of view	140 degrees; user can see edges of display	210 degrees	40 degrees; doesn't cover entire glasses	90 degrees
Sensors		Small set of sensors to track body (eg, hand); not precise enough for fine tracking (eg, eyelid blink)	Full-body virtual tracking	Limited body and eye tracking	Precise eye tracking to have 0 mm error in display overlay and 0 ms lag with display movement
Usability	**Weight,** pounds	1–1.5; causes neck strain		~1–1.5	<0.15 (pair of eyeglasses)
	Battery life, hours	~3–4; insufficient for high-powered compute	~8 with current compute requirements	~3–4	>8
Price, $		~300–1,000	~300–500	~3,500	~400–1,100

[1]Graphics processing unit.
[2]Megabits per second.
[3]Gigabits per second.
[4]Milliseconds.

Source: McKinsey analysis

Significant advancements are still required for AR/VR and are 8–10 years out

While some capabilities are technically possible today in isolation, device makers need to balance features, such as life, weight, ergonomics, etc, which makes the problem particularly hard (eg, 8K displays exist but are too heavy and expensive for common use)

AR requires technology significantly superior to that of VR

Unlocking scalability will require **reducing prices by >50%**

What are the most noteworthy technologies? (continued)

Additionally, a diverse set of peripherals will be needed, expanding the peripherals market by 10–20×

	On-body sensors	Off-body sensors	Haptics
	 	 	 
Why are they needed?	**Track/identify users and surrounding objects** (eg, reflect their limb movements and nearby physical objects such as table and chair in the virtual world)	**Enable more precise re-creation of elements of the physical world** (eg, virtually re-create a room, using stand-alone sensors such as lidar, cameras)	**Convey sense of touch to user with specialized/diverse vibrations** (eg, when user knocks on door, haptic glove vibrates around knuckles to replicate sensation)
What do they look like?	**Group of sensors** (eg, gyroscopes, accelerometers, cameras) **within headsets** themselves **Handheld sensors** that enable users to wield tools in the virtual space; currently limited to the whole hand (ie, cannot track individual fingers)	**Consumer applications** have existed for over a decade across **gaming platforms broadly** **Enterprise applications** are rapidly becoming **more powerful** (eg, Matterport is creating dedicated **spatial mapping hardware**)	**Haptic-feedback smartphones** (eg, on-screen keyboards) present foundational work **Haptic-feedback gloves** are under experimentation
What does the future look like?	**Higher-resolution and smaller sensors concealed in other worn devices** (eg, rings, bracelets, shoes)	**Reduced size and a huge increase in the number of sensors** (eg, simple beacons for geographical awareness)	**Full-body haptic suits**

Source: McKinsey analysis

What examples of disruption could AR cause?

Nonexhaustive

Capability		AR – Current	AR – What's needed
Computation	**Hardware acceleration**	Moderate-performance GPU can render low-detail worlds	Specialized hardware acceleration using device tethered to AR display
Network	**Bandwidth**	~20–40 Mbps; cannot stream fully realistic worlds	250 Mbps–1 Gbps
	Latency	~50–350+ ms; ~40–50 ms of 5G latency adds to underlying network transit time	10–20 ms total latency; massive reduction in latency to edge node needed
Display	**Resolution**	2K–4K	8K
	Refresh rate	60 Hz	120 Hz
	Field of view	40 degrees; doesn't cover entire glasses	90 degrees
Sensors		Limited body and eye tracking	Precise eye tracking to have 0 mm error in display overlay and 0 ms lag with display movement
Usability	**Weight,** pounds	~1–1.5	<0.15 (pair of eyeglasses)
	Battery life	~3–4 hr	>8 hr
Price, $		~3,500	~400–1,100

Source: McKinsey analysis

Maturity level

Expected developments by AR over time

Near term
0–3 years

AR **exists mostly as a proof of concept** with **few enterprise use cases;** experiences occur within **narrowly defined environments** (eg, warehouses) and overlay low-fi visuals over the real world

Medium term
3–10 years

Consumer AR is introduced as a **low-fi experience** while **enterprise AR improves**, with augmented visuals interacting more fluidly with external inputs and **usability expanding** out of preprogrammed spaces and use cases

Long term/ end state
10+ years

Consumer AR shrinks and use cases proliferate, with a seamless digital layer acting as an overlay to the real world; as users navigate fluidly throughout their day, external sensors interpret, interact with, and enhance the physical environment

What examples of disruption could VR cause?

Nonexhaustive

Capability		AR	
		Current	**What's needed**
Computation	**Hardware acceleration**	Moderate-performance GPU can render low-detail worlds or tether to console	Specialized hardware acceleration per computation type
Network	**Bandwidth**	~42 Mbps; cannot stream fully realistic worlds	250 Mbps–1 Gbps
	Latency	~10–300+ ms; too long for instant communication across large distances	Consistently <50 ms, but ideal is 10–20 ms
Display	**Resolution**	4K; pixels are visible	8K
	Refresh rate	90 Hz; choppiness induces nausea	120 Hz
	Field of view	140 degrees; user can see edges of display	210 degrees
Sensors		Small set of sensors to track body (eg, hand); not precise enough for fine tracking (eg, eyelid blink)	Full-body virtual tracking
Usability	**Weight**	1–1.5 lb; causes neck strain	
	Battery life	~3–4 hr; insufficient for high-powered compute	~8 hr with current compute requirements
Price, $		~300–1,000	~300–500

Source: McKinsey analysis

Maturity level

Expected developments of VR over time

Near term
0–3 years

Medium-fidelity VR experiences offer **limited virtual worlds and experiences;** avatars are manipulated using external peripherals that limit immersion

Medium term
3–10 years

High-fidelity and **comfortable VR** experiences are **available at scale;** avatars are manipulated via body movements captured by sensors

Long term/ end state
10+ years

Virtual worlds in VR are **almost indistinguishable from real life**, and haptics have improved to give a realistic sense of feel across the body

What examples of impact could immersive-reality solutions cause across industries?

Overall, industries with a higher proportion of nondesk workers are leading in adoption

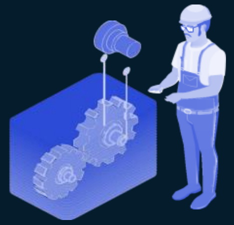
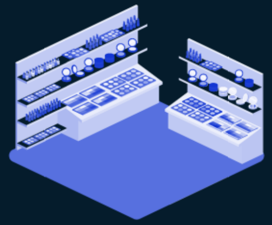
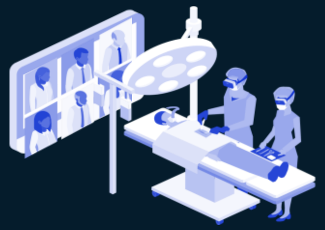
~75% of deskless workers spend most of their time at work using some form of tech, with >60% reporting lack of satisfaction or feeling the need for improvement in the tech they use

Source: "The rise of the deskless workforce," Emergence, 2018; McKinsey analysis;

What examples of impact could immersive-reality solutions cause across industries? (continued)

Use cases are emerging both horizontally and vertically across industries

Nonexhaustive

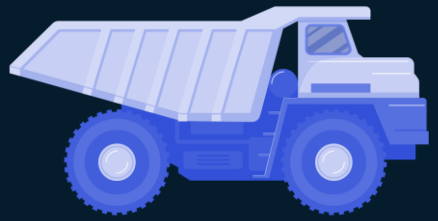
Industry	Horizontal	Manufacturing	Retail	Healthcare
Use cases	Learning and development Remote collaboration Field-worker assistance Customer support Conferences and events	Digital twins/operations Factory design Product design Training Remote assistance Safety	3-D catalog Virtual store/digital showrooms Interactive try on Store layout and design Warehouse optimization	Surgical assistance (AR) Telemedicine (mental health, pain management, etc) Imaging/pathology Training R&D/simulations
				
Significance	**63%** of companies that are metaverse adopters have undertaken learning and development for employees in the metaverse	**~100%** of design of physical products/spaces (eg, factories, warehouses) could be simulated in a synthetic environment	**~33%** of customers who are active on the metaverse have purchased real-world items there	**Increasing efficacy** of immersive-reality solutions in treating mental disorders

Source: "Value creation in the metaverse: The real business of the virtual world," McKinsey, June 2022; "Extended reality for anxiety and depression therapy amidst mental disorders: A systematic review," ResearchGate, March 2022

What examples of impact could immersive-reality solutions cause across industries? (continued)

Immersive reality is going to change the way the energy and materials industries operate

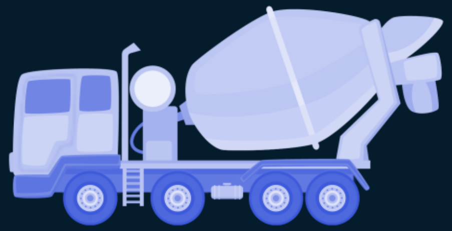
Nonexhaustive



Mining

Using VR to remotely control robot operations on-site and **using AR** to visualize geology and geophysics overlaid onto physical locations

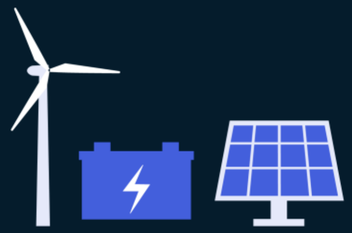
Example: Repair technician can view process information overlaid on tech equipment and receives support during the repair or decision to request replacement parts



Construction

Using VR to create immersive, virtual environments, giving architects a better sense of a space before it physically exists

Example: Architects and designers can provide virtual tours of the future space's design that bring it to life



Energy and utilities

Using AR to view overlaid visualization of underground assets and complex components for improved operational safety

Example: Field technician can access required data and support using AR device, through which subject-matter **e**xpert or AI could advise on what actions to take

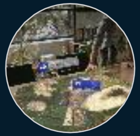
Source: McKinsey analysis

Who has managed to successfully drive impact through leveraging this tech trend?

Many industries have started to experiment with AR applications

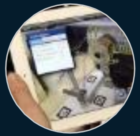
Electronics

Fujitsu uses **AR in the sales process** to allow customers to see all product characteristics



Mining

BGC leverages AR to evaluate **the total life cycle of mines,** allowing for quick decisions



Aerospace

Boeing leverages AR to improve manufacturing process efficiency, and has achieved a **90% quality increase** and **30% speed increase** on its pilots

Airline

Japan Airlines is experimenting with Hololens AR as a **technical training tool** for its maintenance technicians

Automotive

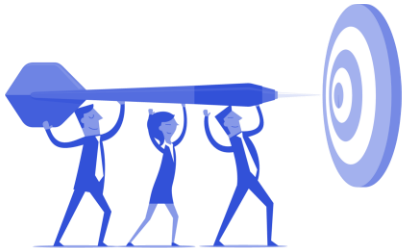
Volvo uses AR to change the **customer experience** when buying cars; **Ford** uses it for **product development; Renault** is experimenting with **AR for manufacturing execution**

Porsche has **shortened operational time** spent on **addressing issues by 40%** through use of AR headsets to simulate virtual models of problem vehicles

Source: Company websites

What should a leader consider when engaging with these technologies?

Nonexhaustive



Benefits

More efficient product prototyping and test simulations through the creation of digital twins to enable virtual walk-throughs of a physical environment or a new physical product

Process improvement through early-warning detection mechanisms, risk management, improved quality assurance, on-the-job visual guidance, and more

Introduction of new products and services by engaging consumers in new ways and enhancing customer experiences

Increased collaboration by facilitating more engaging virtual-team interactions, without the need of being physically present

Scalability of trainings by allowing users to develop hands-on skills, especially when simulating unusual situations, all while ensuring consistency in the quality of training provided

Cost savings as a result of effective product development, improved processes, and scalable, quality-assured trainings

Risks and uncertainties

Pace of hardware improvements to enable miniaturization/weight reduction, ruggedness, nausea mitigation, etc

Cost reductions required to make many more applications commercially viable and scalable

Uncertainty on whether consumer applications will target niche customer segments or focus broadly on mass markets

Improvements needed in sensors' precision to better track user's body movements and synchronize with changing visuals

Exposure to complex security vulnerabilities must be mitigated, as typical AR/VR applications need access to many technologies (eg, smartphones, body sensors, glasses) and may be linked with social-media accounts and external applications

Concern about user's ability to control what data are collected and how data are processed or shared with third parties (eg, to what extent will users be "surveilled"?)

Source: McKinsey analysis

What are some controversial topics within immersive reality?

Nonexhaustive

1 Ways of working

Will immersive reality shift the new wave of (remote) work?

Many business are reconsidering their remote vs in-person work operating models as COVID-19 measures are relaxed. As immersive-reality tech boosts collaboration and facilitates remote operations, will remote work be here to stay?

2 Scalability

Will initial ideas continue to stall at proof of concept—or begin to breakthrough to scale? What will be the triggers for breakout success?

Significant tech advancements still required for AR/VR are approximately 8–10 years out. Although some of the required individual capabilities are technically possible today, device makers still need to produce these features (eg, battery life, weight, ergonomics) in conjunction with each other to improve sensory precision, mitigate security and privacy concerns, and broaden consumer applications, among other factors.

3 Enterprise architecture integration

How will consumer-oriented pioneering platforms integrate with enterprise tech architectures?

Adopting immersive-reality solutions puts a strain on tech architecture. Enterprises will have to evolve their capabilities to integrate with these new technologies while mitigating privacy and security concerns; the investments required to do so are unclear.

4 False information

To what extent can immersive reality facilitate the spread of false information?

Deepfake technology and mixed reality facilitate misrepresentation (eg, facial swap features), which could have social implications like cultural appropriation or spread “fake news” for targeted political influence or any other malicious intent.

5 Virtual crimes

How can virtual crimes be mitigated and regulated?

Ethical questions are emerging around the potential psychological effects of immersive-reality technologies, raising questions around how to deal with different forms of harm, such as virtual violence, bullying, and trespassing.

Source: McKinsey analysis

Additional resources

Related reading

Augmented and virtual reality: The promise and peril of immersive technologies

Product development gets a makeover—with virtual reality

Meet the metaverse: Creating real value in a virtual world

Value creation in the metaverse

McKinsey & Company

Industrializing machine learning

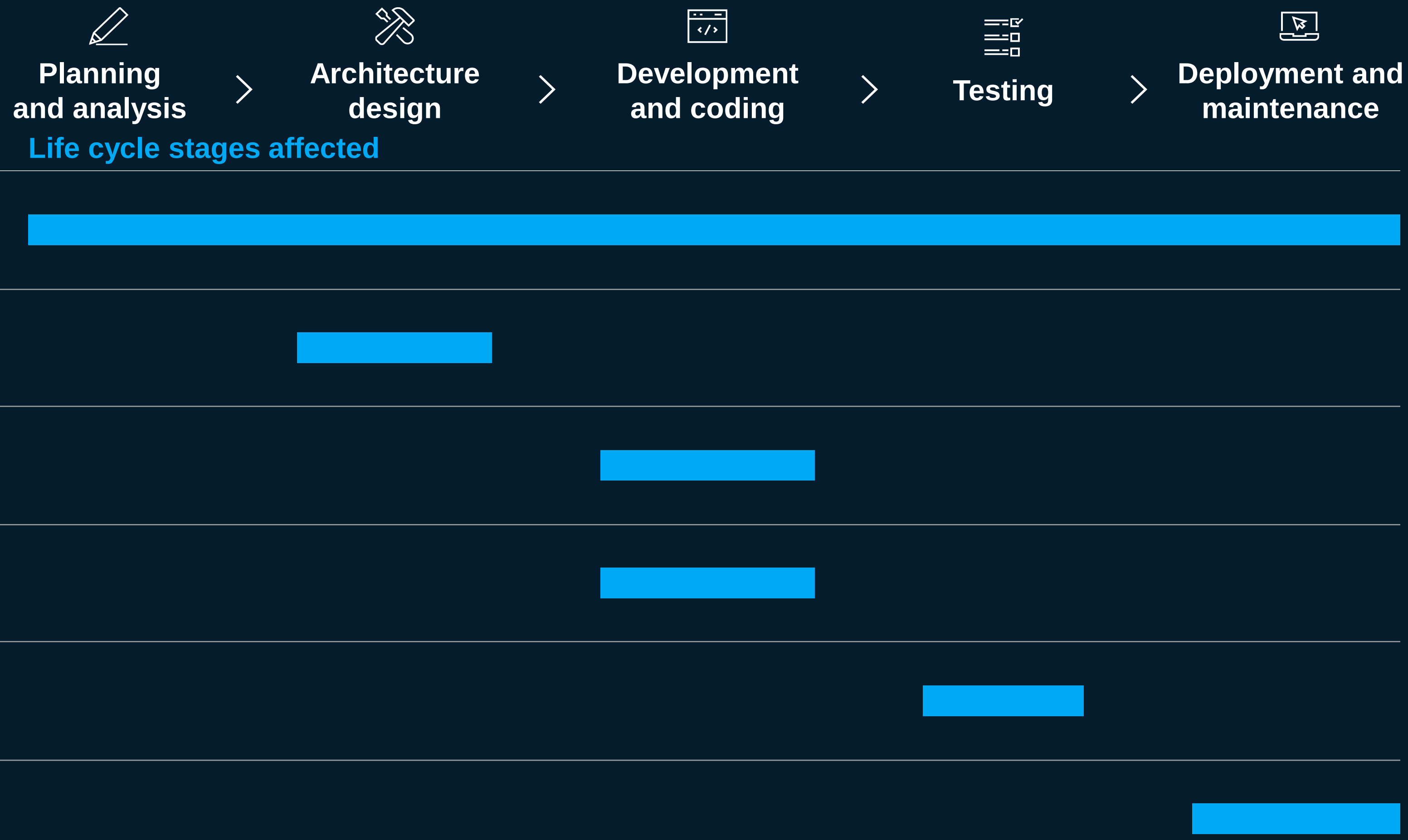
McKinsey & Company

Next-generation software development

August 2022

What is this trend about?

The next generation of software development involves tooling that aids in the development of software applications, improving processes and software quality across each stage of the software development life cycle, including AI-enabled development and testing, as well as low-code/no-code tools



Technology or tool kit

Low-code/no-code platforms
Graphical user interface (GUI)–based platforms for nondevelopers to use in building apps

Infrastructure-as-code
Configuration templates to provision infrastructure for applications using Terraform, Ansible, etc

Microservices and APIs
Self-contained modular pieces of code that can be assembled into larger applications

AI pair programmer
Code recommendations based on context from input code or natural language

AI-based testing
Automated unit and performance testing to reduce developer time spent on testing

Automated code review
Automated software checks of source code through AI or predefined rules

Source: McKinsey analysis

Why should leaders pay attention?

Developers will focus more on the capabilities their applications would enable than on the details of building the apps

Growth in market and adoption

Greater adoption

~70%

Share of new application development that will leverage low-code/no-code by 2025 (vs <25% in 2020)

Growth in market size

~21%

Growth in size of market for software development, **CAGR for 2021–26,** reaching ~$600 million by 2026

Augmented capabilities

Faster development

Up to ~90%

Reduction in development time due to low-code/no-code applications

Faster deployment

~2×

Increase in deployment speed reported by ~60% of developers, driven by practices such as continuous integration and continuous delivery (CI/CD)

Faster code testing

~37%

Share of respondents saying they **use AI and ML to test better** and faster

Reduced resolution time

<1 day

Time to resolve configuration issues reported by ~75% of companies with automated infrastructure-as-code security testing

As repetitive tasks become automated and resource requirements to build digital products decrease, developers will **focus on adding new, innovative features**

Many methods, including CI/CD and infrastructure-as-code, will **benefit from cloud migration** and accelerate this transition

Source: Gartner; "Software development AI market overview," IndustryARC; *Intelligent process automation and the emergence of digital automation platforms*, Red Hat, February 2018; *A maturing DevSecOps landscape*, GitLab, May 4, 2021; Forrester Analytics Business Technographics Developer Survey, 2020; *Infrastructure as code security insights*, Snyk, 2021

Why is this interesting, compared with what already exists?

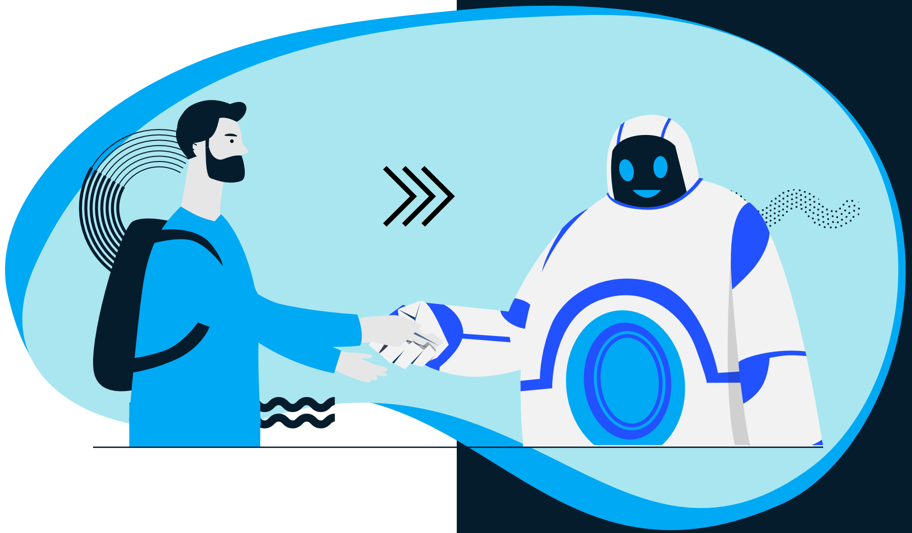
From manual, time-intensive work flows and techniques …

Reliance on dedicated developers to participate in every step of the development cycle, from planning to maintenance, contributes to higher costs and talent gaps

Manual infrastructure configuration and monitoring involve high mean time to restore (MTTR), security risks, and task repetition, leading to inefficient resource utilization

Developers working together to write code as 'pair programmers' on the same workstation expend a high number of person-hours to build the program

Development cycles are slow because teams experience interruptions, code has more defects, and time is spent on manual tasks



… to automated, simplified, and faster development techniques

Greater participation of 'citizen developers' (business users who have insignificant technical experience but are able to build business applications without involving technical teams) facilitates quick development of solutions more aligned to business needs

Automated configuration and monitoring through infrastructure-as-code reduces downtime and increases overall productivity and security

AI-based pair programmers, such as GitHub's Copilot, are making solo developers more efficient and improving quality of code

Fully automated CI/CD pipelines enable lower disruption, higher code quality, and drastically shorter development cycles

Source: McKinsey analysis

What are the noteworthy technologies and their benefits?

Across the entire software development life cycle, technologies are already improving developer velocity

Nonexhaustive

1. Planning and analysis
2. Architecture design
3. Development and coding
4. Testing
5. Deployment and maintenance

Infrastructure-as-code

Higher scalability as configuration templates are used to set up new environments rapidly and consistently

Reduced risks as configuration templates eliminate possibility of human error

AI pair programmer

Rapid development as developers **code faster** with reduced friction to aid "developer flow"

Enabler of automatic translations and **no-code /low-code tools**

Microservices and APIs

Faster development as microservices and APIs serve as building blocks companies use to effortlessly add functionality to software, unlocking significant business agility

New revenue streams as APIs can be provided to customers in an as-a-service model and externally to other businesses for integration

AI-based testing

Faster, more efficient testing via smarter automation

Improved test coverage and effectiveness, with automated script writing expected to exceed 80% of test coverage within the next decade and to auto-generate insights for improvement

Automated code review

Faster, more efficient code reviews with greater coverage as a result of eliminating manual inputs and removing human biases

Low-code/ no-code platforms

- **Standardized tools and processes** that scale tech innovation via reuse of components
- **Acceleration application development** through plug-and-play software components
- **Stronger business alignment** as a result of bringing technical requirements closer to business units
- **Automated deployment** of models into production applications
- **Augmented monitoring and maintenance** (eg, model retraining) to minimize performance degradation

Source: Expert interviews; McKinsey analysis

What industries will be affected?

Beyond the software industry, these technologies will have **impact on software development across all industries** by reducing digitization challenges

4 industries are already reaping the benefits of low-code/no-code platforms, given their **common qualities** and requirements

Industry	Examples
Finance	Evolving business rules for processes such as onboarding, know your customer (KYC), and customer due diligence can be continuously handled by business analysts for efficiency
Healthcare and pharma	Case management processes for handling customer data, tailored and specific processes for high-risk patients, development and testing of new drugs, etc, can be customized by healthcare provider
Manufacturing	Production floor management allows industrial engineers to optimize operations, reduce training expenses for new developers, reduce production floor failures, and standardize safety/handover protocols
Retail	Consumer-friendly front-end applications can be rapidly created and tailored to the needs of an organization and its customers

Common industry qualities

Compliance requires a **wide variety of frameworks, protocols,** and **regulations,** which typically vary by region, license agreement, etc

Heavily process-based industries

Significant custom-ization requirements

Rapid pace of innovation to meet evolving customer needs

Source: Expert interviews; McKinsey analysis

What are some uncertainties affecting next-generation software development?

Low-code/no-code platforms

Modest amount of customization is possible, compared with traditional programming languages

Monitoring and debugging applications is **difficult**, especially when they are integrated across several low-code/no-code platforms

Infrastructure-as-code

Comprehensive monitoring and version control is required to ensure errors do not spread across servers

Fragmented vendors could disrupt integrated applications, given uncoordinated changes and upgrades

AI pair programmer

Generated code **may be unusable or inefficient** and may **have security vulnerabilities**

Coders can be steered in the wrong direction if tools are not regularly updated with the latest market trends and standards

Microservices and APIs

Customizing APIs is difficult without significant time and effort

APIs **introduce security risks** by adding another attack layer that can be exploited

AI-based testing

Autonomous tools are typically specialized (eg, by programming language, test type)

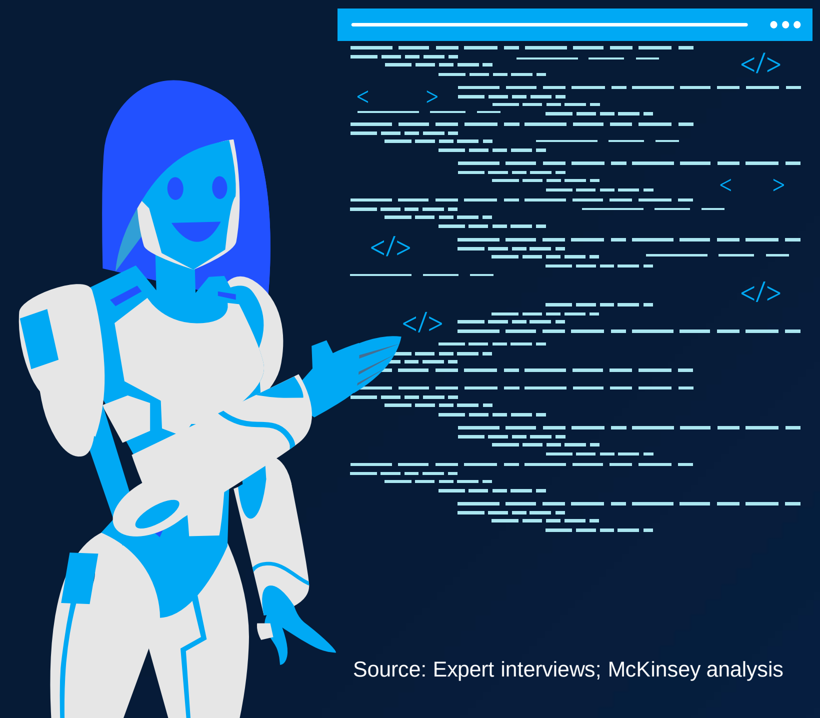
Automated code review

Tools **do not identify all defects and inefficiencies** in code

Companies over-rely on automated testing/reviews when this tech scales; humans do not consistently check for errors in test and review outcomes

Source: Expert interviews; McKinsey analysis

What are some associated risks and topics of debate for these technologies?



Source: Expert interviews; McKinsey analysis

1 To what extent can no-code tech reduce the need for traditional software developers?

While low-code/no-code platforms help teams rapidly prototype or enable citizen developers to take over some of the work developers do, they are still not flexible enough to replace developers at every stage of the software development life cycle (eg, when systems require upgrades)

2 From a cultural standpoint, will teams: both developers and non-developers embrace or resist next-generation technologies?

Automation technologies reduce time spent on development, which raises concerns for employees whose workflows are highly automatable; developers, testers, and analysts may be reluctant or eager to switch to new technologies, depending on job security, technical comfort, etc

3 What intellectual-property issues might affect code written by an AI application?

As companies leverage AI generation tools, there is a concern around ownership: Will the company that developed the application own it, or will it belong to the AI generation tool provider?

4 To what extent will business units take responsibility for the 'health' of applications?

As next-generation software brings development closer to citizen developers and business units, questions about organizational structure and responsibilities emerge—eg, as business users create applications, who is responsible for maintaining them?

Who has succeeded at driving impact through leveraging next-generation software development?

Leading players across industries have already leveraged advanced DevOps tools to optimize their SDLC[1]

Stage of SDLC[1]	Technology	Example
Across the SDLC	Low-code/no-code platforms	**Salesforce uses low-code/no-code platforms to enable citizen developers** to fill clients' customer needs where there is a void in Salesforce's default offerings
Architecture design	Infrastructure-as-code	**Decathlon used infrastructure-as-code to automate infrastructure deployment,** reducing deployment time from weeks to 30 minutes, allowing IT teams to focus on more complex tasks
Development and coding	Automated CI/CD	**Capital One leverages microservices and automated CI/CD to increase delivery speed without compromising quality** through reusable building blocks and generation of templated pipelines
	AI-based code recommender	Powered by OpenAI, **GitHub's Copilot automatically recommends blocks of code** based on functionality the developer wants to achieve
Testing	AI-based test automation	**Goldman Sachs uses the AI-based tool Diffblue cover to generate unit tests** for legacy software, leading to a 180× increase in the speed of writing tests for a core back-end application
Deployment and maintenance	AI-based code reviews	**Atlassian uses AI-based tools by Amazon Web Services to improve code performance** by identifying code paths that demonstrate poor CPU[2] utilization or latency

[1]Software development life cycle.
[2]Central processing unit.

Source: Company websites; expert interviews

Additional resources

Developer Velocity: How software excellence fuels business performance

Security as code: The best (and maybe only) path to securing cloud applications and systems

Developer Velocity at work: Key lessons from industry digital leaders

McKinsey & Company

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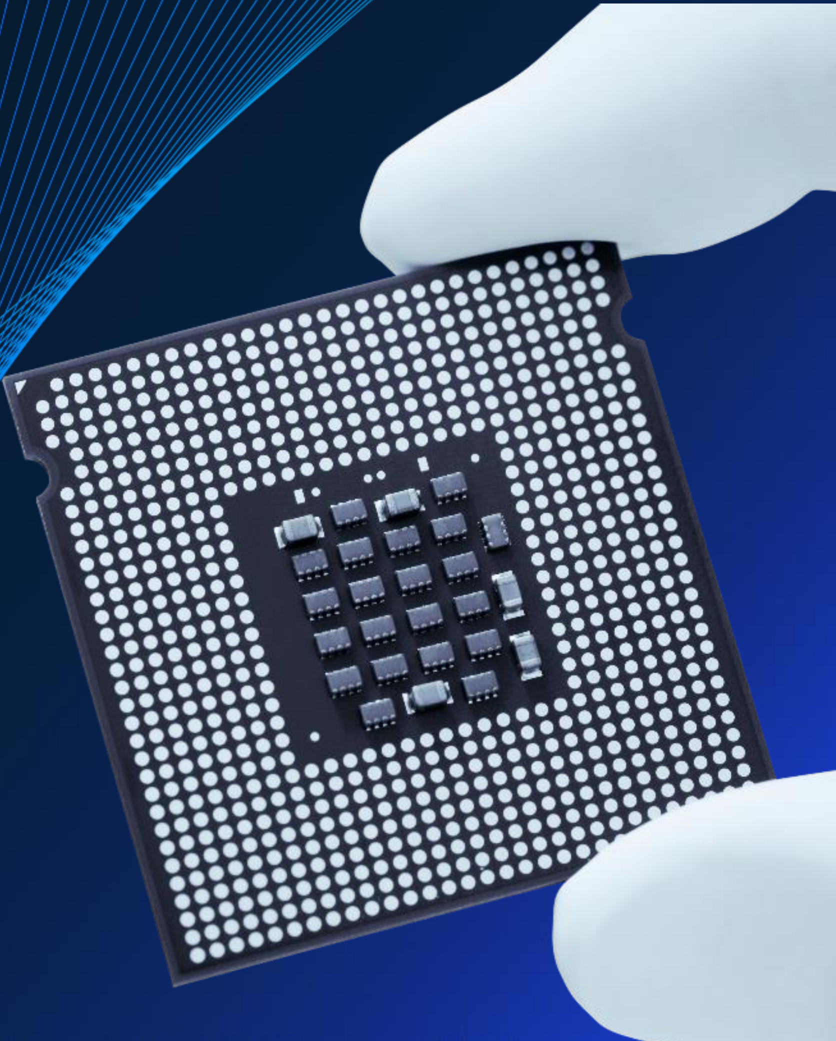
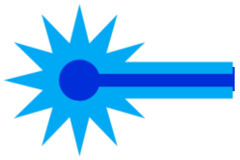
Quantum Technologies

June 2022

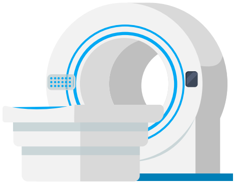


[Quantum technologies] What are the most noteworthy technologies?

Quantum technology has been around for a longtime…



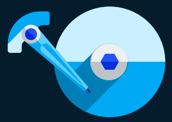
Lasers - Works using the quantum mechanical effect known as *stimulated emission*



Magnetic Resonance Imaging – Uses the quantum phenomenon known as *magnetic resonance*

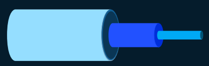
… but there are emerging technologies which we are looking at

These futuristic technologies aspire to change our computational, networking and sensory infrastructure in the coming decades unlocking use cases and capabilities previously unimaginable



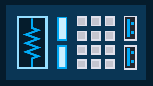
Quantum Computing uses quantum properties of particles to process information at a much higher rate than a classical computer

For a certain number of computational problems, it could speed up computation exponentially compared to classical computers



Quantum Communication is the transfer of encoded quantum information between distant locations based on an optical fiber network or satellites

A central aspect is the quantum-secure connection through quantum encryption



Quantum Sensing could provide measurements of various physical quantities at a sensitivity that is orders of magnitude higher than classical sensors

Applications include radar, microscopy, magnetometers etc.

$300 - $700 billion

Is the **conservative estimate[3] of value-at-stake** of quantum use cases in industries such as pharmaceuticals, chemicals, automotive and finance

1. IDC, Nov 2021, Worldwide Quantum Computing Forecast, 2021–2025
2. Google's research published in Nature
3. McKinsey Report on Quantum Computing, December 2021

[Quantum technologies] Why should leaders pay attention?

The quantum age is just over the horizon …

Rapid acceleration in investments

$1.7 billion

invested in quantum start-ups in 2021, more than double the amount in 2020

Technology approaching maturity

<10 years

Estimated timeline to unlock several of the currently identified use cases as it matures and scales

Market expected to grow rapidly

~$10 billion[1]

projected market size of Quantum Computing services in 2027 from ~$400 million in 2020, growing at 50% per annum

Enormous processing power today

>10,000 yrs[2]

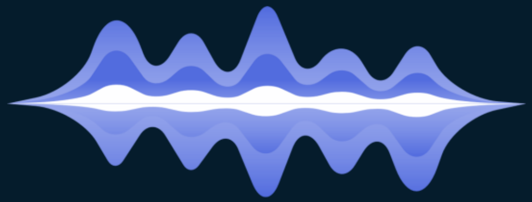
time taken by traditional computers to complete a task that can be done in a few seconds by Google's quantum computers

However, Quantum technology is still very much in its nascent phase, and it would be difficult to predict when or if this technology will mature and scale up

[Quantum technologies] Why is Quantum Computing interesting compared to what already exists? (1/2)

	Classical Computer	Quantum Computer
Information Storage	Information is stored in *bits,* where each bit can be **either** “0” or “1” 	The information is stored in *qubits*, where each qubit represents **any possible combination** of “0” or “1” with each other 
Computation	Results can be read **directly from the bit string** of 0s and 1s	Results of the computation are retrieved via **statistical analysis** of repeated quantum measurements
Performance	The performance scales **linearly** with the number of bits	The performance may scale **exponentially** with the number of qubits for certain problems
Pros / Cons	+ Good for general-purpose computing + Mature technology with low errors + Robust and cost effective – Cannot scale well for certain problems	– Cannot perform general-purpose computing – Nascent technology with high error rates – Currently requires expensive specialized infrastructure + Good at solving certain specific problems

[Quantum technologies] Why is Quantum Communications interesting compared to what already exists? (2/2)



The **ambition** of Quantum Communications is to offer transfer of encoded quantum information between distant locations through a universal quantum communication network.

Quantum Communications enables major applications such as

Enhanced Security based on quantum mechanics

Secure Quantum Communications guarantees full security of information transfer in the presence of a quantum computer

It will enable

- Verified randomness for generating shared keys
- Quantum encryption
- Tamper proof communications

Enhanced quantum computing power

Quantum Communications enables

- **Distributed Quantum Processing** where two or more quantum computers are connected to enhance computing power
- **Blind quantum computing** where a remote quantum computer is accessed such that it learns nothing about the performed operation

Source: Expert interviews; McKinsey analysis

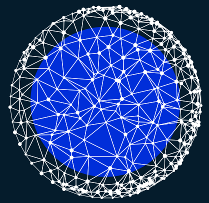
[Quantum technologies] What are the examples of disruption that Quantum Computing could cause? (2/2)

Quantum computing could unleash significant business value across industries, but significant research and development is needed

Applications

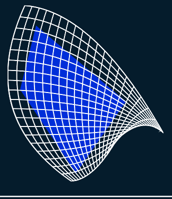
Most known use cases can fit into four archetypes:

Quantum Simulation



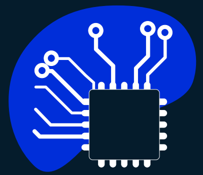
Simulation of quantum-mechanical systems such as molecules, chemical reactions, or electrons to enable use cases such as **lead identification in drug discovery** or **simulating proteins in pharmaceuticals / agriculture**

Quantum Linear Algebra



Algorithms that can provide an exponential speedup over conventional algorithms and be used in tasks such as providing **financial advice, autonomous driving, automated trading,** and **predictive maintenance**

Quantum Optimization



Real-time optimization by compressing computation times from hours to seconds and enable use cases in almost every industry such as **generative design, traffic management,** and **portfolio optimization**

Quantum Factorization

The earliest identified application of quantum computing, efficient quantum factorization is readily applicable to **breaking RSA encryption**, the basis of most of today's secure data-transfer protocols

Source: McKinsey, December 2021, Quantum computing: An emerging ecosystem and industry use cases

[Quantum technologies] What are the examples of disruption that Quantum Communications could cause? (2/2)

Quantum Communication enables secure communication of quantum information across distant locations

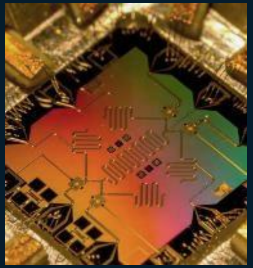
Applications

Quantum-enhanced (classical) cryptography

Quantum random number generators (QRNG)

Enhances security of classical cryptography protocols e.g., cryptography, PINs, lotteries, numerical simulations

Quantum cryptography



Quantum encryption protocols

Secure communication enabled by a quantum-generated confidential key shared between distant partners; e.g., Quantum Key Distribution (QKD), BB84

Quantum internet

Quantum communication infrastructure

Quantum information exchange across continental or global distances to enable

- Long-distance secure communication
- Distributed quantum computing

Source: Expert interviews; McKinsey analysis

[Quantum technologies] Who has managed to successfully drive impact through leveraging this Quantum Technologies?

Recently, many public and private entities have made announcements regarding their early applications of quantum technologies

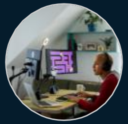
	Case example
Quantum Communi-cations	The **University of Science and Technology of China** in collaboration with industry partners has deployed an integrated communication network with QKD spanning over 4600km
	Toshiba and the University of Cambridge have deployed quantum encryption protocols through existing city-wide fibers with high-bandwidth data traffic
Quantum Computing	Companies such as **Alibaba, Amazon, IBM, Google, and Microsoft** have already launched commercial quantum-computing cloud services with varying levels of customer adoption and technical maturity
	BMW has used quantum machine learning for autonomous vehicles by using it to train highly accurate models with massive amounts of data and used quantum computing for car fleet routing optimizing
	Goldman Sachs is exploring the business applications of quantum computing and has experimented using novel Quantum Mote Carlo algorithms to run on near-term quantum computers
	Pfizer is applying quantum computing to predict the behavior of electrons in a molecule to determine its 3D structure in order to understand more about new molecules that are potential drug candidates

Source: Expert interviews, press search, team analysis

[Quantum technologies] What are some implications of Quantum technologies across industries?

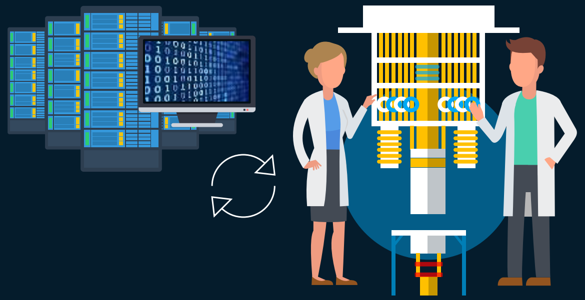
Quantum computing is still in the nascent stage with few, isolated examples of players adopting them for solving optimization challenges

Quantum communications is relatively more mature with several players globally establishing networks with QKD and reaping the benefits of this technology

Industry impacted	Implications from technology trend
 **Telecom**	Companies are improving network security with relatively mature quantum key distribution technology Networks that transmit information with quantum particles are being prototyped
 **Technology**	Cloud providers are developing capabilities or forming partnerships to offer quantum computing services Increasingly more startups are providing quantum computing, communications hardware and services
 **Automotive & Logistics**	Quantum computers could process of large amounts of data to train AI models and conduct simulations to improve fleet routing, traffic management and autonomous driving
 **Chemicals & Pharma**	Quantum computers could help with the molecular simulations involved in identifying potential pharmaceuticals and creating new materials
 **Financial Services**	Quantum networking and computing could improve the security and speeds with which financial data can be gathered and processed

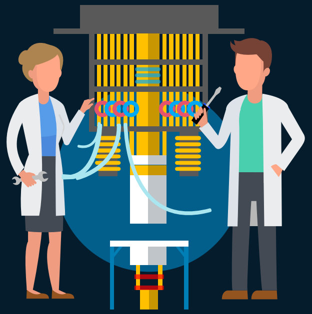
[Quantum technologies] What should a leader consider if pursuing Quantum technologies? (1/2)

Initially, incremental value from quantum will be created through hybrid solutions with high performance computing



Before "impossible tasks" will be solvable, we expect incremental value creation through hybrid solutions with conventional supercomputers such as …

- Solving business-relevant optimization problems in certain niches would be **10% faster** than previously possible
- Simulating the properties of small molecules like surfactants with **5% higher accuracy** to develop a better carpet cleaning product
- Better data sampling to train an AI – this may take longer, but the trained algorithm gives **20% better answers**



Meanwhile, researchers work on improving quantum computers with two major goals …

- **Improve Processors** - Create stand-alone fully capable quantum processors with high count of quality qubits in order to achieve 'quantum advantage' over classical computers
- **Market Ready Tech Stack** - Overcome engineering challenges and build a technology stack of hardware and software in order to make state-of-the-art quantum computers market-ready

Source: McKinsey, Expert Interviews

[Quantum technologies] What should a leader consider if pursuing Quantum technologies? (2/2)

Advantages

Early mover advantage – Organizations can begin investing in talent & infrastructure, establish / join quantum technology ecosystems early and prepare for upcoming disruption by identifying relevant use cases for their businesses while the technology matures through fundamental scientific research

Short term applications – Many industries stand to gain from the benefits of quantum computing in the very short term even if it requires combined inputs from traditional high-power computation

Uncertainties / risks

Cost-effectiveness – Most calculations done by enterprise Quantum Computers can be done reasonably well by traditional supercomputers at a much lower cost, this is expected to change once quantum advantage is achieved and general-purpose quantum computers take center stage

Uncertain roadmap – Current advancements paint a promising future but there may be potential barriers to adoption (regulatory, technological, financial etc.) that may not be apparent today

Nascent ecosystem – There are only a handful of proven hardware platforms commercially available and a massive dearth of talent skilled in quantum computing, this may change in the future as the technology matures and adoption increases

Source: McKinsey

[Quantum technologies] What are some notable topics of debate?

Quantum technologies are still very nascent, and many questions remain unanswered and despite generally optimistic outlooks, the future remains uncertain for these technologies

1 Impact of edge computing

Will quantum be ready in the next ten years?

- Edge is **extremely flexible** and supports a **wide array of devices** while lying in a **business and regulatory sweet spot**
- However, Traditional cloud enables economies of scale that would **not be possible for edge computing** networks and requires a **high level of interoperability and commonality of standards** currently absent in networking

2 Future outlook

Will hyperscale cloud providers win the Edge race?

- Public cloud providers already **have dedicated services and partnerships** with other vendors to provide seamless edge and cloud connectivity to their customers
- **However, telcos with 5G enabled MEC** can choose to either contend or partner with hyperscalers while **OEMs, networking and edge service providers** will be important as edge networks scale up and customers require custom solutions

3 Security vulnerabilities

Will the increase in number of storage and processing units lead to security vulnerabilities?

- Keeping **sensitive data at edge locations** away from centralized servers helps restrict access and minimizes risks in the event of a major hack
- However, by increasing the number of edge locations, the **attack vectors for malicious actors increases** and if proper precautions aren't taken, security vulnerabilities may arise

4 Energy consumption

How will cloud & edge evolve in line with sustainable IT paradigm?

- Datacenters are increasingly relying on green IT measures such as **sustainably sourced energy, energy efficient cooling systems** etc. making them more
- Edge computing also reduce the overall energy requirements as **lesser data is transmitted across the network** and more of it is processed and stored locally
- However, as networks expand, the number of devices, datacenters, critical infrastructure and **related energy requirements will continue to increase**

Source: McKinsey, Expert input

Additional resources

Quantum computing use cases are getting real—what you need to know

The Rise of Quantum Computing

A game plan for quantum computing

Video - The growing potential of quantum computing

Shaping the long race in quantum communication and quantum sensing

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Trust Architectures & Digital Identity

August 2022

What is the tech trend?

Increasing cyberattacks and data breaches continually pose new challenges by leveraging trending technology (e.g., encryption breaking from quantum computing). **Digital-trust technologies** empower organizations to protect trust with stakeholders (e.g., customers, regulators) and gain a competitive advantage by managing these risk, strengthening security, and enhancing organizational performance and relationships. Technologies of high growth include:[1]

Zero-trust architecture (ZTA)

Type of **IT security system design,** where **all entities,** both inside and outside of the organization's computer network, **cannot trusted by default** and need to prove trustworthiness

Elements include access management, device protection, network security, data encryption, continuous monitoring, and more

Digital Identity

Mechanisms of providing full information that **characterizes** and **distinguishes an individual entity** in the digital space

Entities (e.g., systems, persons, organizations) have **identities** which consist of distinguishing **attributes** (e.g., names, identifiers, characteristics)

Privacy engineering

Techniques used to enable the practice overseeing implementation, operation, and maintenance of privacy

Elements include data privacy risk reduction, resource allocation, and implementation

Explainable Artificial Intelligence (XAI)

Techniques that help **understand** and **build trust in AI models** for real world deployment

Topics influencing fairness, accountability, responsibility, transparency, and ethics

Digital trust addresses digital risk across data, cloud, AI & analytics, and risk culture

1. Technology areas and specific technologies are non-exhaustive of all developments in cybersecurity

Source: McKinsey analysis

Why should leaders pay attention? (1/2)

Digital trust technologies can reduce risk and potential negative impact from cyberattacks

Cyberattacks and cyber regulations are accelerating…

1 out of 3

Global organizations have experienced a cyberattack in 2019 (+36% compared to prior year)

Increasing complexity and frequency of cyberattacks

220x

increase in spam from Feb to Mar 2020 due to COVID-19 outbreak vulnerabilities

Increasingly high costs and losses from cyberattacks

~$10.5 trillion

Forecasted costs and losses related to cybercrime by 2025, which has a 15% annual increase

Growing regulation in the US and globally

+31

New national cyber policies in the US in the past 5 years with greater numbers globally

… so technology needs to keep up by developing

$101.5 billion

projected spending on service providers in digital trust by 2025[1]

3-13%

Improvement in economic benefits equivalent of GDP predicted by 2030 via digital identity

85%

of small and midsize enterprises intend to increase IT security spending until 2023

~85%

% of companies that are victims of fraud related to digital identity each year each year

1. Service providers include consultants, hardware support, implementation, and outsourcing

Source: Center for Strategic & International Studies; IBM; Identity Theft Resource Center; Kaspersky Lab; National Cyber Security Centre; press; PurpleSec data survey; Statista; McKinsey Cyber Market Map, McKinsey Global Institute

Why should leaders pay attention? (2/2)

Digital trust offers value creation, enabling organizations to scale faster and become more effective

Digital-trust opportunities are increasing and…

- Exponential potential for stacked wins
- Increased speed of digitization
- High potential market value advantage
- Better ability to engage in risk reduction

…mitigating a landscape of complications and pitfalls…

- Increasingly aggressive regulatory scrutiny leading to substantial fines and penalties
- Heavy reliance on legacy governance processes and technologies
- AI algorithms more difficult to understand, more complex, and less predictable than traditional analytics
- Increasing scrutiny from public, media, and watchdog organizations
- Increasing global uncertainty

…leading to economic impact and value

- Build a strong foundation of digital trust with customers, leading to increased acquisition
- Leverage digital trust to scale internal data and analytic programs sustainably
- Advance strategic position for advantage over competitors across AI & analytics, data, cloud, and risk culture

Source: McKinsey analysis

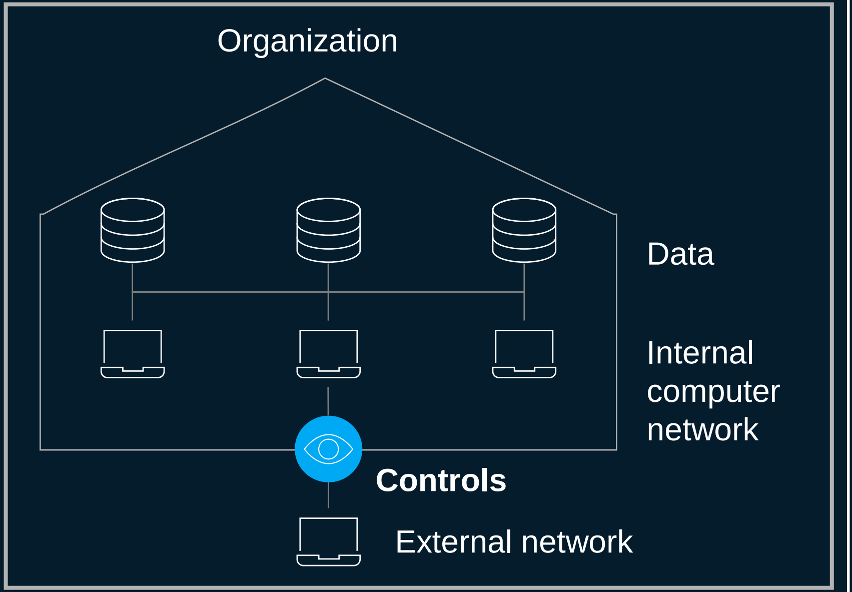
What are the noteworthy technologies? (1/3)

Zero-trust architecture (ZTA) assumes "zero trust" for more robust and secure data flow across technical systems

FROM:

Traditional, perimeter-based architecture

After being verified and gaining access past the perimeter controls, **everything within the network** is **assumed safe**, which does not robustly protect against inner threats

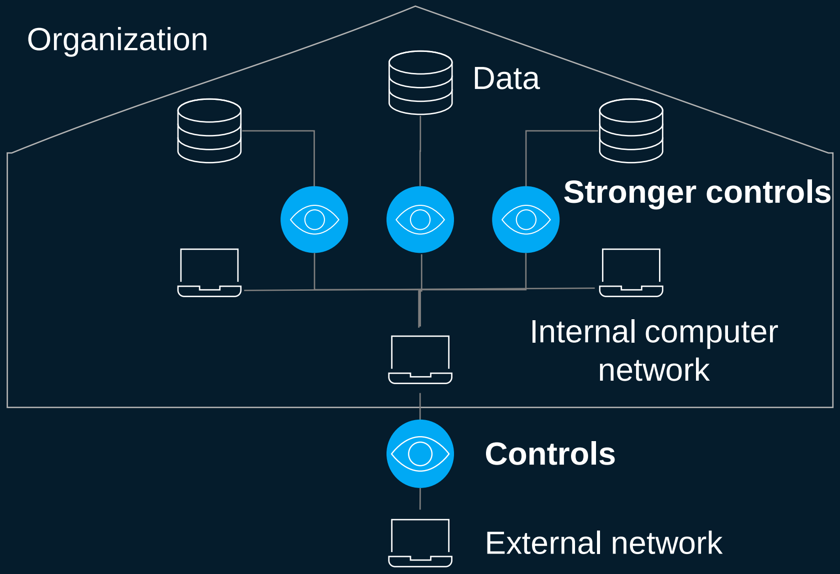


TO:

Zero-trust architecture

Zero trust assumes that **all entities**, both within and outside of the organization, **are not to be trusted:**

- **Controls** (e.g., identity and access management, network controls) are **set up for any interaction by an entity** throughout the network
- **Strength of controls** vary based on **importance and risk level** of the data and/or asset protected
- **The network is micro-segmented** to divide data and isolate attacks to data segments



Benefits

- **Increased security and reduced risk** from increased controls across organizational network and customer data
- **Cost reduction** due to decreased losses from cyberattacks
- **Increased visibility and understanding** into user access and traffic across the network from continuous monitoring
- **Upskilled workforce and streamlined technical stack,** where implementation will uplevel the company with stronger, faster technical capabilities and mitigate tech stack complexity. Company will be primed for incorporation of other cybersecurity technologies
- **Improved reputation** due to decreased breaches in security and stronger technical stack, which can attract customers to a company

Source: McKinsey analysis

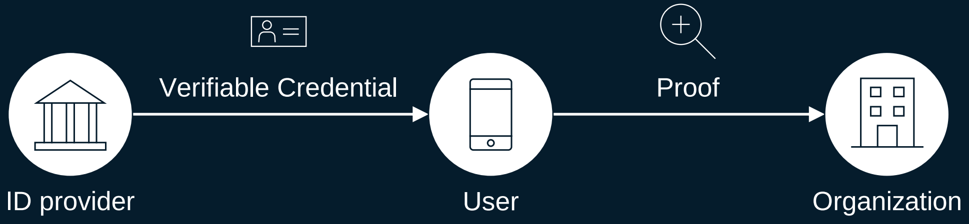
What are the noteworthy technologies? (2/3)

Digital identity is enabling decentralization and new forms of verification respectively

Self-sovereign identity (SSI)

Diagram

Data flow



Description

- Users **have control over their verified credentials** (attribute information to identify an individual), where they can select the specific data for sharing (e.g., name, password) and the sharing audience (e.g., employers, healthcare provider)

Functionality

- Users interact directly with ID issuers and organizations without relying on an intermediary to facilitate data exchange
- Data and user credentials are stored on a decentralized ledger (e.g., blockchain) for easy access and verification

Benefits

- **Increased individual control** over identity for **trusted transactions without an intermediary**, where users themselves control what data they share and with whom from an interoperable and convenient identity source
- **Improved security,** where decentralized data storage limits vulnerability to attacks

Passwordless identity

Diagram

Biometric verification[1]

Description

- Users can verify and authenticate their digital identity without traditional alphanumeric passwords but other forms of identifying information

Functionality

- Users can provide alternative identifying information, such as:
  - Biometrics (e.g., facial scan, retinal scan, thumbprint, voice)
  - Devices and apps (e.g., mobile phone, email)
  - Documents (e.g., driver’s license, passport)

Benefits

- **Alternative protections** against rising vulnerability attacks (e.g., phishing, brute-force password cracking)
- **Reduced inefficiencies** for the user (e.g., too many passwords, lost password)
- **Efficiency and convenience**, where users can rely on streamlined identifying info based on the level of risk associated with the system

1. Diagram adapted from Alex Brown, “Passwordless Authentication Guide,” Transmit Security, January 2022.

Source: McKinsey analysis, Expert input

What are the noteworthy technologies? (3/3)

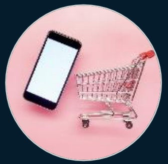
Privacy engineering governs data privacy protection while XAI builds trust in AI models

	Privacy Engineering	Explainable AI
Description	• Design techniques used to enable the practice governing implementation, operations, and maintenance of privacy. Broadly, these technologies support the strategic reduction of privacy risks, resource allocation, and implementation of privacy controls	• **AI-related techniques combining social science and psychology** to enable people to understand, appropriately trust, and effectively manage emerging AI technologies • Different types of explainability apply based on the explanation objective. Examples include explaining how the model works, clarifying why a model input led to its output, and providing additional information needed for people to trust a model and deploy it
Benefits	• **Increased safety and control over data** for customers, employees, and organizations by adding controls and protective measures • **Easier process to implement privacy changes** as the technologies form a privacy infrastructure that can facilitates privacy updates from the continually evolving regulatory landscape	• **Fairer algorithmic outputs** where XAI technologies can help mitigate bias in the data, model, and other processes • **Increased transparency, confidence, and reliability in AI models,** improving organizational performance, reputation, and relationships • **Improved efficiency and effectiveness across AI model pipeline** due to greater understanding of model data, inputs, outputs, and algorithms

Source: McKinsey analysis; Alejandro Barredo Arrieta et al., "Explainable Artificial Intelligence (XAI): Concepts, Taxonomies, Opportunities and Challenges toward Responsible AI," Information Fusion, June 2020; Katherine Miller, "Should AI Models Be Explainable? That depends," Stanford HAI, March 2021;

What is notable potential impact across industries?

Digital-trust technologies could have impact across all industries leveraging digital technology via **reduced risk**. **Technology** and **finance** industries are leading adoption, followed by industries managing highly sensitive and regulated data (e.g., healthcare, retail)[1]

Industry impacted[1]	Impact from technology trend
 **Technology**	**Decreased losses and mitigated risk** due to more secure systems preventing cyberattacks from ZTA and privacy engineering **Improved software solutions and AI model development and deployment** via embedded protocols and controls from privacy engineering and XAI **Potential organizational culture shift** due to focused privacy efforts, increased controls, and layers of security **Enhanced customer experiences and reduced customer friction** (e.g., easier verification, login-in, etc.) through easier access and wider optionality for digital identification **Support of Web3 and Metaverse technologies**, where blockchain can support decentralized storage for SSI and digital avatars offer opportunity enabling digital identity technologies
 **Finance**	**Decreased losses and mitigated risk** due to more secure systems, where digital identity verification is crucial for transactions in financial services **Pressure on regulators** to increase compliance related to digital identity and data sensitivity **Support of decentralized finance (DeFi) related to Web3**, where digital identity can expand and enable DeFi applications (e.g., verification for crypto loans)
 **Healthcare & pharmaceuticals**	**Value creation balancing protection of sensitive data and new use cases from healthcare data** from privacy engineering **Improved secure access to patient medical records**, whereas ZTA controls strengthen protection and digital identity can enable a single, unified data source **Advanced development of AI models for healthcare diagnostics, drug design, and treatment** due to greater understanding from XAI
 **Consumer goods & retail**	**Improved secure access to sensitive customer data** from ZTA controls and digital identity **Advanced development of AI models to improve the customer journey and increase revenue** due to greater customer understanding from XAI **Stronger brand reputation** as the technologies encourage stakeholder trust

1. Non-exhaustive, focus on industries leading business adoption

Source: McKinsey analysis

What are risks and uncertainties with this technology?

Zero-trust architecture

Long-term effort with incremental progress

- Effective and full-fledge ZTA, privacy engineering, and expli cannot be implemented immediately. For reliable results, organizations should gradually increase their controls and test them

Performance efficiency and scalability

- Added authentication steps (e.g., secure communications using VPN and PKI infrastructure) can slow daily work and network efficiency. This can vary based on the frequency of controls and size of the network

Privacy Engineering

Inherent tension between privacy and fairness

- Privacy and fairness can conflict, whereas privacy approaches could restrict collection of personal data while fairness approaches would collect personal data to detect bias

Digital Identity

Nascent ecosystem

- SSI has relatively few standards available, and Web3 is a rapidly growing space

Various dependencies

- Progress is dependent on use of existing standards and infrastructures (e.g., data regulations) as well as development of rising technologies. Registering alternative verified credentials can also be a complex process

Concerns over privacy on biometric data

- Control, storage, and use of biometric data is a debated topic within privacy and ethics

Explainable AI

Lack of standardization

- Deciphering the "black box" of large AI models with a meaningful explanation is challenging and dependent on the task. Resulting solutions could still face new or unaddressed risks, needing to balance privacy, fairness, accountability, responsibility, transparency, and ethics

Overarching risks and uncertainties

High implementation complexity

- There is a need for high upfront investment, advanced tooling, technical talent, and organizational change to implement these technologies within existing technical infrastructures. Organizations can face a scarcity of resources and unstandardized protocols and methods

Compatibility challenges

- Legacy systems are often incompatible and may require bespoke solutions for these new technologies. For compatible systems, there could be issues during updates, migration, or merging with new technologies (e.g., blockchain)

Evolving regulations

- Regulations involving digital trust and privacy has become a prominent topic as past standards conflict with these technologies, such as on data privacy and data permanency. As regulators reconcile these differences and define newer areas, this will influence the direction of digital trust

Stakeholder perceptions

- Changing expectations of customers, employees, and other stakeholders will also guide digital trust

Source: McKinsey analysis

Who has managed to successfully drive impact through leveraging this tech trend?

Zero-trust architecture

A **Latin American oil and gas company** with a small IT estate first began maturing its capabilities before establishing a STA roll-out plan. Their security update plan was rolled out on a system-by-system basis, targeting high risk assets first. The first full ZTA proof-of-concept was implemented 1 year following rollout

Self-sovereign identity

BankID is a digital identification service providing a single source of ID for users in Sweden through their mobile phone. With BankID users can make payments, participate in financial services, login to government platforms, and access their medical records

Passwordless identity

Apple has been continually working towards passwordless sign-ins, such as with Touch ID (i.e. thumbprint) and Face ID (i.e. facial recognition). As of May 2022, numerous technology companies and service providers are working with the FIDO Alliance and W3C to support passwordless sign-in standards. Besides Apple, Google and Microsoft are also incorporating support for these solutions

Source: McKinsey analysis, Company websites

What are topics of debate?

Development in digital trust is dependent on other trending technologies and the overall ecosystem, raising questions on its path forward

1 Designing a secure system

How should organizations determine which technologies and their trade-offs are most relevant to their needs?

While digital-trust technologies offer ways to reduce risk, there is no guarantee of security against all cyberattacks, which are advancing in association with other tech trends. These technologies offer tradeoffs across efficiency, scale, governance, and implementation speed, which further depend on the organization's existing resources and cyber vulnerabilities

2 Data & privacy regulation

How do regulators reconcile past standards with rising technologies that have inherent conflicts?

Data privacy has become increasing critical among organizations, regulators, and customers. The "right to be forgotten" from the General Data Protection Regulation (GDPR) in the EU enforces the right for people's data to be deleted. SSI and passwordless present conflicting ideas, such as storing on the blockchain (i.e., blockchain is an immutable ledger that cannot "delete" past data)

3 Web3 & Metaverse

How will developments in Web3 and metaverse shape the progress of digital identity?

Cybersecurity, web3 (e.g., DeFi, blockchain), and metaverse have mutual influences on one another. Web3 and metaverse can expand use cases for digital identity, but the ecosystem is nascent and rapidly changing.

Source: McKinsey analysis

Additional resources

McKinsey Risk and Resilience

McKinsey Cybersecurity

Getting to know—and manage—your biggest AI risks

Derisking digital and analytics transformations

Cybersecurity trends: Looking over the horizon

Web3

Report Conclusion