Volume 10 of 12

14th Annual Edition

2021 Tech Trends Report

Strategic trends that will influence business, government, education, media and society in the coming year.

5G

Robots

Transportation

Future Today Institute

Overview

The 1920s began in chaos. Cataclysmic disruption resulting from the first world war and the Spanish flu shuttered businesses and provoked xenophobia. Technological marvels like the radio, refrigerator, vacuum cleaner, moving assembly line and electronic power transmission generated new growth, even as the wealth gap widened. More than two-thirds of Americans survived on wages too low to sustain everyday living. The pace of scientific innovation—the discovery of insulin, the first modern antibiotics, and insights into theoretical physics and the structure of atoms—forced people to reconsider their cherished beliefs.

The sheer scale of change, and the great uncertainty that came with it, produced two factions: those who wanted to reverse time and return the world to normal, and those who embraced the chaos, faced forward, and got busy building the future.

It's difficult not to see striking parallels to our modern world. A tumultuous U.S. election, extreme weather events and Covid-19 continue to test our resolve and our resilience. Exponential technologies—artificial intelligence, synthetic biology, exascale computing, autonomous robots, and off-planet missions to space—are challenging our assumptions about human potential. Under lockdown, we've learned how to work from our kitchen tables, lead from our spare rooms, and support each other from afar. But this disruption has only just begun.

With the benefit of both hindsight and strategic foresight, we can choose a path of reinvention. Our 2021 Tech Trends Report is designed to help you confront deep uncertainty, adapt and thrive. For this year's edition, the magnitude of new signals required us to create 12 separate volumes, and each report focuses on a cluster of related trends. In total, we've analyzed nearly 500 technology and science trends across multiple industry sectors. In each volume, we discuss the disruptive forces, opportunities and strategies that will drive your organization in the near future.

Now, more than ever, your organization should examine the potential near and long-term impact of tech trends. You must factor the trends in this report into your strategic thinking for the coming year, and adjust your planning, operations and business models accordingly. But we hope you will make time for creative exploration. From chaos, a new world will come.

Amy Webb

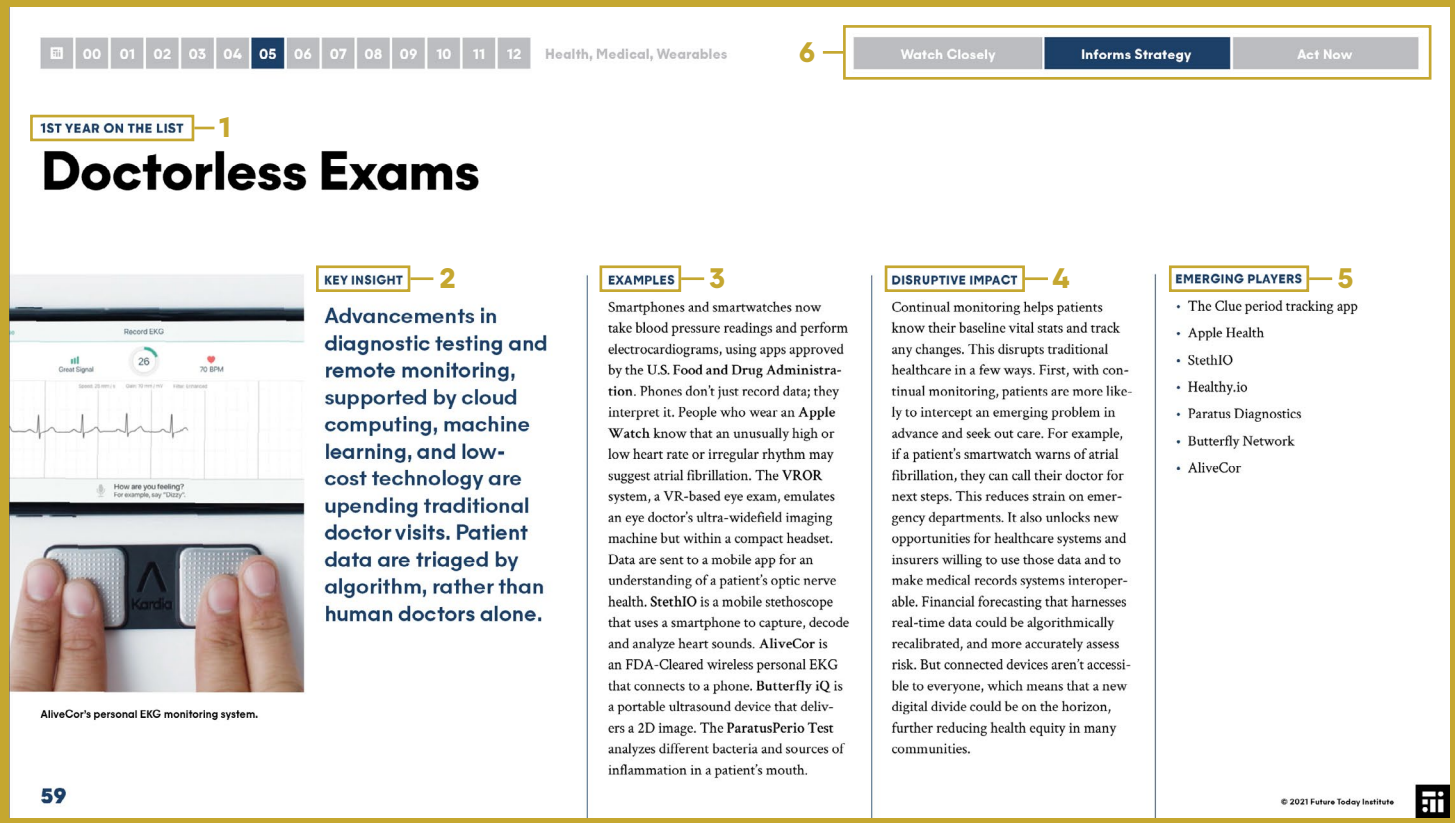
Founder
The Future Today Institute

Macro Forces and Emerging Trends

For nearly two decades, the Future Today Institute has meticulously researched macro forces of change and the emerging trends that result. Our focus: understanding how these forces and trends will shape our futures. Our 14th annual Tech Trends Report identifies new opportunities for growth and potential collaborations in and adjacent to your business. We also highlight emerging or atypical threats across most industries, including all levels of government. For those in creative fields, you will find a wealth of new ideas that will spark your imagination.

Our framework organizes nearly 500 trends into 12 clear categories.

Within those categories are specific use cases and recommendations for key roles in many organizations: strategy, innovation, R&D, and risk.



Each trend offers six important insights.

1. Years on the List

We track longitudinal tech and science trends. This measurement indicates how long we have followed the trend and its progression.

2. Key Insight

Concise description of this trend that can be easily understood and repeated to others.

3. Examples

Real-world use cases, some of which should be familiar to you.

4. Disruptive Impact

The implications of this trend on your business, government, or society.

5. Emerging Players

Individuals, research teams, startups, and other organizations emerging in this space.

6. Action Scale

FTI's analysis of what action your organization should take. Fields include:

Watch Closely

Mounting evidence and data, but more maturity is needed. Use it to inform your vision, planning, and research.

Informs Strategy

Strong evidence and data. Longer-term uncertainties remain. Use it to inform your strategic planning.

Act Now

Ample evidence and data. This trend is already mature and requires action.

Macro Forces and Emerging Trends

Scenarios Describe Plausible Outcomes

You will find scenarios imagining future worlds as trends evolve and converge. Scenarios offer a fresh perspective on trends and often challenge your deeply held beliefs. They prompt you to consider high-impact, high-uncertainty situations using signals available today.

1. Headline

A short description offering you a glimpse into future changes.

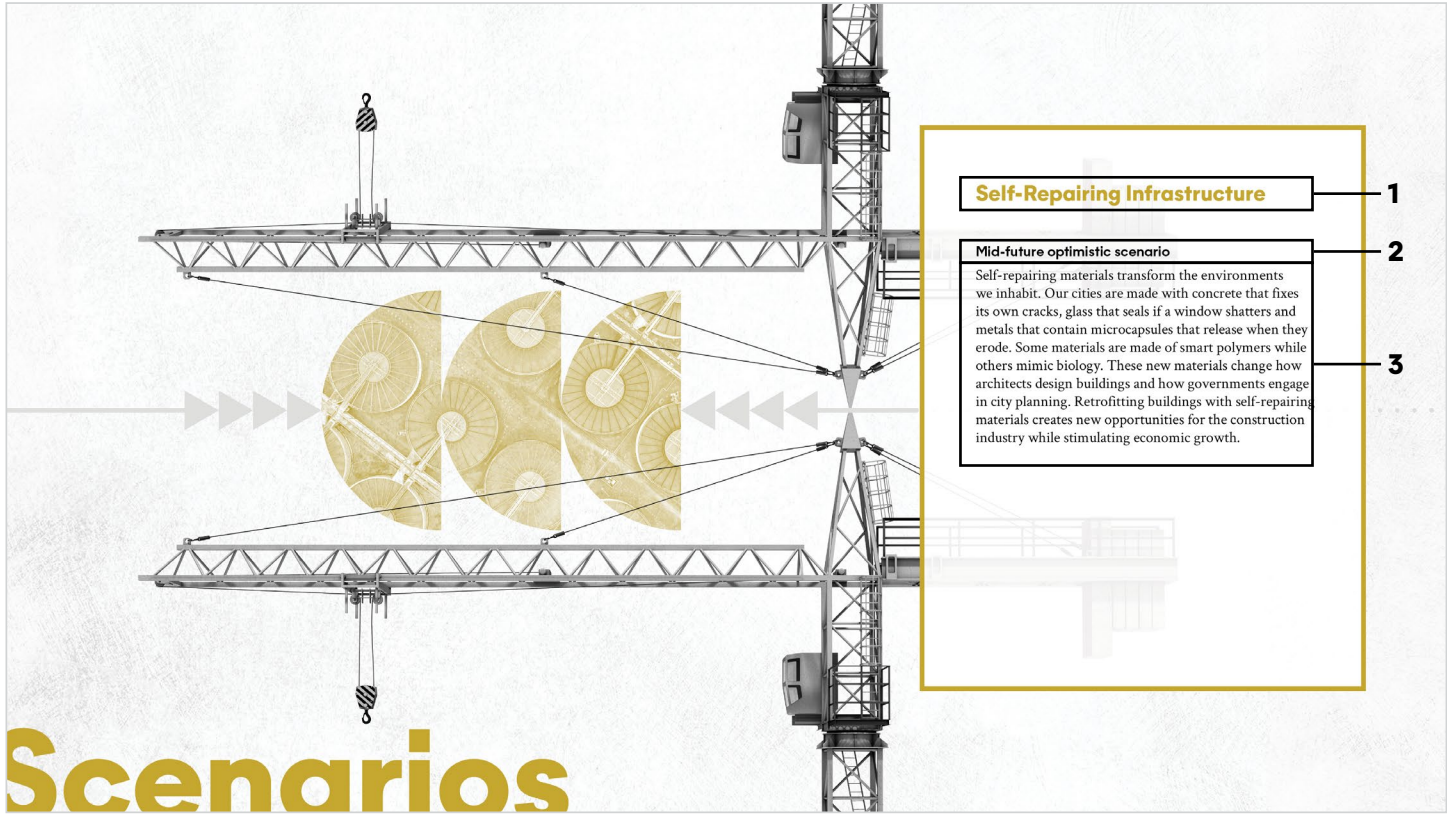
2. Temporal and Emotive Tags

A label explaining both when in the future this scenario is set and whether it is optimistic, neutral, pessimistic, or catastrophic.

3. Narrative

The descriptive elements of our imagined world, including the developments leading us to this point in our future history.

Scenario sources: The Future Today Institute uses a wide array of qualitative and quantitative data to create our scenarios. Some of our typical sources include patent filings, academic preprint servers, archival research, policy briefings, conference papers, data sets, structured interviews with experts, conversations with kids, critical design, and speculative fiction.



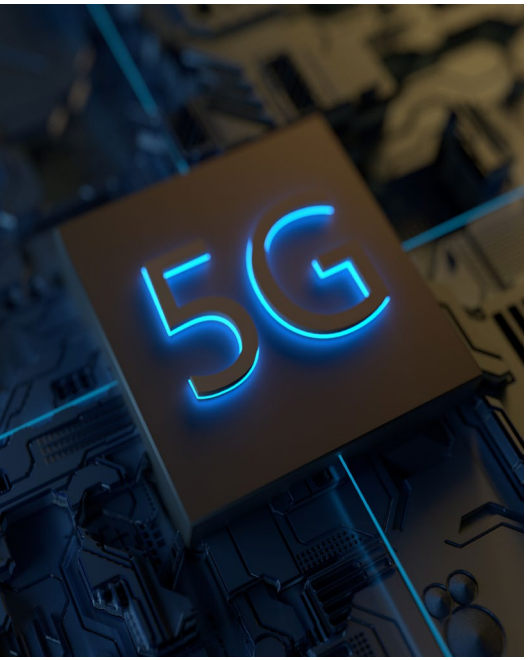
5G Robots & Transportation Summary

+ 6G will be the sixth generation of wide-area wireless technology, following the transition to 5G. Planning for this new standard is already underway.
+ A new standard for latency is in the works and could break the millisecond barrier.
+ The global quantum computing race is on, and equity deals for quantum computing startups surged in 2020.
+ There will be millions of implementations of robots-as-a-service over the next five years, which could generate billions of dollars of revenue.
+ As 5G comes online and reduces latency, robots will process spatial data at fast enough speeds to adapt to environmental changes.
+ Robots are now capable of "sweating" thanks to a soft, robotic muscle that can autonomously regulate its internal temperature, just like living organisms do.
+ Robotic dogs specially designed for Mars will travel in packs and assist each other as they climb, jump, and descend new terrains.
+ Some governments will consider granting the legal status of "electronic persons" to sophisticated robots.
+ Construction materials such as bricks could soon behave like human cells and evolve, replicate, and assemble organically with others.
+ China is creating a new mobility ecosystem that includes electric vehicles, apps, communications systems, artificial intelligence, and data, and it is intending to ship its products to the West.
+ Saudi Arabia is developing futuristic new megacities. They will have advanced technologies and urban ecosystems that rival every other major city.
+ Efforts are underway to create fully autonomous, AI-powered ships, along with a legal framework for them to operate safely and officially in international waters.

5G

4TH YEAR ON THE LIST

5G



5G is the fifth generation of wireless connectivity.

KEY INSIGHT

5G is the fifth generation mobile network and a global wireless standard. Since the first 5G mobile networks began launching in 2019, this new standard has rolled out slowly around the world. Eventually, 5G will offer higher speeds, low or even no latency in data transfer, and the ability for billions of devices to connect with one another.

EXAMPLES

5G advances today's networks using a more responsive kind of radio technology that not only moves data faster but also requires less power to do so. It will shorten transmission latency from 30 milliseconds to just a single millisecond, allowing essentially instantaneous connectivity between devices on a network. This means big opportunities for telemedicine and robotic-assisted surgery, autonomous vehicles, gaming, and streaming. Unlike Wi-Fi, a 5G network can be built to prioritize certain data transmissions over others. For example, heavy manufacturing companies and utilities will be able to automate more of their core processes using advanced robotics systems, which will in turn create a new market for all the components, devices, and consulting services necessary for operating such a network.

DISRUPTIVE IMPACT

Monetizing 5G remains a challenge for mobile network operators (such as Verizon, Vodafone, and Telefónica), which must gradually make network improvements while continuing to provide service for previous 3G and 4G standards. This last mile of the telecom ecosystem is the most complex and costly to maintain, and earns revenue mainly through customer plans. South Korea launched high-value, premium 5G plans to increase revenue alongside new products and services to entice adoption. VR cloud gaming, augmented reality shopping, and live sports streaming are bundled in new premium plans. South Korea notwithstanding, most 5G launches still lack the use cases needed to convert users and justify the investment in network upgrades. In the U.S., the Federal Communications Commission created two Innovation Zones, city-scale test beds in Salt Lake City and in New York City's West Harlem, for advanced wireless communications and network research, including 5G networks.

EMERGING PLAYERS

- National Spectrum Consortium
- 5G Fund for Rural America
- Open Radio Access Network (O-RAN)
- Spectrum Forward Other Transaction Agreement
- U.S. Department of Defense's Research and Engineering Division

4TH YEAR ON THE LIST

5Geopolitics

Huawei is a major supplier of network components.

KEY INSIGHT

There's a geopolitical fight underway, pitting the U.S. against China in a race to deploy the telecom equipment and systems required to build 5G networks.

EXAMPLES

The Trump administration tightened the screws on China when it banned Chinese companies ZTE and Huawei from supplying gear to American network operators in the U.S. Chipmaker Qualcomm, meanwhile, is one of a scant few U.S. companies making components necessary for a widescale 5G rollout. Trump revoked licenses to Huawei suppliers, which included Intel, and thereby weakened the Chinese tech giant's position in the global market. American security experts are urging the Biden administration to build a 5G network with and for geopolitical allies and to exclude Chinese equipment. As of this writing, only Ericsson, Nokia, and Samsung are allowed to build 5G networks in the U.S. Meanwhile, Chinese President Xi Jinping has made it clear that he intends to wean China and its allies off of Western-made technology entirely.

DISRUPTIVE IMPACT

New entrants are circumventing politics. Japanese e-commerce giant Rakuten launched a virtual network running on cloud native and open radio access network (O-RAN) technology. The network architecture costs far less to build and operate, and doesn't rely as much on equipment from traditional suppliers. Elon Musk's Starlink is developing a low-latency broadband internet system with speeds of 300Mbps—fast enough to manage Wi-Fi calling and just about anything else consumers might stream, play, operate, or build.

EMERGING PLAYERS

- Semiconductor Industry Association
- Open Radio Access Network (O-RAN)
- Rakuten Mobile
- Starlink

Expert Insight

5G Will Transform Transportation, Entertainment, Retail and More

Igal Elbaz

SVP of Wireless and Access Technology, AT&T

A little more than 25 years ago, AT&T debuted a bold advertising campaign predicting a future world enabled by emerging technologies. At the time, the ads mimicked science fiction—video calls from a payphone, sending a fax on the beach and talking to a friend on a watch. While the experiences look different than our predecessors imagined, they are now realities and even necessities, as 2020 pivoted the needs of our customers and forced transformation across all industries.

What can we accomplish in the next five, 10 or 25 years? Innovation is happening at the speed of 5G, and the next wave of bold predictions is well on its way.

5G will ultimately be a paradigm shift from prior networks. The increased speeds, lower latency and higher reliability will create the ideal foundation for transformational use cases. The ecosystem is developing capabilities never before imagined with LTE. There's no better time than now to take a visionary approach to the possibilities. We're collaborating with customers and allies to identify how technology can create a safer, more connected world.

Take the healthcare industry, for example. The combination of 5G,

> There's no better time than now to take a visionary approach to the possibilities.

edge computing, artificial intelligence (AI), and Internet of Things unlocks a new realm of possibilities for medical professionals. Last year, 2020, triggered the rise of telehealth, and this momentum will only continue. Faster speeds, lower latency, and massive connectivity will enable more real-time remote consultations, crucial data transfers, and connected ambulances. As 5G matures, we'll see the advancement from today's telemedicine and remote consultations during surgery to robotic-assisted surgeries and development of life-saving wearables.

5G is also paving the way for the future of transportation. At the AT&T 5G Innovation Studio in Plano, Texas, we're working with collaborators to showcase how 5G and edge computing can enable autonomous drones. And, as the edge expands, self-driving cars will eventually become ubiquitous, creating safer roadways. Flash forward even further, and you could be looking toward the sky for a flying taxi.

Today's technology will also transform the retail world, because 2020 shifted how we shop. There could be "magic mirrors," or connected displays, that use 4K sensors and digital displays to replicate the experience of standing in front of a mirror. Instead of having to physically try on clothes, consumers could swipe left and right to try on outfits and accessories. Then, using a connected tablet, an employee could place the order, and the clothes could be on a customer's doorstep in 48 hours. This will become a widespread reality that many retailers are expected to embrace.

Another exciting area of opportunity is the entertainment industry. 5G is already re-imagining how we create and consume media in this new world. Holographic communication proved useful during last year's NBA playoffs when reporters were able to perform holographic interviews with players from hundreds of miles away, a necessity given restrictions around in-person interviews.

Now, imagine holographic communication for the masses. In the not-so-distant future, we could enjoy live, immersive concerts from the comfort of our couch. And, we've taken the initial steps toward this reality. AT&T recently used 5G, machine learning, and edge computing to deliver a live 3-D augmented reality interactive concert for a select group of fans. Entertainment will become more immersive with the advancement of AI and edge computing, and we'll eventually blur the divide between the physical and digital world.

5G is triggering the next wave of business transformation and industrial revolution, and these use cases are only a glimpse of what's on the horizon.

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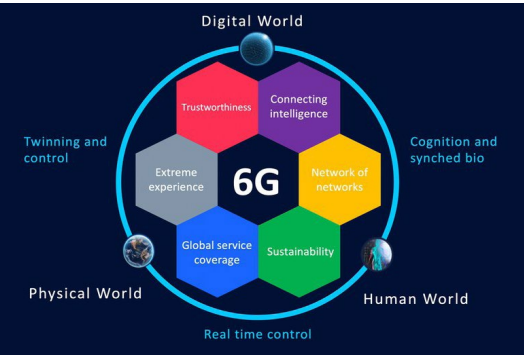
Igal Elbaz is senior vice president of Wireless and Access Technology. He is responsible for wireless and wireline access network architecture, design and technology roadmap, including radio access network, 5G and LTE mobility, voice core network functions, network AI and driving industry standards.

4TH YEAR ON THE LIST

6G



Hexa-X is developing standards for 6G.

KEY INSIGHT

6G will be the sixth generation of wide-area wireless technology, following the transition to 5G. Planning for this new standard is already happening.

EXAMPLES

Project Hexa-X, the European Commission's early 6G research initiative, kicked off in January 2021 in preparation for the global standard that comes after 5G. The current global transition from 4G to 5G is a tricky one: There are lots of variables over which no one entity has control. Core components—licensed and unlicensed spectrum bands, shared spectrum, antennas, and network architectures—aren't necessarily uniform. Experts believe that what they learn building 5G networks will make the transition to 6G easier. Researchers at the University of California, Santa Barbara, are already working on component upgrades: They built a device that could push 6G's terahertz frequency signals out of antennas using what's known as an N-polar gallium nitride high-electron-mobility transistor (HEMT). Nokia is leading the 6G joint research initiative, and Nokia Bell Labs is already researching the fundamental technologies that will comprise 6G.

DISRUPTIVE IMPACT

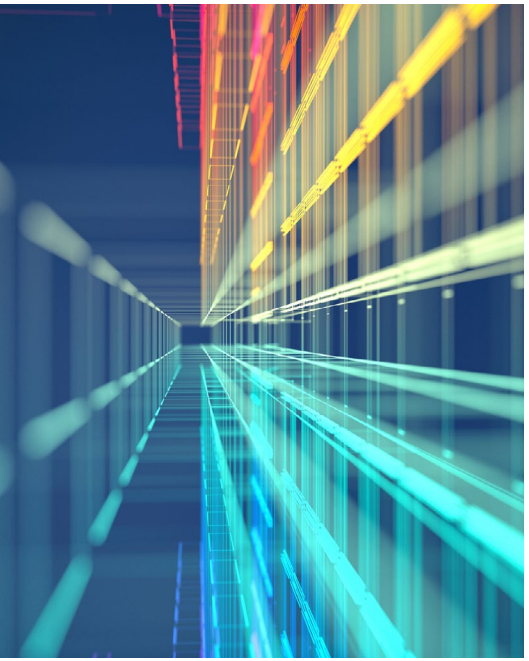
6G should support data rates of 1 terabyte per second, making latency and capacity balancing a thing of the past. This new standard will support technologies that demand real-time awareness—which are likely to include human-machine interfaces that intuitively understand our intentions. Combined with artificial intelligence, the new infrastructure of 6G will make networks capable of making decisions autonomously for things like data storage, processing, and sharing.

EMERGING PLAYERS

- Hexa-X
- Nokia
- Next G Alliance
- University of Oulu
- University of Padova
- Beijing University of Posts and Telecommunications
- NTT DoCoMo
- Samsung
- Ericsson
- Huawei
- ZTE

1ST YEAR ON THE LIST

Breaking the Millisecond Barrier



A new 1 millisecond standard is being developed.

KEY INSIGHT

The amount of latency in mobile networks differs, based on how far a signal must travel, the number of routers it passes through, and a variety of other factors. A new standard for latency is in the works that could result in just 1 millisecond of lag.

EXAMPLES

Latency causes problems in gaming, videoconferencing, and VR. A typical 4G network incurs 50 milliseconds of lag, and with more devices and people connecting to networks, systems can quickly become glitchy. As people worked and learned from home during the pandemic, signals weakened, causing interruptions or crashes. The coming swarm of signal-hungry consumer devices will put added strain on networks, unless current latency barriers can be broken. Reducing latency from 4G's 50 milliseconds to 5G's 10 milliseconds and below will be crucial to support applications such as autonomous vehicles and multiplayer games.

DISRUPTIVE IMPACT

A new 1 millisecond standard is being developed at New York University's NYU Wireless research center. It will require a new approach to encoding, transmitting, and routing data—but it also promises a wild new frontier in communications. If signals transmit fast enough that humans can't perceive any lag at all, teleoperated surgical robots could go into widescale use. Haptic devices that map sight and sound could convince us that a digital environment is real, not virtual.

EMERGING PLAYERS

- NYU Wireless
- Internet Engineering Task Force's L4S
- U.S. Department of Defense

Edge

4TH YEAR ON THE LIST

Edge Computing

Snowcone is used to run edge computing workloads, or to collect, process, and transfer data to Amazon Web Services.

KEY INSIGHT

Edge computing performs computations near or at the source of data.

EXAMPLES

Edge computing differs from the current norm, as much of today's computing takes place in the cloud, with distributed data centers handling the processing work. The challenge for existing cloud-based computing environments is the potential for delay, which is also known as latency.

DISRUPTIVE IMPACT

In the near future, more of the computational work could be done locally—for example, a car's computer vision system would process and recognize images immediately rather than sending that information to the cloud for verification. Edge computing requires custom chips and hardware, and will work alongside the cloud rather than replace its functionality. Consumer devices that perform biometric recognition and authentication—from smartphones to smart toilets—will rely more on the edge to shore up privacy and security.

EMERGING PLAYERS

- Open Neural Network Exchange
- AWS Snowcone
- AWS IoT Greengrass
- Nvidia's EGX AI
- IBM's Edge Ecosystem

Edge Computing Trends

Edge computing is accelerating and will impact data centres and cloud expansion in 2021.

Near-real-time Application Environments

Within the next decade, there could be as many as 50 billion devices online generating enormous amounts of data. Edge computing is closely tied to the Internet of Things and 5G connectivity. As virtual reality and extended reality become popular, more processes will be pushed onto headsets. For example, AWS IoT Greengrass, the platform for extending Amazon Web Services to edge devices, was created to more easily deploy applications.

AI at the Edge

With the proliferation of smart cameras and speakers, developers are building edge systems that can recognize natural language, people, pets, and objects. Open standards, such as the Open Neural Network Exchange (ONNX) are making on-device machine learning easier, while TensorFlow Lite and TinyML encourage artificial intelligence at the edge. Nvidia's EGX AI platform for edge computing features an extensive range of software accelerated by GPUs (graphics processing units). This includes Helm Charts (collections of files) for deployment on Kubernetes, or portable, open-source systems for managing "containerized" work and services. It also gives users access to third-party, domain-specific, pretrained models and Kubernetes-ready Helm Charts that make it easy to deploy software or build customized solutions.

Edge Management

Because data and applications now live in many places-individual devices, the cloud, local storage—a traditional, one-size-fits-all approach to monitoring won't work. Instead, new processes will be required to help manage the overall digital experience, from security risks to latency and bandwidth.

Big Tech Companies at the Edge

AWS invested $29 billion in its edge computing project Snowcone. Part of the AWS Snow Family of edge computing, edge storage, and data transfer devices, Snowcone is designed to fit inside a messenger bag. The edge computing device collects and processes data locally. For example, a Snowcone device could sit inside a manufacturing center, collect and analyze data from a production line, and gain insights from AI systems built into the AWS ecosystem. Microsoft is integrating edge capabilities with Azure, while IBM's Edge Ecosystem is an open standards–based cloud native solution that can be deployed and autonomously managed at the edge at massive scale.

Hyper-local Data Centers for Edge Computing

The new streaming services—such as Apple TV+, Peacock, Disney+, HBO Max—are entering a crowded field dominated by Netflix, Amazon, Hulu, and YouTube. But there's a problem looming: compression and bandwidth. As a result, we will need lots of hyper-local data centers positioned closer to consumers. AWS is now building "local zones" close to major cities, with the goal of managing latency-sensitive workloads.

Quantum

4TH YEAR ON THE LIST

Quantum Computing

Google's Sycamore performed a challenging calculation in 200 seconds.

KEY INSIGHT

Quantum computing uses the properties of quantum physics to store data and perform computations using specialized machines.

EXAMPLES

In short, quantum computers can solve problems that are computationally too difficult for a classical computer, which can only process information in 1s or 0s. In the quantum universe, those 1 and 0 bytes can exist in two states (qubits) at once, allowing computations to be performed in parallel. So, if you build two qubits, they can hold four values at the same time: 00, 01, 10, 11. Scientists have theorized about the possibilities of quantum computing for decades and only built the first working system in 1998. The challenge, however, has been proving that a quantum machine is actually carrying out quantum computations. That's because in a quantum system, the very act of observing information in transit changes the nature of that data.

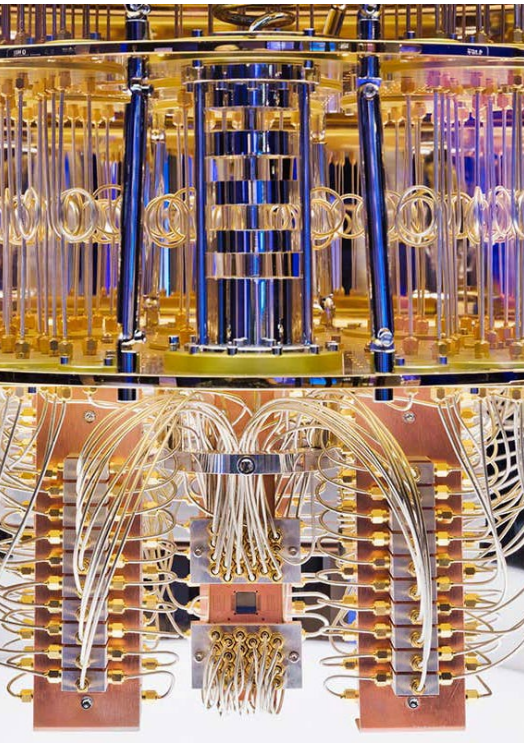
DISRUPTIVE IMPACT

Quantum computers are becoming more powerful and available. Equity deals for quantum startups surged in 2020, nearly doubling from the previous year. Most activity is aimed at transforming health care, logistics, and finance. But a persistent fear is driving much of today's research: Quantum computers could break today's encryption protocols at a speed and scale beyond anything we've ever seen.

EMERGING PLAYERS

- U.K. National Quantum Technologies Programme
- European Union's Quantum Flagship
- U.S. National Quantum Initiative Act
- National Institute of Standards and Technology
- Google AI Quantum
- Rigetti Computing
- IBM Q Network

Quantum Computing Trends



Quantum computing could transform the future of security, encryption and national security.

Updating Post-Quantum Cryptography Standards

U.S. National Institute of Standards and Technology will recommend new guidelines in 2021 to help organizations transition to new cryptography standards. In the U.K, the National Cyber Security Centre published recommendations for any organization using secured transactions. Today's encryption standards could quickly become outdated as quantum computers improve, and the complexity of upgrading IT systems in large organizations will take years to complete.

Quantum Supremacy

In October 2019, Google researchers published a paper in the journal Nature as well as a blog post on the company's website explaining that they had achieved "quantum supremacy" for the first time. It was a significant revelation. Physicists said that their 53-bit quantum computer, named Sycamore, calculated something that an ordinary computer—even a very powerful one—simply could not have completed. Sycamore performed a challenging calculation in 200 seconds. On the world's current fastest traditional computer, that same calculation would have taken 10,000 years. In February 2021, researchers from Google and quantum computing company D-Wave Systems solved a real-world challenge 3 million times faster than a classical computer.

Global Quantum Computing Race

The global quantum computing race is underway. Several nations, including the U.S., France, the U.K., and China, want to become the global leader in quantum computing. Governments are setting the stage now to attract talent and investment, ahead of the first real-world quantum use cases. The U.S. passed the National Quantum Initiative Act in 2018, earmarking $1.2 billion for quantum research. Last year, the U.S. launched five new quantum computing centers, including one at the Lawrence Berkeley National Lab to codesign algorithms, quantum devices, and engineering solutions; a center at the Fermi National Accelerator Laboratory to make it easier to deploy quantum systems; and a center at Brookhaven National Laboratory to build new nuclear, chemical, and physics applications. Some would say that the U.S. showed up a day late and a few billion dollars short. The U.K. National Quantum Technology Program kicked off in 2013 and is now in its second phase, with $1.3 billion in investment. Germany's program is funded at $2.4 billion. A team of researchers from the University of Science and Technology of China published a paper in the journal Science describing their quantum computer achieving speeds that were 10 billion (yes, billion) times faster than Google's Sycamore.

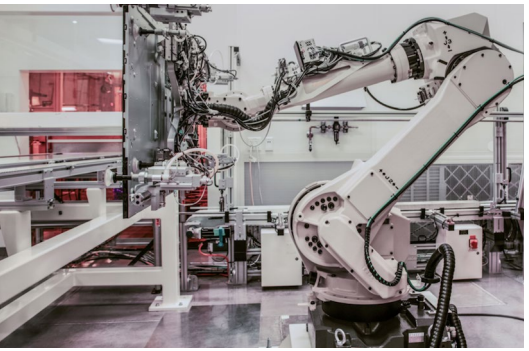
Quantum Boosts for Classical Computers

New kinds of processors are being designed to add on to existing equipment, to give classic computers a quantum boost. The end result isn't a complete quantum computing system, but more of a hybrid. Rigetti Computing is building small quantum processors that integrate with the cloud. Pharmaceutical company Merck is experimenting with the processors for faster drug development and production.

Robots

3RD YEAR ON THE LIST

Robots-as-a-Service (RaaS)



Microsoft's partnership with Open Robotics will open the Azure cloud platform to ROS developers.

KEY INSIGHT

Cloud robotics and automation is a field in which physical robots share data and code, and perform computations remotely via networks, rather than within their containers alone.

EXAMPLES

Autonomous vehicles are robots that use a network to access maps, understand spatial information, and more in order to make decisions. Each vehicle's data is indexed to the network and optimized for further use by researchers and other vehicles. This is an example of cloud robotics, which is used within autonomous driving as well as in warehouse automation and logistics. Amazon's AWS RoboMaker is a cloud robotics service created to develop, test, and deploy intelligent robotics applications at scale. Its partners include Nvidia, Qualcomm, and UP Squared, and it supports the most widely used open-source robotics software framework, Robot Operating System (ROS). Google's Cloud Robotics Core is an open-source platform that provides digital infrastructure essential to building and running robotics solutions for business automation.

DISRUPTIVE IMPACT

Using the cloud certainly offers advantages: greater efficiencies and opportunities for data sharing and insights, as well as collective learning across robotic networks and shared platforms. Soon, businesses will be able to take advantage of cloud-based robotics for a variety of uses, including strategic warehouse selection in anticipation of seasonal retail spikes, security in large buildings, and factory automation. There will be millions of implementations of RaaS over the next five years, which could generate billions of dollars of revenue.

EMERGING PLAYERS

- Amazon AWS Robomaker
- Google Cloud Robotics
- Fetch Cloud Robotics

4TH YEAR ON THE LIST

Cobots

Cobots are used in a variety of settings.

KEY INSIGHT

Collaborative robots—or cobots—work alongside humans or together with other machines. Teams of robots can communicate with one another about when to wait, when to move, when to carry out an activity, or even to ask what to do next.

EXAMPLES

Collaborative robots are finding more widespread use in industrial settings, which can often prove challenging for humans alone. ABB's YuMi is a cobot that works alongside humans, assisting with repetitive tasks. In China, automotive components supplier Hella uses YuMi to help workers assemble parts. Comau's Advanced Use Robotic Arm (AURA) is a high-payload cobot that combines vision technology, laser area scanners, and a touch-sensitive tactile skin that allows it to slow its speed and force when it comes into contact with a human operator.

DISRUPTIVE IMPACT

As 5G comes online and reduces latency, cobots will process spatial data at fast enough speeds to adapt to environmental changes. Today, collaborative robots make up just 3% of the current installed robot base around the world, but that's going to change. According to the International Federation of Robotics, collaborative robots are the fastest growing segment of new robot sales.

EMERGING PLAYERS

- Massachusetts Institute of Technology's Interactive Robotics Group
- Sapienza University of Rome
- Johns Hopkins Applied Physics Laboratory
- Karlsruhe Institute of Technology

3RD YEAR ON THE LIST

Autonomous, Programmable Robot Swarms

Robot bees could be the future of agriculture.

KEY INSIGHT

Autonomous robot swarms are coordinated and distributed to perform complex tasks in a more efficient way than a single robot or non-networked group of robots could.

EXAMPLES

Researchers at Harvard University's Wyss Institute are experimenting with different form factors drawn from nature. They developed robots that can autonomously drive interlocking steel sheet piles into soil. In the future, robots like these could be used to build retaining walls or check dams for erosion control. Another project, called Kilobots, involves 1,024 tiny robots working collectively to self-assemble and perform a programmed task. Walmart filed a patent for robot bees, which would work collaboratively in teams to pollinate crops autonomously. If the project works at scale, it could potentially counterbalance the effects of the world's honeybee population decline.

DISRUPTIVE IMPACT

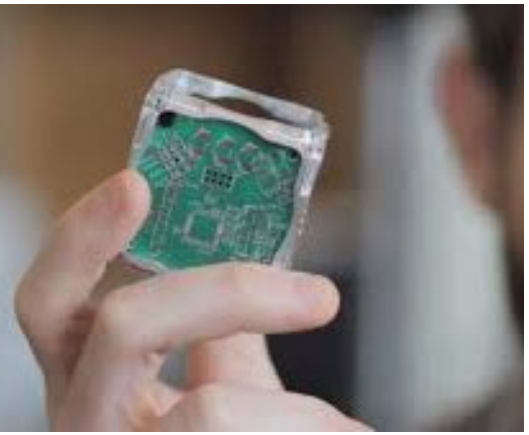
The possibilities are staggering: Autonomous robot teams could be used to inspect dams and bridges, build complicated 3D structures, and lay protective barriers in the case of toxic chemical spills—freeing up their human counterparts and keeping them out of harm's way.

EMERGING PLAYERS

- Academy of Opto-Electronics at the Chinese Academy of Sciences
- Wyss Institute at Harvard University
- Amazon Robotics

3RD YEAR ON THE LIST

Self-Assembling Robots



M-Blocks are tiny, cube-shaped wheeled robots with sensors and cameras.

KEY INSIGHT

A new generation of robots can now self-assemble, merge, split, and repair themselves.

EXAMPLES

Massachusetts Institute of Technology developed a set of robots called M-Blocks that use a barcode system to communicate. They can identify each other and move as needed to perform designated tasks, which at the moment include forming a straight line and moving down a pathway. The Modular Robotics Laboratory at the University of Pennsylvania developed SMORES-EP robots—tiny, cube-shaped, wheeled robots with sensors and cameras. Moving independently and docking with nearby modules, they can form different structures and even self-assemble to lift objects and drop them off. They also created Variable Topology Trusses, a new class of robot that can quickly reconfigure itself.

DISRUPTIVE IMPACT

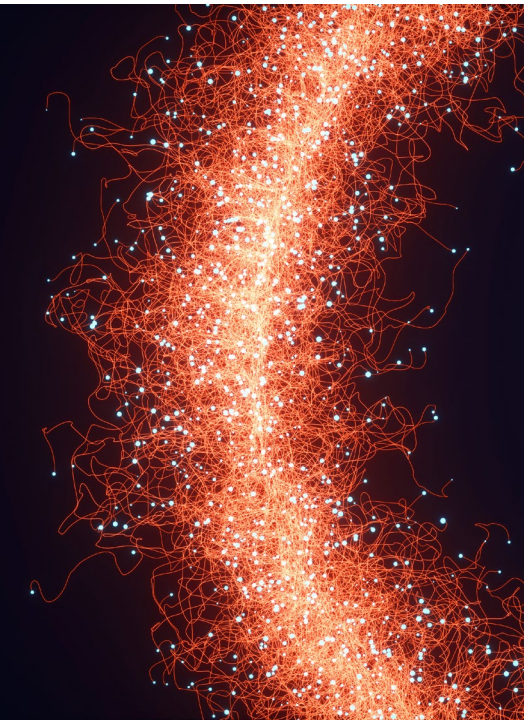
Self-assembling robots offer a host of possibilities for medicine, manufacturing, construction, and the military. The MIT Computer Science and Artificial Intelligence Laboratory built a self-assembling robot called Primer that is controlled by magnetic fields. It can put on exoskeleton parts to help it walk, roll, sail, or glide better, depending on the environment. Researchers at Georgia Institute of Technology and China's Peking University discovered a new technique that mimics automatic origami—in initial testing, structures could fold and unfold on their own using inexpensive liquid polymers and LED projector bulbs. Self-assembling robots will be tremendous assets in emergency response situations. Imagine a set of robots forming a temporary staircase to rescue someone from a burning building, or a set of bots that can lock together to form a bridge over flooded roads.

EMERGING PLAYERS

- The Modular Robotics Laboratory at the University of Pennsylvania
- MIT Computer Science and Artificial Intelligence Laboratory

4TH YEAR ON THE LIST

Robot Compilers



Advanced compilers will supercharge robot fabrication.

KEY INSIGHT

We will soon tell computer systems what tasks we need completed, and they will automatically fabricate new robots for the job. Robot compilers would offer greater efficiencies, big cost savings, and increased production for manufacturers in every industry.

EXAMPLES

Today, the process of designing, programming, and building robots is time-intensive—and the robots' capabilities are limited by original specifications. In the future, advanced compilers will enable much faster conceptualization and fabrication for a host of different tasks.

DISRUPTIVE IMPACT

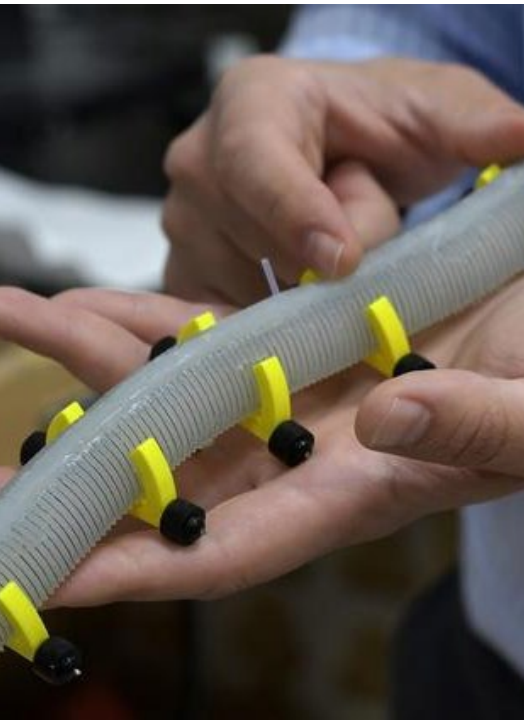
Researchers from the Laboratory for Embedded Machines and Ubiquitous Robots at the University of California, Los Angeles; MIT Computer Science and Artificial Intelligence Laboratory, University of Pennsylvania; and Harvard University are developing new methods for rapid robot fabrication. 3D robotic systems can now be produced using basic software and programmed using natural language commands. Fabricating programmable robots may not exactly be a simple, DIY weekend project, but promising research indicates that robot compilers could soon enable people with limited technical knowledge to sketch, design, fabricate, and control a robot drawn straight from their imagination.

EMERGING PLAYERS

- MIT Computer Science and Artificial Intelligence Laboratory
- Laboratory for Embedded Machines and Ubiquitous Robots at the University of California, Los Angeles

5TH YEAR ON THE LIST

Soft Robotics



This robot snake would investigate disasters.
Image credit: Worcester Polytechnic Institute.

KEY INSIGHT

Soft robotics are created to mimic living organisms. Made of flexible materials, they move in fluid ways and adapt in real time to their surroundings.

EXAMPLES

Researchers at Worcester Polytechnic Institute created a robotic snake that could navigate through rubble or confined spaces. Bioengineering researchers at the University of California, Los Angeles, developed a tissue-based soft robot that mimics the biomechanics of a stingray. Scientists at the BioRobotics Institute Sant'Anna School of Advanced Studies in Italy created a robot octopus, capable of emulating the animal's agile motions. To replicate the biology of an octopus, they built computer models using exact measurements and then experimented with a number of soft actuators to develop artificial muscles.

DISRUPTIVE IMPACT

Massachusetts Institute of Technology engineers created soft and compact 3D printed structures that can be guided using magnets. The hope is that they can someday help control biomedical devices, take images within the body, clear arterial blockages, deliver targeted drugs to specific body parts, or even extract tissue samples. Researchers at Cornell University developed a robot capable of "sweating." They built a soft robotic muscle that can autonomously regulate its internal temperature, just like living organisms do. Someday soon, soft robotics will let us enter and explore environments previously unreachable by conventional methods: deep ocean waters, the terrain of Mars, and perhaps even the gushing rivers of blood inside our own bodies.

EMERGING PLAYERS

- Harvard Biodesign Lab
- Sant'Anna School of Advanced Studies
- University of California, Los Angeles, Samueli School of Engineering
- MIT Computer Science and Artificial Intelligence Laboratory's Soft Contact Modeling Group
- Worcester Polytechnic Institute

4TH YEAR ON THE LIST

Smart Dust

The Defense Advanced Research Projects Agency's miniaturized "laboratories on a chip" were developed to detect biological weapons in the field, among other uses.

KEY INSIGHT

Smart dust, also known as microelectromechanical systems or MEMS, represents a new way of atomic-level materials engineering.

EXAMPLES

If you watched the "Arkangel" episode of "Black Mirror" (season four), you're already familiar with smart dust. For years, researchers have been hard at work on miniaturization, trying to shrink computers as much as possible, down to the size of grains of sand or specks of dust. Each particle-computer consists of circuits and sensors capable of monitoring the environment, and even taking photographs. They can also harvest energy while suspended, using passive Wi-Fi and human body heat to power themselves.

DISRUPTIVE IMPACT

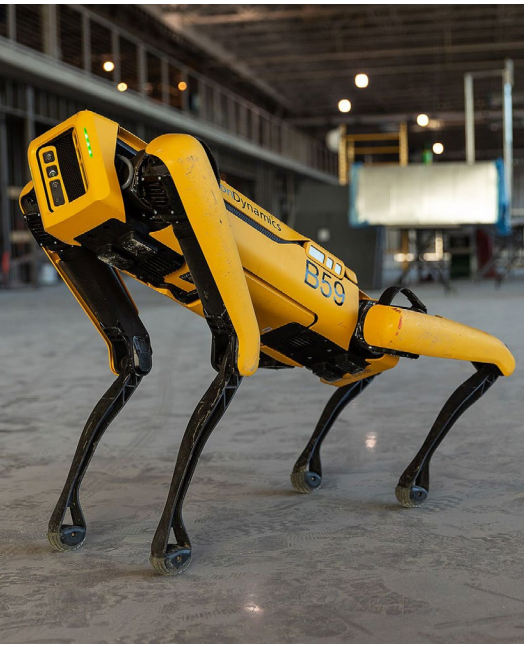
It sounds fantastical, but the use of MEMS is becoming more common. They're the accelerometer sensors for our airbag systems and are also found in biosensors. Scientists at the University of California, Berkeley, developed what they call neural dust, which comprises microscopic computers that work alongside remote ultrasound to send and receive data about the brain. Meanwhile, researchers at the University of Stuttgart figured out how to print tiny 3D lenses—120 millionths of a meter in diameter, or about the size of a fine grain of sand. In health and medicine, this technology will dramatically change our approach to imaging. Rather than relying on our current endoscopic technology, which is bulky and invasive, a patient could simply inhale smart dust. Beyond medicine, trillions of smart dust particles could be released in the wind to measure air quality or take photos.

EMERGING PLAYERS

- University of Southern California Robotics Research Lab
- CardioMEMS
- The Center for Advanced Materials Processing at Clarkson University
- Whitesides Research Group at Harvard University
- Center for Research in Advanced Sensing Technologies and Environmental Sustainability at Binghamton University

2ND YEAR ON THE LIST

Commercial Quadrupedal Robots



Spot is a robotic dog from Boston Dynamics.

KEY INSIGHT

Quadrupedal robots have four articulated legs and can move around difficult terrain, making them useful tools for inspections and security applications.

EXAMPLES

By emulating the form and mobility of four-legged animals, these robots can be deployed in situations that wheeled or tread-equipped robots cannot navigate and that may be too dangerous or physically inaccessible for human intervention. Boston Dynamics started selling a quadruped in October 2019 and released an enterprise model last year. The robot, named Spot, looks like a headless dog and moves with the agility and athleticism of a border collie. Spot can map environments, move around difficult terrain, and interact with a range of different objects. It docks and charges on its own.

DISRUPTIVE IMPACT

For now, Boston Dynamics is the only company selling advanced robots like Spot for commercial, nonmilitary purposes. The ecosystem is still forming, but as developers build applications across different industries, we expect to see new use cases emerge, particularly in safety, security, maintenance, emergency response, military, and even consumer contexts.

EMERGING PLAYERS

- Boston Dynamics

1ST YEAR ON THE LIST

Mars Dogs

A robotic dog could someday patrol Mars.
Image courtesy of NASA/JPL-Caltech.

KEY INSIGHT

NASA is working on Mars Dog, a four-legged robot for exploring the red planet.

EXAMPLES

Current robots designed for off-planet exploration have wheels. While they're designed to roll over rugged terrain, they're limited to generally flat surfaces or gentle slopes. Scientists from NASA's Jet Propulsion Laboratory and Ames Research Center and McGill University are developing a modified version of Spot, the quadrupedal robotic dog created by Boston Dynamics. Au-Spot, as it is known, is built for Mars: It has AI to learn about surfaces, a communications module, and an array of sensors (thermal, visual, motion). Au-Spot should be able to climb over rocks, up steep hills, and into underground caves.

DISRUPTIVE IMPACT

These biomimetic robots will work as teams, much as human explorers do. Au-Spots, traveling in packs, will assist each other as they climb, jump, and descend unfamiliar terrain on Mars.

EMERGING PLAYERS

- NASA Jet Propulsion Laboratory
- NASA Ames Research Center
- McGill University
- Boston Dynamics

5TH YEAR ON THE LIST

Ethical Manufacturing

Workers at a garment factory in Southeast Asia.

KEY INSIGHT

Robots could bring an end to forced labor and lead a new era of ethical manufacturing.

EXAMPLES

Sometimes a $5.99 T-shirt is too good to be true. Unfortunately forced labor is common in places including Uzbekistan, China, and Bangladesh. More humane manufacturing processes in fast fashion and other industries could lead to improved working conditions for millions of people.

DISRUPTIVE IMPACT

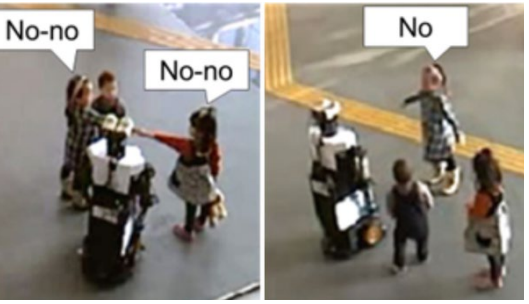
As robots become more affordable and available, they could eliminate unethical practices in manufacturing. But creating more humane work environments could destabilize developing economies. Even with extremely low wages, a workforce can sustain a local economy—when those wages are lost as workers are replaced by robots, the flow of money through the community can go from a trickle to a drought.

EMERGING PLAYERS

- United Nations Alliance for Sustainable Fashion
- World Fair Trade Organization
- Bluesign Technologies
- Oeko-Tex
- Ethical Trading Initiative

4TH YEAR ON THE LIST

Robot Rights



Children bullied a robot.

Image credit: ATR Intelligent Robotics and Communication Laboratories.

KEY INSIGHT

Some believe that we have moral obligations to our machines, and that robots should have rights.

EXAMPLES

Instances of humans bullying or abusing robots have increased. The Human Interaction With Nature and Technological Systems Lab at the University of Washington discovered that children didn't show the same kind of empathy for robots that they do other humans. In the study, 60% of the child subjects thought that a humanoid robot named Robovie-II had feelings—yet more than half of them thought it was fine to lock him in the closet. Researchers at ATR Intelligent Robotics and Communication Laboratories, Osaka University, Ryukoku University, and Tokai University conducted an experiment to measure human empathy toward robots. They deployed Robovie through a mall in Osaka, Japan, without a human minder. If someone walked into the robot's path, it would politely ask the human to move. Adults complied—but children didn't. And if unsupervised, the children were intentionally mean, kicking the robot, yelling at it, and bullying it.

DISRUPTIVE IMPACT

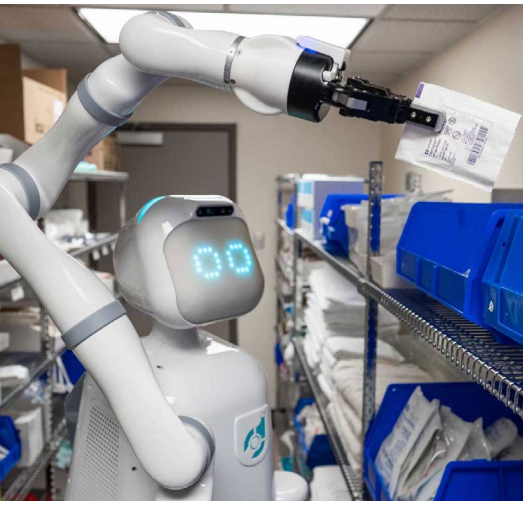
When it comes to our interactions with robots, what constitutes a moral violation? What rights should robots have, given that so many companies are building smart interfaces and cognitive systems? If we are teaching machines to think, and to learn from us humans, then what moral codes are we programming into our future generations of robots? Answering these questions will become increasingly urgent as robots proliferate in many aspects of our everyday lives.

EMERGING PLAYERS

- Human Interaction With Nature and Technological Systems Lab at the University of Washington
- ATR Intelligent Robotics and Communication Laboratories

1ST YEAR ON THE LIST

Robots as Essential Workers



Robots retrieved supplies so hospital staff could focus on patient care.

Image courtesy of Diligent Robotics.

KEY INSIGHT

During the pandemic, robots became essential workers.

Governments need to create national registries of robots. Such a registry would let citizens and law enforcement look up the owner of any roaming robot, as well as learn that robot's purpose. It's not a far-fetched idea: The U.S. Federal Aviation Administration already has a registry for drones.

— Stacey Higginbotham, tech journalist

EXAMPLES

Fleets of robots were deployed worldwide in 2020. They autonomously sanitized hospital rooms, monitored patients remotely, picked up and delivered prescriptions, took our temperatures, made pizzas and salads, and assisted front-line medical workers. Some robots required direct supervision, but many of them worked alone. In Austin, Texas, robots developed by Diligent Robotics retrieved supplies for hospital rooms, which freed staff to spend more time with their patients.

DISRUPTIVE IMPACT

Do robots need worker rights, too? Researchers raise this question now, especially as robots are predicted to take on more meaningful roles within the workplace and in society. The European Union is already discussing whether there ought to be a special legal status of "electronic persons" to protect sophisticated robots.

EMERGING PLAYERS

- Diligent Robotics
- UBTech Robotics
- Sanbot
- Zipline
- Starship Technologies
- JD.com
- ZoraBots
- UVD Robots

Expert Insight

The Next Generation of Robots Must Be Adaptable, Customizable and Trainable

Dr. Henny Admoni

A. Nico Habermann Assistant Professor, Human-Computer Interaction Institute, Carnegie Mellon University

With COVID-19 locking us all at home, robots should have had their moment in 2020, taking over basic tasks that keep society functioning.

We did see some examples of robots disinfecting public spaces, taking temperatures, and enabling telepresence for tele-health. However most of these robots were limited to simple, pre-scripted routines or required teleoperation by a human.

This underscores the challenge facing robots today: Deploying robots in the chaos of hospitals or grocery stores is much more complex than deploying them in the relatively consistent and controllable environment of factories and warehouses. As robotics moves forward, the field must grapple with dynamicism at every part of the robot's sense-plan-act loop.

One way to deal with dynamic or surprising environments is to be adaptable, and robot learning thus continues to be a perennial theme. The field has gotten pretty good at making robots that perform pre-scripted tasks, and now the big challenge is creating robots that are adaptable, customizable, and trainable.

> Robot learning will likely continue to be a hot topic in academic programs, research, and industry for several years.

Deep learning (DL) continues to be a dominant force in this area, especially in perception and natural language generation. However, people are also finding the limits of DL systems—such as their reliance on very large data sets and their brittleness to novel inputs. Human-in-the-loop learning (in which a person curates input or provides feedback on a robot's performance) and active learning (in which a robot seeks out the most relevant new information) are both promising approaches. Robot learning will likely continue to be a hot topic in academic programs, research, and industry for several years.

If the 2010s was the decade for dreams about autonomous vehicles, the 2020s are the decade in which we wake up and realize it's not as easy as we thought. (By the way, I'm not picking on AVs; this is a recurring trend in robotics.)

The end of 2020 saw big news with Uber selling off its autonomous driving unit to Aurora Innovation, a startup with deep robotics expertise. Many of the bold promises about autonomous vehicles from the last few years have not panned out, and the industry seems to be settling down now to solve the very real, very hard problems of perception, prediction, controls, and human-robot interaction. I'm confident we'll get there, but, as with much of robotics and AI, it's more complicated than it initially seems.

Of course, it's impossible to talk about robotics (and its close cousin AI) without mentioning robot ethics. The past year has seen increased social consciousness along a number of dimensions, not least of which is the societal impact of automated systems. In late 2020, Google fired researcher Timnit Gebru, launching a national conversation around accountability and ethics in AI. Even before that, though, we saw major AI failures in vaccine distribution, education, and policing. One heartening trend is an increased awareness and interest in AI ethics. For example, universities are starting to offer more tech ethics courses and students are increasingly asking for ethics to be included in their technical education.

**

Henny Admoni is an Assistant Professor in the Robotics Institute at Carnegie Mellon University, and also has a courtesy appointment in the Human-Computer Interaction Institute at CMU. She leads the Human And Robot Partners (HARP) Lab, which studies how to develop intelligent robots that can assist and collaborate with humans on complex tasks like preparing a meal. She holds an MS and PhD in Computer Science from Yale University, and a BA/MA joint degree in Computer Science from Wesleyan University.

Logistics & Supply Chain

4TH YEAR ON THE LIST

Capturing IIoT Metadata

Sensors, switches, and connected machines generate lots of data.

KEY INSIGHT

The industrial internet of things (IIoT) refers to all of the hardware that's collecting, sharing, and using data within industrial settings. Some of what's being collected is metadata, which describes the data that's being generated.

EXAMPLES

In an industrial setting, sensors, switches, and connected devices generate a tremendous amount of data. That data can be mined, refined, and analyzed for cost savings, greater efficiencies, and even new product development. For example, Palo Alto, California–based Maana extracts metadata to optimize a company's processes by revealing previously unknown relationships. Austin, Texas–based SparkCognition uses metadata for predictive maintenance applications in energy, gas, and utilities.

DISRUPTIVE IMPACT

There is no unified approach for how to handle metadata in manufacturing and other IIoT settings—and at the moment, not all systems and devices are interoperable. The metadata itself could help solve that problem, by identifying communication protocols that would facilitate the exchange of data throughout a network. Metadata will make it easier for businesses to organize the data generated from all of their connected machinery within the IIoT. Advances in artificial intelligence will offer deeper levels of insight into process automation.

EMERGING PLAYERS

- Maana
- Plataine
- Augury
- ThetaRay
- SparkCognition

2ND YEAR ON THE LIST

Automating the Supply Chain

Berkshire Grey raised $263 million in new funding last year.

KEY INSIGHT

Mobile automation in the supply chain is a quickly maturing market. While this means greater efficiencies and cost savings for businesses, it also portends job losses for workers who operate warehouse equipment.

EXAMPLES

Autonomous mobile robots (AMRs) and autonomous guided vehicles (AGVs) will become more commonplace, which will bring cost savings and efficiencies for businesses. A new class of autonomous robots and vehicles running on AI-powered logistics systems is coming. In a warehouse setting, autonomous mobile robots assign global tasks, set paths, and optimize tasks like picking. Berkshire Grey is an AI-powered automated system that picks, packs, sorts, and transports products autonomously to fulfillment centers, resulting in a 75% reduction in direct human labor.

DISRUPTIVE IMPACT

The robotics industry will drastically transform the supply chain. Some researchers anticipate that 6 million mobile robots will be shipped within the next decade, shifting every sector of the global economy.

EMERGING PLAYERS

- Amazon Robotics
- Robotic Industries Association
- Mobile Industrial Robots

2ND YEAR ON THE LIST

Sustainability in Supply Chain and Logistics

Sustainability in the supply chain is a primary driving force in business.

KEY INSIGHT

Pressure from investors, customers, and governments—in addition to extreme weather events and trade tensions—demands new efforts to build sustainable supply chains.

EXAMPLES

The U.N. Global Compact encourages companies to make sustainability a priority from the top of the organization down into supply chains. India, Indonesia, and China have mandated reporting of sustainability practices, and they will begin publishing their findings. Levi Strauss & Co. partnered with the International Finance Corp. to provide lower interest rates for vendors that have sustainability practices in place.

DISRUPTIVE IMPACT

As buying power shifts from Gen X and Millennials to Gen Z, supply chain sustainability will become more important—younger consumers repeatedly say they prefer brands that support environmental causes. Investors are taking note: In an Oxford University Saïd Business School study of 70 senior executives at 43 global institutional investing firms, including the world's three biggest asset managers (BlackRock, Vanguard, and State Street), sustainability was a key priority for 2021 and beyond.

EMERGING PLAYERS

- Sustainability Accounting Standards Board
- Global Reporting Initiative
- U.N. Sustainable Development Goals

2ND YEAR ON THE LIST

Rethinking the Cold Chain

Many COVID-19 vaccines require a stable cold chain.

KEY INSIGHT

Cold chains are temperature-controlled supply chains—critical for goods such as medications, produce, and frozen foods.

EXAMPLES

Last year the cold chain was in the national spotlight, because the most promising COVID-19 vaccines from Pfizer-BioNTech and Moderna required an ultracold transportation system. If the temperature fluctuates or the cold storage fails, it could render doses ineffective. The cold chain is how your local grocery store can sell sushi made from raw tuna and salmon farmed halfway around the world. The reason we can enjoy ice cream in the heat of the summer is the cold chain: a complicated system of storing and transporting food and medicine in exactly the right temperature range during the trek from farm to factory to store. But in some areas of the world, the cold chain has contributed to climate change.

DISRUPTIVE IMPACT

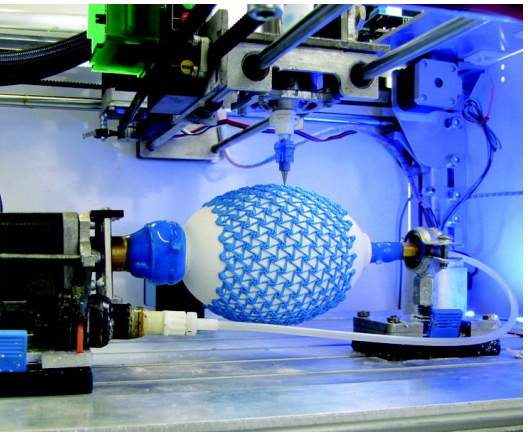
We put an enormous amount of trust in the cold chain to protect the food and medicines we ingest. Companies are beginning to look at new sustainability opportunities to improve the cold chain. One area of interest is artificial intelligence in the cloud, which can help monitor temperatures and can also optimize travel routes. New packaging materials insulate food and medicine, keeping both at low temperatures without having to refrigerate entire trucks. Climate change could result in new regulations that limit how the cold chain works, but new kinds of intelligent packaging and automated transportation systems mean new business opportunities.

EMERGING PLAYERS

- QCMedchain
- StaTwig
- Smashtag Chill
- Solar Freeze
- NelumBox

10TH YEAR ON THE LIST

Additive Manufacturing



A team at U.K.'s Nottingham Trent University are printing artificial muscles.

KEY INSIGHT

Additive manufacturing is a process by which materials are deposited layer by layer as objects are printed.

EXAMPLES

3D additive manufacturing has moved from the fringe to the mainstream, offering new opportunities in medical and biosciences, manufacturing, and art. LaserFactory, a project from MIT's Computer Science and Artificial Intelligence Lab, uses silver conductive ink to attach circuits together and print circuit boards. Soon, "one size fits all" will take on a whole new meaning. Chinese researchers successfully printed ceramics capable of transforming over time in response to stimuli such as heat and light. It's a process known as 4D printing, and the practical applications are boundless. Imagine a heat shield that suddenly materializes during a fire, or a garden that plants itself when the ground has warmed to precisely the ideal temperature for each seed.

DISRUPTIVE IMPACT

If you're thinking of the "Star Trek" replicator, you're not far off. Researchers are working toward scanning and producing objects in seconds—over time, this technology will be used in surgical centers to rapidly print replacement valves and joints using your own biomatter as models. We don't yet have international product liability and intellectual property standards, norms, and regulations that govern additive manufacturing and printing. A regulatory framework built to protect designers, patents, corporations, and individuals is likely on the horizon.

EMERGING PLAYERS

- Autodesk
- Formlabs
- Apis Cor

> Could a brick ever behave like a human cell and evolve, replicate [and] assemble organically with others? Could the objects we now build out of concrete and steel ever be as adaptable, intelligent, and multifunctional as those grown from the earth?
>
> — Paola Antonelli, Museum of Modern Art curator and director of MoMA R&D

Drones

10TH YEAR ON THE LIST

Drones

The COVID-19 pandemic accelerated the adoption of drones.

KEY INSIGHT

Drones have seen unprecedented market growth and rapid adoption across various industries, thanks to lower costs, easier manufacturing, and their effectiveness in a wide range of use cases.

EXAMPLES

Companies now use drones for mapping and inspections in agriculture, mining, and construction. Drones inspect dangerous and hard-to-reach places such as chemical weapons plants and erupting volcanoes. The emergence of COVID-19 and racial injustice protests accelerated the already-fast adoption of drone technology. Last year, UPS, CVS, and drone tech company Matternet launched a drone delivery pilot program that allowed Florida residents to shelter in place and receive medical deliveries including documents and blood samples. Controversially, government and citizen drones also tracked protesters and police during widespread marches for social justice, and monitored social distancing amid the pandemic in places including New York, Paris, Mumbai, and China.

Drones continued

Agricultural drones can manage crop health from the air.

DISRUPTIVE IMPACT

The use of drones allows us to work outside the limitations of the human body in a very cost-effective way. We'll likely see a wave of mergers and acquisitions among flight service providers, hardware startups, drone and aircraft manufacturers, asset and flight path management software makers, and data processing platforms. The growing sector may give rise to a new "drones-as-a-service" business model akin to the car and scooter sharing industry, delivering access to drones without the intervention of specially trained experts. We'll also see more government uses, including identifying terrorists and monitoring immigration. In 2017, U.S. Rep. Will Hurd (R-Texas) proposed the Secure Miles with All Resources and Technology (SMART) Act, which would employ a constellation of AI-powered cameras, biometric recognition systems, airborne unmanned vehicles, lidar, and mobile phone monitoring systems, to create a "smart wall" that conducts detailed surveillance, primarily for use at the Texas-Mexico border. The bill stalled in committee, but in the wake of recent public unrest, there's renewed interest—and now, better technology—to make the proposal a reality.

EMERGING PLAYERS

- Zipline
- Anduril
- Terra Drone
- Hemav
- Matternet

5TH YEAR ON THE LIST

Drone Swarms

300 unmanned drones performed aerial formations and light shows during the rehearsal for Singapore National Day Parade in 2017.

KEY INSIGHT

Drone swarms, or fleets of networked drones capable of coordinated operations and communication, are being developed for military operations, surveillance, and other complex functions without human interaction. In a drone swarm, the collective functionality of the overall network becomes more important than each individual drone, and the group of drones can "learn" and adapt synergistically.

EXAMPLES

The U.S. Army is developing a Cluster UAS Smart Munition for Missile Deployment that would allow a swarm of small drones to fan out and destroy vehicles with "explosively formed penetrators," or EFPs. The U.S. Navy Office of Naval Research intends to launch a swarm of Coyote drones, made by U.S. military contractor Raytheon, for intelligence, reconnaissance, and potentially weaponry. Turkey has deployed Kargu tactical kamikaze drones on the Syrian border via remote pilots. In October, China conducted a test launch of 48 "suicide" drones from a truck and helicopter. This follows a number of other larger swarm-drone experiments by the country in 2017. The U.S. Army plans to build an autonomous charging system that swarm drones could fly to for charging before redeployment. The Army is also working on a giant recharging drone called the Joint Tactical Aerial Resupply Vehicle, which is also intended to serve swarms.

Civilian applications include dazzling light shows and dynamic aerial artwork. Disney and Intel are creating a new type of light show that uses 300 drones with multicolored lights that fly in unison at Disney World.

Drones Swarms continued

Drone swarms fan out to automatically amd work as a team to accomplish goals.

DISRUPTIVE IMPACT

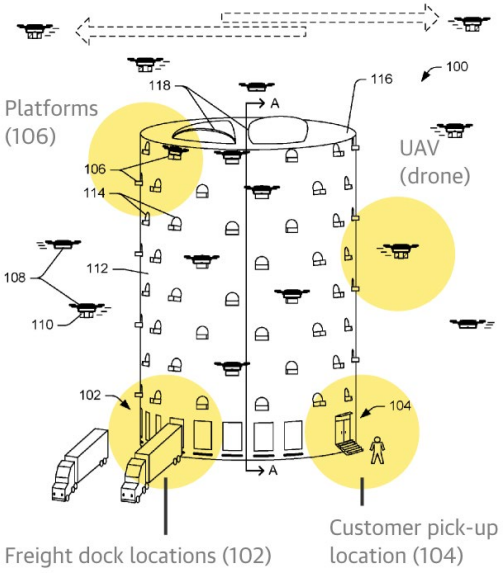
Swarms of drones would allow a single delivery truck to service a full neighborhood or multiple drones to work together in the manner of a school of fish. Ideally, future swarms will use what Nora Ayanian, a roboticist at University of Southern California, calls "leveraging diversity in the control policy," in which each drone is programmed slightly differently so that the one best suited to the task teaches the rest of the swarm how to act. This could make drones more robust in unstructured and uncertain environments, such as in disaster response, environmental monitoring, and military applications.

EMERGING PLAYERS

- U.S. Navy Office of Naval Research
- U.K. Defence Science and Technology Laboratory
- China Electronics Technology Group

2ND YEAR ON THE LIST

Drone Fleets



Amazon's patent for a multilevel urban hive.

KEY INSIGHT

Fleets of drones operating as air carriers will begin making package deliveries soon.

EXAMPLES

The pandemic accelerated drone-delivery certification approvals, as many consumers avoided brick-and-mortar stores. Amazon received U.S. Federal Aviation Administration clearance last year to begin making commercial deliveries under a trial program. Amazon joined UPS and Google as companies certified to make autonomous deliveries. Google's Wing, partnering with Walgreens and FedEx, began its tests last year. UPS now flies medical supplies between buildings on a Raleigh, N.C., hospital campus.

DISRUPTIVE IMPACT

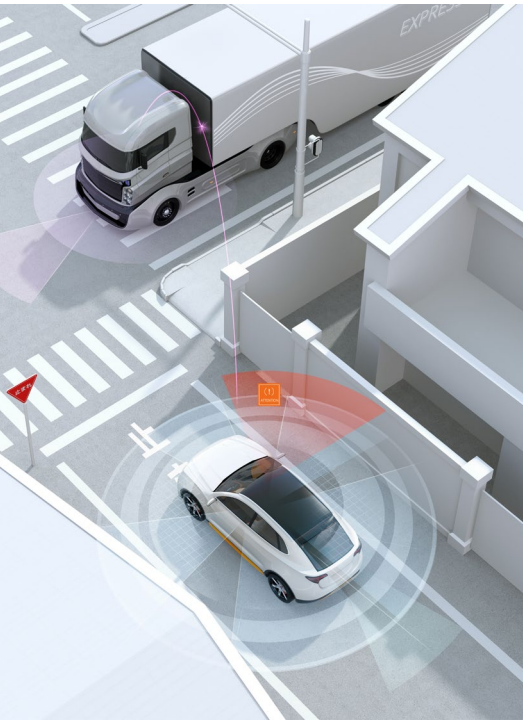
Amazon has also filed patents for interesting drone-fleet logistics, including a gigantic beehive-like structure, where drones would dock and receive packages, and a laundry chute system attached to houses where packages would drop safely and tumble down to customers.

EMERGING PLAYERS

- Amazon
- Google's Wing
- UPS
- FedEx
- Walgreens
- CVS

3RD YEAR ON THE LIST

Cognitive Active Safety Features



Increasingly advanced safety features are laying the foundation for autonomous vehicles.

KEY INSIGHT

Car manufacturers, seeking to meet consumer preferences, are quickly adopting proactive safety functions that also provide the building blocks for full autonomous driving.

EXAMPLES

Netradyne makes AI-powered dash cameras that monitor real-time road conditions to reduce accidents. Companies can use the technology inside fleet vehicles to monitor driving behavior and teach commercial drivers how to be safer and more efficient drivers. Comma.ai created Openpilot, an open-source software driver assistance system that uses a $1,200 camera and development kit that allows people to transform their cars so they steer, accelerate and brake automatically, as with Tesla's Autopilot. Comma.ai works with a large variety of car models and manufacturers via a customized Android cell phone mounted to the windshield and connected to the vehicle's existing adaptive cruise control hardware.

DISRUPTIVE IMPACT

Vehicle manufacturers will continue to implement and tout active safety features to attract safety-minded consumers, with software representing the next wave of advances. Car manufacturer development cycles, historically occurring over a 10 year span, will accelerate as platforms become increasingly software-driven.

EMERGING PLAYERS

- Netradyne
- Driveri
- Comma.ai
- Tesla

3RD YEAR ON THE LIST

Autonomous Last Mile Delivery

Starship Technologies uses robots to deliver food and drinks to George Mason University students.

KEY INSIGHT

Autonomous delivery is becoming more common, driven in part by an increased desire for contactless interactions brought about by the pandemic. Delivery is an ideal testing and development ground for autonomous vehicles, as the hurdles for safely transporting food are lower than those for safely transporting humans.

EXAMPLES

Nuro, a startup founded by former Google engineers, is developing autonomous vehicles for last-mile deliveries, including take-out, groceries, laundry, and packages. JD.com has autonomously delivered more than 13,000 packages, traveling 6,900 kilometers in lockdown environments. Cenntro Automotive Group's CityPorter electric vehicle will soon make urban deliveries, while General Motors launched a new last-mile delivery business called BrightDrop.

DISRUPTIVE IMPACT

A study from the World Economic Forum found that rising demand in e-commerce will lead to a 36% increase in delivery vehicles in the largest 100 global cities by 2030, and last-mile delivery will spike 78%. The first widely deployed autonomous vehicles likely won't be transporting humans but rather familiar goods—like pizza. These sorts of autonomous deliveries will continue to gain momentum as a reliable, data-rich, and cost-effective solution for last-mile transportation with the potential to improve customer experiences. These relatively low-stakes deliveries will socialize autonomous technology in everyday society, easing the transition to autonomous vehicle systems for transporting people.

EMERGING PLAYERS

- Nuro
- Refraction AI
- Cenntro Automotive Group
- Arrival
- Rivian

5TH YEAR ON THE LIST

Air Lanes

Proactive planning can help avoid an aerial overload.
Image credit: Flightradar24.

KEY INSIGHT

The proliferation of drones will lead to more aviation guidelines, including "air lanes" that will guide low-flying aircraft, both piloted and autonomous. Where and when these new aircraft can operate will significantly impact the built and natural environment, and managing the number of flying drones will be important to ensure safety and noise pollution.

EXAMPLES

The U.S. Federal Aviation Administration has updated its Part 135 certification process for package deliveries by drone and is creating new regulation for air safety and industry guidelines. UPS Flight Forward was the first to receive a Standard Part 135 air carrier certificate to operate a drone aircraft in 2019. The FAA is now working with industry as well as state, local, and tribal governments to inform future rules and regulations.

The FAA's new BEYOND program will develop and scale drone delivery operations, establishing rules for infrastructure inspection and public operations. The program will also gather data and community feedback on the social and economic benefits of drones. Vodafone and Ericsson will work together to prove how safe flight path corridors can be created within existing cellular network coverage. Using network traffic data ensures that autonomous drones avoid areas of poor network coverage to guarantee connectivity from departure to destination.

DISRUPTIVE IMPACT

Regulators have an opportunity to preempt congestion, ensure safety, manage community perception, ensure privacy and learn from road and air travel if they proactively create aerial infrastructure along with key stakeholders. Cities and states will then need to develop regulation to ensure interoperability of drone lanes.

EMERGING PLAYERS

- U.S. Federal Aviation Administration
- International Civil Aviation Organization
- European Union Aviation Safety Agency
- Civil Aviation Administration of China
- South African Civil Aviation Authority
- Civil Aviation Authority of Singapore

4TH YEAR ON THE LIST

Flying Taxis

General Motors debuted its concept eVTOL in 2021.

KEY INSIGHT

Compact, unmanned electric aircraft have moved beyond the concept stage, and now a flurry of prototype tests at companies worldwide could open the door for autonomous air travel services to take individuals and small groups short distances.

EXAMPLES

In 2021, Cadillac introduced a vertical take-off and landing (eVTOL) personal air taxi. It's General Motors' first foray into the increasingly crowded aerial mobility space. Hyundai, Aston Martin, and other carmakers announced plans to build their own eVTOL aircraft. But there have been setbacks: A fire inside a hangar destroyed a prototype by Germany-based Lilium; Boeing's Aurora Flight Sciences prototype crashed; and Kitty Hawk's one-person vehicle, Flyer, suffered fires involving batteries, electric motors, and wiring.

DISRUPTIVE IMPACT

Most designs use electric engines that allow for vertical landing and takeoff in urban spaces, enable short- to medium-distance trips, and rely on both piloted and autonomous formats. NASA Ames Research Center and the U.S. Federal Aviation Administration are currently working to create regulations for safety and air traffic control. The result could be hundreds of thousands of delivery drones and air taxis flying in urban and suburban airspace, opening up a new medium of travel for the mainstream passenger and impacting transit design, congestion, and travel times. The high rate of crashes in the helicopter travel industry, including the high-profile fatal crash of Kobe and Gianna Bryant and seven other people in 2020, highlights the need for increased safety in this burgeoning area.

EMERGING PLAYERS

- European Organisation for the Safety of Air Navigation
- New Zealand government
- EHang

4TH YEAR ON THE LIST

Follow-Me Autonomously

Follow-me functionality allows drone operators to capture the moment without worrying about piloting.

KEY INSIGHT

"Follow-me" functionality, whereby a drone is able to detect and pursue a moving subject, has burst onto the scene in personal drones for photography and videography, but it has potential applications in a range of settings and situations.

EXAMPLES

Many photo- and video-enabled consumer drones available today have "follow-me" and crash-avoidance functionality, enabling semi-autonomous flight, where a subject is kept in the frame of the camera without the need for a designated pilot. This is ideal for capturing solo activities like skiing, surfing, and dance. Most of these drones rely on GPS transmitter technology or recognition software, such as DJI ActiveTrack.

DISRUPTIVE IMPACT

The ability to automatically avoid crashes and reroute around obstacles greatly increases a drone's safety and versatility. Autonomous conflict avoidance and follow-me functionality reduce stress and sensory demand on the remote pilot, making indoor flight easier and expanding the range of circumstances in which drones can be safely operated.

EMERGING PLAYERS

- DJI
- Skydio
- Yuneec

3RD YEAR ON THE LIST

Inspection Drones

Drones can inspect infrastructure in places that are too dangerous for humans.

KEY INSIGHT

As natural disasters and extreme weather events become more common, drones will help with the rapid inspection and interpretation of critical infrastructure.

EXAMPLES

Drone inspections are being performed in almost every industry that requires visual inspections, in the aftermath of a weather event or as part of routine maintenance. Drones can capture visual data more safely than humans can—and AI systems process those data in real time. Carnegie Mellon University researchers are developing an AI system that will review amateur drone footage of damage from 2020's Hurricane Laura so that it can perform rapid damage assessments in the future. The system would automatically identify buildings and offer preliminary damage assessments, increasing situational awareness and significantly reducing cost and human labor.

DISRUPTIVE IMPACT

Increasingly frequent extreme weather events will further strain infrastructure. As civil aviation authorities grant new certifications to allow flights beyond the visual line of sight, drones will gain access to remote gas pipelines, power lines, and other areas that are often only reachable by dangerous backroads.

EMERGING PLAYERS

- Carnegie Mellon University
- Neurala
- Optelos
- PowerVision Robots

4TH YEAR ON THE LIST

Autonomous Underwater Vehicles

Autonomous vehicles could significantly help to maintain and inspect underwater structures.

KEY INSIGHT

Drones aren't just for air and land. Underwater drones have been around since the 1950s, but in recent years the technology has improved dramatically due to better batteries, low-light high-definition cameras, and lighter control boxes and sensors.

EXAMPLES

The U.S. Navy first developed underwater drones, and such devices were used to discover the wreck of the Titanic in 1985. Modern drones are far more advanced. Today's autonomous underwater vehicles are used to disable mines; to explore for oil and gas drilling; to inspect nets; to feed and stock fisheries; and to reduce costs for monitoring, building, and maintaining underwater assets. General Dynamics' Bluefin-21 drone is known for its 2014 search for the wreckage from Malaysia Airlines Flight 370. Boeing's Echo Voyager is the largest autonomous underwater vehicle, weighing 100,000 pounds, and it can also go the deepest. Boeing and Huntington Ingalls Industries are now developing the Orca drone submarine, designed for military combat, surveillance, and minesweeping. Lockheed Martin's Marlin can create 3D models of its surrounding environment in real time. The navies of France, Japan, Russia, and China, meanwhile, are developing their own underwater technologies. Underwater drones have even become popular among consumer hobbyists and can be purchased online for $500 to $3,000.

DISRUPTIVE IMPACT

Underwater drones are changing the business dynamics of marine construction, potentially increasing underwater land usage. The potential of improved underwater surface mapping could also cut the costs of laying the transatlantic cables that serve as the backbone of the internet, enabling increased competition and connectivity. Military autonomous underwater vehicles could be used in both offensive and defensive capacities including intelligence, network infrastructure, port security, and more.

EMERGING PLAYERS

- Blueye Robotics
- Geneinno
- Youcan Robot
- Notilo Plus

Transportation

1ST YEAR ON THE LIST

Vehicular Biospheres

Cars are being used as mobile "quarantine" zones.

KEY INSIGHT

Vehicles are evolving into controlled mobile biospheres that allow people to move through the world and spend extended periods in their cars without subjecting themselves to the elements and contagions.

EXAMPLES

In its 2015 Model X SUV, Tesla designed an air filtration system called Bioweapon Defense Mode that's allegedly capable of protecting passengers from a military-grade biological attack. The system uses a HEPA filter that can remove particles as small as 0.3 micrometers, roughly the width of a single strand of spider silk. Geely Group says it will spend $53 million to develop cars that purify the air of the cabin and filter out viruses. These sorts of features arrive as vehicular activities like drive-by parties and parades become increasingly common as distanced options for socializing and attending events amid the pandemic, along with an uptick in curbside or in-store pickups for online purchases. The world's largest drive-through animated light show—in Marietta, Georgia, for the 2020 holiday season—extended 1 mile in length and took 30 minutes to traverse.

DISRUPTIVE IMPACT

The pandemic has made people more sensitive to potential environmental hazards. Many limit their travel source to only their private cars in order to limit exposure. Vehicles as extended personal biospheres or exosuits could necessitate the expansion of dense urban environments and prompt designers to build experiences with the assumption that everyone will participate from within their own personal biosphere.

EMERGING PLAYERS

- Tesla
- Illumination
- Geely Group

Intra-biosphere and intra-pod mobility

Far-future pessimistic scenario

Car customization shops begin adding options for virus safe air-conditioning systems in addition to their existing armor plating and explosive device countermeasures to a-la-carte modifications for the ultra-rich. The option becomes so popular that car manufacturers take notice, creating car-based biosphere isolation specifications for the entire industry to follow. As a result, cars come with biosphere certifications that allow occupants to prove they did not encounter any contagions, so they can speed through any contagion testing or quarantine restrictions.

Scenarios

3RD YEAR ON THE LIST

Battery-Supported Transportation

Transitioning to grid power from fossil fuels will test energy delivery infrastructure.

KEY INSIGHT

The rise of battery-supported transportation will change how we power vehicles, transforming an infrastructure that has historically sourced energy from gasoline to one that delivers it via the electrical grid.

EXAMPLES

Battery-powered transportation now extends beyond cars, trucks, and buses to motorized bicycles, hoverboards, skateboards, and scooters. The battery-powered transportation movement will drive new business models and gradually cut demand for fossil fuel-powered transport. California will phase out the sale of gasoline-powered cars by 2035, making a robust and reliable electrical grid even more critically important in the state. Risks are highlighted by the regular rolling power outages during California's wildfire season—or Texas's widespread blackout during a winter storm in early 2021—and are underscored by Tesla's new in-car warnings to drivers about upcoming power outages nearby.

DISRUPTIVE IMPACT

Energy prices, reliable and safe batteries, and convenient, affordable recharging infrastructure will drive adoption of electric transportation. Utility providers will be pressured to improve grid resiliency as demand grows for domestic charging. Those first movers to provide charging infrastructure along travel routes will shift traffic patterns and create new networked economies—similar to how the interstate highway system created an economic boom for certain towns and hurt those cities that were bypassed.

EMERGING PLAYERS

- Tesla
- ChargePoint
- EVgo
- Blink Charging

Distributed Grid

Mid-future optimistic scenario

Charging infrastructure becomes fully standardized and interoperable. Charging stations become commonplace and are readily available publicly and privately on highways, rural roads, and urban centers. Fast and slow charging is readily available in homes and at charging stations. The electrical infrastructure adapts and offers dynamic energy consumption across the entire system, reducing pollution and delivering cleaner energy than its petroleum-based predecessors.

The grid becomes distributed, scalable, and self-routing in a manner that maximizes efficiency and safety. Consumption can be predicted and mapped very accurately, reducing peak load and overcapacity needs. Systems are designed and developed where batteries and devices connected to the grid can receive and return power as needed in an open ecosystem.

Competing Standards

Mid-future neutral scenario

Charging infrastructure develops regional level interoperability with one or two primary standards to which all-electric vehicles can connect. Public charging stations concentrate around interstate highways and urban centers, driven by the adoption of upper-middle-class commuters and commercial trucks. Most of the charging happens at home with residential charge points. Electricity infrastructure has a limited adaptation to the increased demand. Power generation continues with limited decreases in overall pollution. Utilities aggressively incentivize consumers to shift electricity demand across non-peak times by limiting fast charge times and conditions. Blackouts and brownouts become more common and predictable like snowstorm and fire disruptions… inconvenient, but generally accepted.

VHS vs Betamax, But for Cars

Mid-future catastrophic scenario

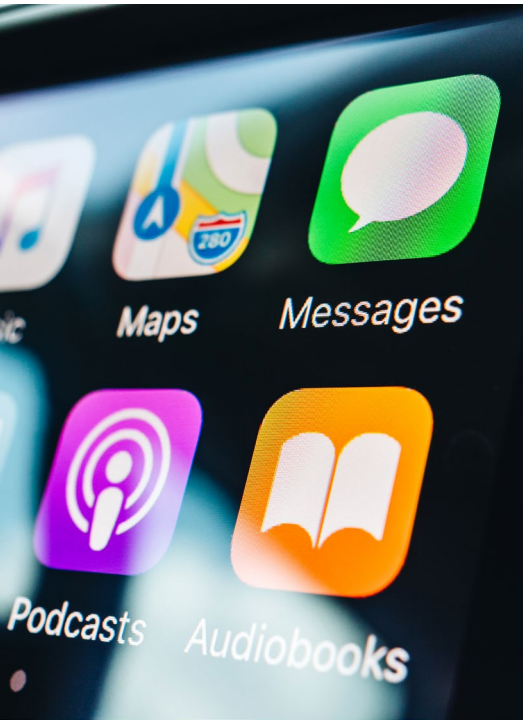
Energy infrastructure delineates the haves from the have-nots. The charging networks are not interoperable, and we develop dongle hell for cars. Fragmentation persists until there is market saturation and the government steps in, mandating interoperability. Think Apple iPhone forcing people to buy Bluetooth headphones versus Android phones, only this time it is Tesla versus Volkswagen.

Fuel for power plants and electricity generation does not adapt, so the electricity powering our transportation is less efficient and more polluting than the gas-powered cars they are replacing. We become increasingly dependent on the outdated infrastructure that begins to decay at an increasing rate under the new load causing frequent brownouts and blackouts. States and municipalities begin to compete on delivering power, redistributing population centers, furthering divisions of wealth and opportunity.

Scenarios

3RD YEAR ON THE LIST

Car OS



Technology companies are building operating systems for the cockpit.

KEY INSIGHT

Platforms are building operating systems for smart cockpits.

EXAMPLES

Amazon, Apple, and Google are competing to gain a foothold in the auto entertainment industry as carmakers incorporate smartphones directly into driving interfaces. Amazon's Alexa Custom Assistant was developed for the enterprise: Companies such as Stellantis are using it to develop their smart cockpits. Volvo's Polestar 2 uses the Android Automotive OS custom-built by Google.

DISRUPTIVE IMPACT

The major platform players increasingly view car ecosystems as prime real estate not only for customer attention but for data collection. As consumers spend more time in their cars without as much need to pay attention to actually driving, carmakers must decide whether to design their own systems and compete with tech titans or to give up ownership of the infotainment dashboard to third parties. The applications available on each car platform will likely determine adoption and ultimately decide the market winners and losers.

EMERGING PLAYERS

- Tesla
- Google's Android Automotive OS
- Amazon's Alexa Custom Assistant
- Apple's CarPlay

5TH YEAR ON THE LIST

Transportation-as-a-Service Business Models

New business models are shifting from ownership to subscriptions and pay-as-you-go.

KEY INSIGHT

The business models for transportation are shifting to subscription and pay-per-use structures, as bike, scooter, and car ride-sharing services become more common.

EXAMPLES

The business model of ride-sharing services Uber, Lyft, Via, and Gett now extends beyond cars. Citi Bike provides rentals of electric and non-electric bicycles, while Bird, Spin, Skip, eCooltra, and Ioscoot offer scooter rentals. Car rental companies like Hertz, Avis, and Sixt now offer rentals by subscription, by the minute, or by the mile in specific urban centers. Carmakers are also testing new ownership models, such as Audi Select, Access by BMW, Genesis Spectrum, Porsche Drive, and Porsche Host.

DISRUPTIVE IMPACT

The high upfront investment, maintenance costs, and rapid depreciation associated with traditional car ownership will dissuade potential car owners as they avail themselves of transportation options with subscription models or per-use rates. Consumers will likely demand business models that are personalized and maximize flexibility and cost-efficiency.

EMERGING PLAYERS

- Gett
- Via Transportation
- Sixt

What year will fleet-owned autonomous cars outnumber family-owned cars in the U.S.?

3RD YEAR ON THE LIST

Forced Updates

A driver attempts to diagnose engine problems on his own in the middle of traffic.

KEY INSIGHT

In an ideal world, keeping software updated ensures the safest and best experience possible. But in reality updates are often mandatory and sometimes cannot be postponed or avoided, meaning they can unexpectedly take systems offline, force unwanted changes, and expose users to unforeseen bugs and vulnerabilities.

EXAMPLES

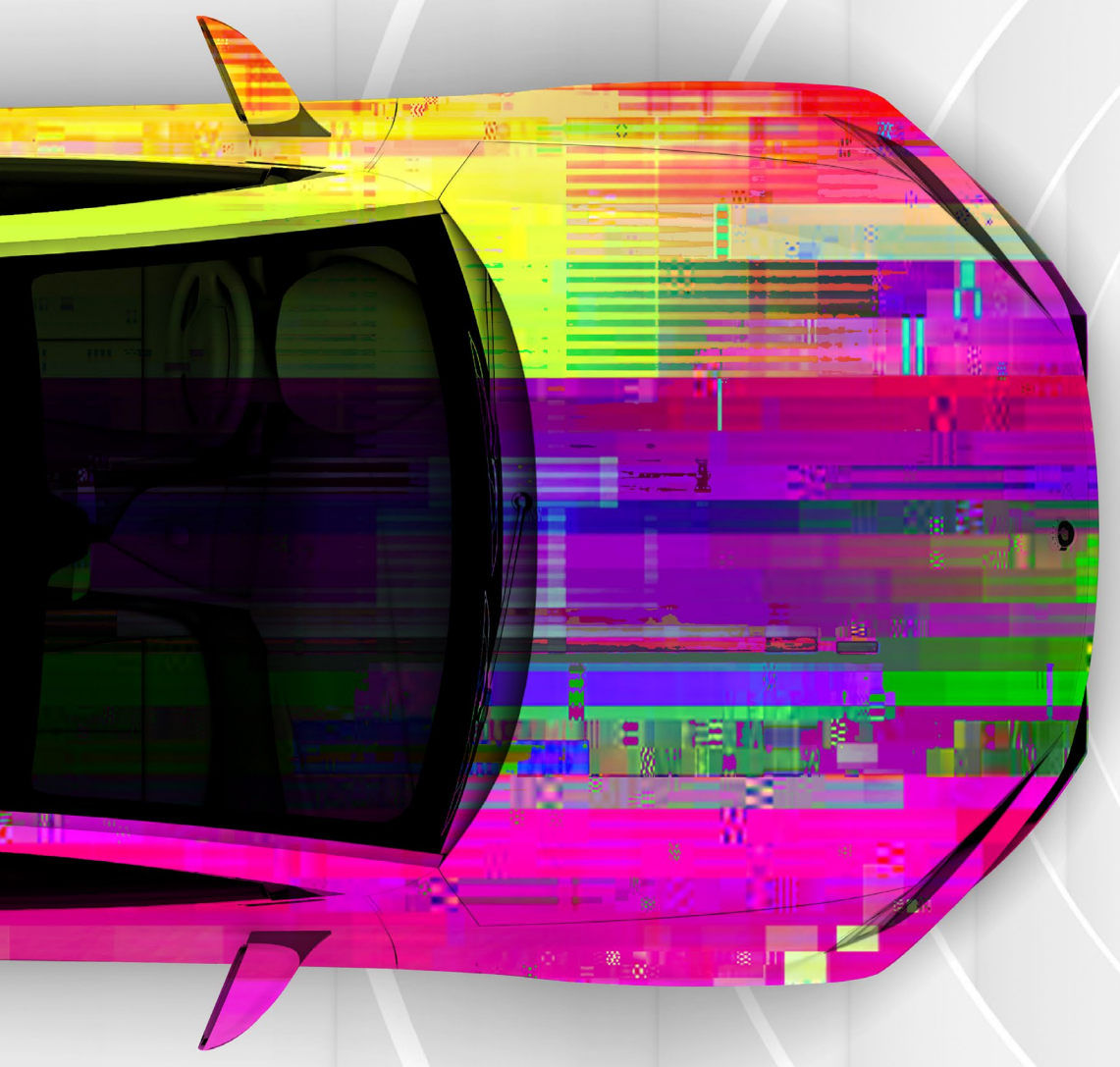
Forced updates can be either good or bad. When Tesla issued an update to its Model 3 that improved braking distance by a full 19 feet, that was good. When Microsoft's Windows 10 forced an unannounced mandatory restart in the middle of a professional gamer's live-stream to 130,000 followers, that was not good. Microsoft has since rethought its policy of forced updates.

DISRUPTIVE IMPACT

When a provider like Microsoft or Google changes a keyboard shortcut or switches the delete and archive button, frustration often ensues. Now imagine if Tesla reprogrammed which button or pedal sounded your horn, or applied your brakes—the result could be catastrophic. Or say you're in a rush to a critical meeting, but because of a billing hiccup on your car's lease, security software suddenly kicks in that restricts your maximum speed to 65 mph. Automotive platforms will evolve continuously, with new features and functionality added via over-the-air firmware updates. Providers will increasingly navigate the difficult path of introducing new features to keep pace with evolving technologies and improving customer experiences, while ensuring major changes are introduced gradually enough to avoid creating new user-error risks.

EMERGING PLAYERS

- Tesla
- Amazon
- Google
- Apple
- General Motors
- Microsoft



Scenarios

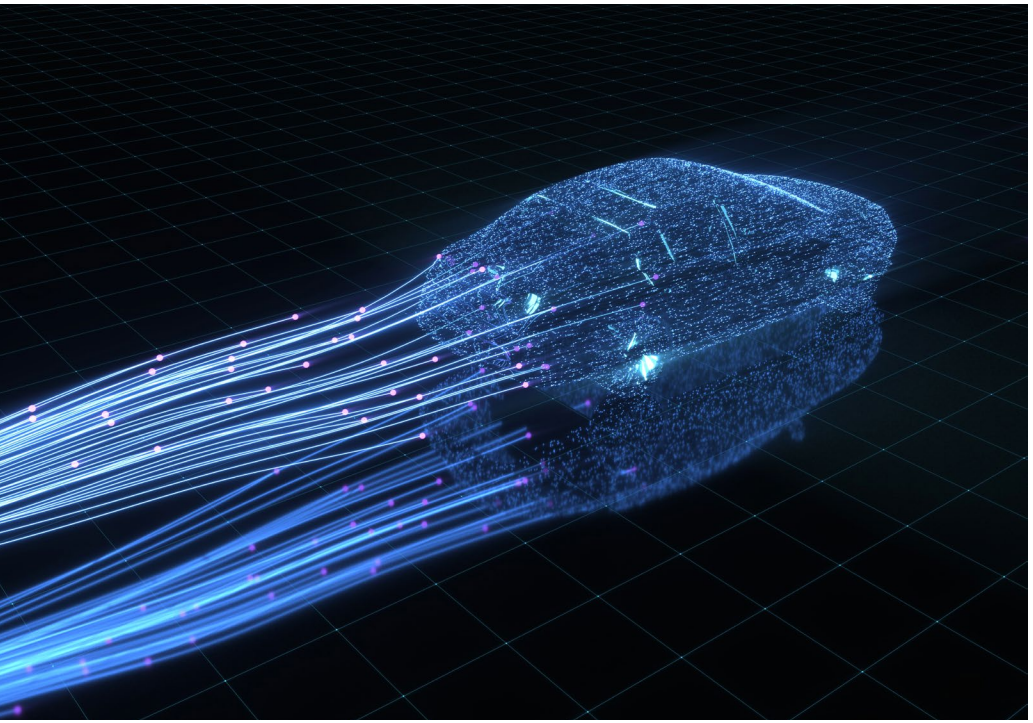
Experiential Interruptions

Near-future neutral scenario

Autonomous vehicles pave the way for experiential transportation. Your car can double as a theater, a cocktail bar, or a library… for an additional fee. When the car is no longer the product you buy, service is essential and content is still king. If you're unwilling to pay a premium, you might be stuck watching a movie you've already seen while also being inundated with deliberate product placement. Pop-up ads block those scenic mixed reality views during long car trips. Augmented OLED windows malfunction and lag, displaying blue screens and spinning wheels, giving new meaning to the term "car crash." Getting from one place to another is a trade-off between the journey and the destination.

3RD YEAR ON THE LIST

Exponential Growth in Autonomous Driving Data



Training data is critical for building AIs like those used in autonomous vehicles.

KEY INSIGHT

The quality of any algorithm has a significant correlation with the size of the dataset on which it is trained. The size of these datasets in autonomous driving is reaching an inflection point as the number of autonomous car users regularly generating real-world driving data approaches critical mass. Beyond this influx of real, raw data, methods of generating synthetic training data are reaching maturity.

EXAMPLES

Approximately 200,000 Tesla vehicles now navigate the roads using autopilot. With the increase in autonomous miles logged, emerging patterns in the data will help solve some of the problematic edge cases in the algorithms (those that occur rarely or only under extreme conditions). The current algorithms have at times struggled to identify stationary objects, in the worst cases resulting in catastrophic crashes. Shortcuts to training the AI systems are beginning to mature. Helm.ai uses a deep teaching methodology that programs the system to understand base rules like object permanence, effectively giving the AI a head start on learning. Massachusetts Institute of Technology created a digital laboratory to translate real-world situations into simulated scenarios using deepfake technology—allowing AI to train quickly and at lower cost in a virtual environment, but on data based on real-life circumstances. Volvo trains AI on edge cases using a virtual environment based on the Unity gaming engine. Rockstar Games received attention for stopping organizations such as OpenAI from using its "Grand Theft Auto" game as a platform for training self-driving cars.

Synthesized data can help us get to the edge cases faster, meaning more progress per mile analyzed, and making the algorithms safer overall. To put edge cases in context, think of how many miles one would have to drive to come across a pedestrian on stilts crossing paths with a cyclist doing a wheelie in a rainstorm? It sounds highly unlikely, but if the algorithm has never been exposed to such a situation, it might make a fatal error—which is why it's important to expose the algorithm to as many of these atypical cases as possible.

Exponential Growth in Autonomous Driving Data continued

As cars with autonomous features become popular, they generate data to help systems improve.

DISRUPTIVE IMPACT

The company with the most training data should best be able to reduce its vehicles' autonomous-driving error rates, potentially cultivating a powerful brand association with safety—think Volvo in the '80s or Subaru in the 2010s. With the stigma of autonomous driving as an under-regulated and potentially untrustworthy technology, perceived safety performance may be the most important factor for winning market share. For carmakers, however, autonomous algorithms aren't necessarily a "winner take all" market, because the developer with the best system could resell or license its software to other players.

EMERGING PLAYERS

- Helm.ai
- Oxbotica
- Nvidia

4TH YEAR ON THE LIST

Autonomous Vehicle Testing Gets Regulated

Who will give AI its driving license?

KEY INSIGHT

New rules will govern how autonomous vehicles can be tested. Current legislation around autonomous cars is in flux and has yet to be set at a national level.

EXAMPLES

Arizona, California, Florida, and Nevada (along with some federal initiatives) lead in testing autonomous vehicles on public roads, with other states and countries catching up. Since 2012, at least 41 states and Washington, D.C., have considered legislation related to autonomous vehicles. More than 50 self-driving companies are testing their technologies in California. ITU, the specialized United Nations agency for telecom and information communications technology, created a focus group to develop performance standards for autonomous vehicles, including what an "AI driving test" should entail.

DISRUPTIVE IMPACT

Creating learner's permits or driver's licenses for AI-enabled autos will help socialize the technology and establish expectations for experiences and protocols on the road. For autonomous vehicles to become safer, they must be tested in conditions similar to those where they will be deployed. Because of this dynamic, autonomous car services will likely arrive soonest in areas with existing testing sites. The fragmented regulatory environment, which will remain until federal laws and guidelines are imposed, will result in conditional and situational rules, such as how Cadillac centrally designates sections of road compatible with Super Cruise, its AI-enabled hands-free driving assistance product.

EMERGING PLAYERS

- Focus Group on AI for Autonomous and Assisted Driving
- U.S. National Highway Traffic Safety Administration
- National Conference of State Legislators

3RD YEAR ON THE LIST

Analog Fallbacks

How do you open a door that is frozen shut—and has no handles?

KEY INSIGHT

As more systems and infrastructure transition to digital formats, and more purely digital systems are built, fewer of these systems will rely on analog or manual fail-safes. When these unprotected digital systems fail, it will lead to increasingly catastrophic outcomes. Electrical systems are historically more sensitive and fragile than their analog counterparts, meaning failures are likely to become harder to assess, repair, and recover from.

EXAMPLES

Many car locks today depend on electricity and become inoperable when the car battery dies. Tesla's Model 3 has a mechanical system for the front doors, but not the rear doors. Such vulnerabilities can cause life-threatening scenarios: A failed car battery locked the doors of an Ohio man's Cadillac and trapped him in the car for 13 hours, and, in another case, a Texas man and his dog died in his Corvette as a result of the same problem. Both vehicles had manual door release mechanisms as a fallback for when electrics failed, but neither person could find the release. To make matters more tragic, one of the victims had the vehicle owner's manual yet was still unable to activate the manual release mechanism. These problems will be exacerbated when cars no longer come with physical user manuals or when firmware updates change a car so drastically that the original physical manual is no longer accurate.

DISRUPTIVE IMPACT

There is hardly a more apt application of the phrase "They don't make 'em like they used to" than the auto industry. As vehicles become more automated, manufacturers must design for the appropriate level of redundancy and for a population of people with limited understanding of how the underlying systems work.

EMERGING PLAYERS

- Cadillac
- Corvette
- Tesla
- Range Rover

Scenarios

When Humans Attack Cars

Near-future pessimistic scenario

Every year, more than 200,000 people die in a car accident. That's about one person every three minutes in the United States. Millions more are hospitalized because of car-related injuries. And now there's a twist: armed with rocks, guns, pocket knives, and in one instance, a PVC pipe, humans have started attacking cars.

The reason: big tech companies must adjust their self-driving technology to real-world communities that aren't interested in being test subjects. Google's Waymo division, which has been testing vans near Phoenix since 2017, has had several run-ins with locals: they've slashed car tires, pelted vehicles with rocks, and tried to run vans off the road. Residents have safety concerns, especially in the wake of a 2018 collision involving a pedestrian and a self-driving Uber car just a few miles away in nearby Tempe. But the real issue here isn't safety. It's that we all struggle to cope with technological change, especially when it disrupts the foundations of everyday life.

2ND YEAR ON THE LIST

Urban Planning for Multi-Use Roads

Road design will accommodate more uses than ever before.

KEY INSIGHT

As the role of car ownership shifts in society, public roads will transform. Streets and sidewalks are increasingly becoming mixed-use spaces as a greater variety of transportation methods become popular and prevalent. The pandemic-related need for outdoor dining and commerce has accelerated the redistribution of street space away from car travel and parking.

EXAMPLES

Strava Metro is using the data from runners and cyclists to help urban planners design safer streets. The National Association of City Transportation Officials released evolving guidelines for street space design and pandemic recovery strategies. They include various street use cases, including protests, voting, outdoor dining, and markets. Slow streets are designed to limit traffic in certain residential areas.

DISRUPTIVE IMPACT

Intelligent load balancing and redistribution of transportation real estate could significantly increase the throughput of existing transportation infrastructure. Increased quality, quantity, and diversity of traffic data will enable cities to redistribute how much attention and space is designated for car travel and storage versus use by pedestrians, cyclists, and others.

EMERGING PLAYERS

- Strava Metro
- Open Streets Project
- National Association of City Transportation Officials

1ST YEAR ON THE LIST

China's Open Road

China's Byton hopes to rival the world's most prestigious auto manufacturers.

KEY INSIGHT

China's ambition to dominate the global car industry is buoyed by its manufacturing sector, work in AI, and vast troves of driving data.

EXAMPLES

Although we don't see their vehicles in the West, there are more than 70 Chinese car manufacturers, and together they produce more cars than any other country. For decades, the Chinese government has been paving the way for joint ventures: Many cars in Beijing with foreign badges were actually made by domestic auto manufacturers. An electric vehicle boom is underway, and China's newest cars are full of high-tech gadgetry including wrap-around digital dashboards and seats that swivel so passengers can enjoy a meal together when in self-driving mode.

DISRUPTIVE IMPACT

China is creating a new mobility ecosystem that includes electric vehicles, apps, communications systems, AI, and data—and it intends to ship its products to the West. Baidu's Apollo is one example of an open-source self-driving system that could become an industry standard. Its partners include Daimler, BMW, and Ford.

EMERGING PLAYERS

- Apollo Committee
- Baidu
- Volvo
- Ford
- Geely Group
- Dongfeng Motor
- Tencent
- Great Wall Motors

1ST YEAR ON THE LIST

New Cityscape Designs

The Line is a linear city proposed in Saudi Arabia.

KEY INSIGHT

Autonomous vehicles, collaborative drones and robots, and AI are leading to changes in how cities are designed.

EXAMPLES

Saudi Arabia is developing futuristic new megacities. A linear city called The Line will stretch from the Red Sea to the mountains of northwest Saudi Arabia and consolidate urban centers into a 106-mile-long stretch of land. The entire city will be arranged along a multilevel spine, which will include local and high-speed transit, a service layer, and a pedestrian layer. The goal is to preserve the area's wilderness, encourage mobility, and test renewable energies at scale. The Qiddiya giga-project is a $500 billion bet on a megacity contained within a 130 square mile site outside of Riyadh, the KSA's capital. If these projects are successful, they will have advanced technologies and urban ecosystems that rival any major city.

DISRUPTIVE IMPACT

With climate change accelerating, these projects are an approach to redesigning how we live. We may have little choice, as sea levels rise and extreme weather events force us indoors or even underground.

EMERGING PLAYERS

- Bjarke Ingels Group
- Arquitectonica
- Rockwell Group
- NEOM CEO Nadhmi Al-Nasr

Unified Rules

Mid-future optimistic scenario

Vehicles with level 2 autonomous driving functionality will become mainstream in the next ten years. Multiple manufacturers will provide the option to have autonomous driving installed in new cars as a safety and convenience feature.

Customers receive full control of their data and privacy safeguards installed by manufacturers. Customers can easily delete data from cars when they're resold in the pre-owned markets. Rules and regulations are unified across the globe, so learnings from driving on one side of the world immediately improve driving on the other side.

Continental Licenses

Mid-future neutral scenario

Vehicles will have regional requirements but will be interoperable at the continental level. Meaning that cars in Europe can function throughout most of the European Union and vehicles in America can operate across most states. Standards will be set and will not require significant alterations to be manufactured for all regions. Standardized production will look very similar to today's car manufacturing and internet privacy rules, where products can be made globally and customized locally. Privacy implementation strives to be done at the most rigorous standard for the region in question.

Uncrossable Border

Mid-future catastrophic scenario

Fragmentation of regulation and data privacy cause a complete lack of interoperability. You can't take a car designed for one state to the next due to regulations that limit design, features, and functionality. Car manufacturers must design platforms and brands for specific jurisdictions. The need for specific jurisdictions removes the ability to have world platforms in manufacturing, driving up production costs, dramatically decreasing the speed of improvements, and extending development cycles exponentially. You must stop at every border and create a new account for your car with additional information and accept the terms and conditions of operating the vehicle in the next jurisdiction. Certain features and functions are enabled or disabled based on where you are traveling and what terms and conditions you accept. Insurance may only cover you in some areas and circumstances.

Scenarios

1ST YEAR ON THE LIST

Decarbonizing Flight

Airbus revealed its zero-emissions plane, one of several hydrogen-powered aircraft projects it has underway.

KEY INSIGHT

Hydrogen fuel cells could power commercial aviation.

EXAMPLES

Last year, ZeroAvia successfully completed an 8 minute flight that resulted in no carbon emissions. Using a retrofitted Piper M-Class plane, the test proved that hydrogen—which carries little or no carbon footprint—could someday become an alternative to fossil fuels. Airbus has three hydrogen power programs in the works and could start testing commercial flights as early as 2025.

DISRUPTIVE IMPACT

Aviation contributes 3% of the world's total carbon emissions. When flights stopped during the COVID-19 pandemic, there were noticeable changes to air pollution. As air travel returns to pre-pandemic levels over the next few years, there will be increased calls to reduce emissions. Hydrogen-powered planes, while still under development, could be a viable alternative.

EMERGING PLAYERS

- ZeroAvia
- Airbus

5TH YEAR ON THE LIST

Supersonic Flights

A sonic boom caused by an F-18 Super Hornet.

KEY INSIGHT

Several companies are developing technology to bring back commercial supersonic jet travel.

EXAMPLES

After years of successful transatlantic flights, the age of supersonic jet travel came to an end in October 2003, when British Airways permanently grounded the Concorde. Driven in part by the enthusiasm and excitement over faster autonomous travel, supersonic jets are being tested once again. Japan Airlines invested $10 million in Colorado-based Boom Supersonic to develop supersonic jets, which will travel at 2.2 times the speed of sound—or about as twice as fast as a standard aircraft. Japan Airlines has already preordered 20 such jets, and Boom unveiled its prototype in October 2020 for test flights in 2021. Aerion Supersonic in Nevada is also developing a carbon-neutral supersonic jet that is expected to take off in 2023.

DISRUPTIVE IMPACT

Faster travel between locations could stimulate economic development and bring cultures closer together. Reduced sonic boom will enable flights to take off over land, overcoming a significant limiting factor in the routes that the original Concorde could fly. But fuel efficiency and safety concerns may slow progress in getting supersonic air travel to market in the short term.

EMERGING PLAYERS

- Aerion Supersonic
- Boom Supersonic

Scenarios

The End of Traffic

Mid-future optimistic scenario

In the next 10 years, companies master vertical takeoff and landing craft that operate similarly to helicopters but they are affordable, easy to pilot and easy to maintain and as cost-efficient as car transportation. Commuters increasingly adopt short distance aerial travel as their regular form of transportation. This redistributes traffic on roadways, which are now dominated only by heavy and long-distance transport, while light transit takes to the air.

Pilot Shortages

Mid-future neutral scenario

New aircraft are developed but continue to require highly trained and skilled operators like helicopter pilots. Technological advances for more economical operation, opening up specific commutes and routes, mostly along existing helicopter routes that will handle increased capacity due to lower cost. Island hopping and taking the chopper to the airport will be available to the affluent instead of just the hyper-wealthy. The adoption of regulations and infrastructure modeled after helicopter transport incorporate more significant pilot assistance systems reflecting autonomous vehicle regulations.

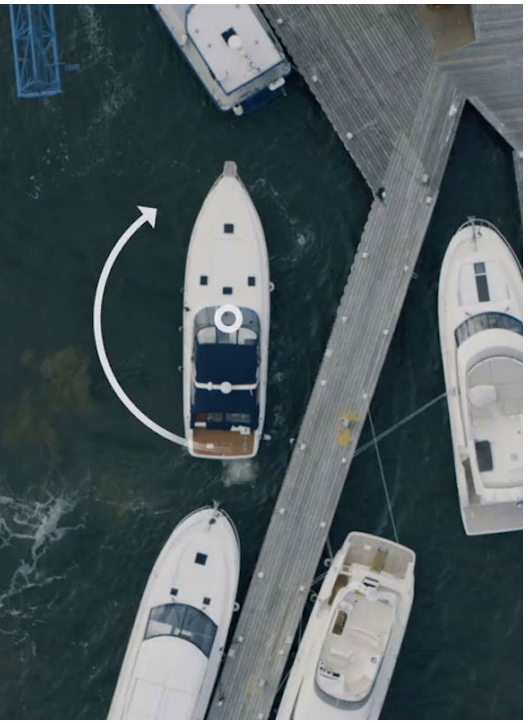
Forgotten Infrastructure

Mid-future pessimistic scenario

Flying taxis become the method of travel of choice for the hyper affluent, who only travel in the air. Air transit becomes a lightning rod for the global wealth divide, as less is invested in land-based transit infrastructure and public transportation.

4TH YEAR ON THE LIST

Autonomous Ships



Volvo Penta launched an autonomous boat docking system.

KEY INSIGHT

Efforts are underway to create autonomous, AI-powered ships, and the legal framework is emerging for them to operate safely and officially in international waters.

EXAMPLES

IBM and ProMare, a marine research organization, launched a fully autonomous ship called Mayflower, from Plymouth, England, last year. It features an AI captain that gives the vessel the ability to assess its environment and make decisions at sea with no human captain or onboard crew. Volvo's maritime subsidiary Penta launched an autonomous boat docking system—boat captains push a button and it docks without human assistance. Norwegian chemical company Yara International built The Yara Birkeland, an electric container ship supported by radar, lidar, machine learning, computer vision, an automatic mooring system, and a network for cameras. The company planned to transition the vessel from human-crewed operation to remote-crewed operation in 2019, and then to autonomous operation in 2020. The pandemic slowed the timeline, and humans are staying on board for now—which helps with regulatory and insurance complications, too.

DISRUPTIVE IMPACT

Large autonomous ships could transform shipping by increasing efficiency, reducing costs, and reducing human error. Electric ships that don't require human crews could offer cost savings throughout the shipping supply chain. They could solve labor shortages, increase safety, and reduce environmental harm. The International Maritime Organization is performing a scoping exercise before drafting the legal frameworks for maritime autonomous surface ship travel. In the near to midterm, the goal is to design AI systems that will support human-crewed ships.

EMERGING PLAYERS

- ProMare
- Penta
- IBM
- Marine AI
- Yara International
- Wärtsilä

3RD YEAR ON THE LIST

China's Foreign Infrastructure Investment

KEY INSIGHT

The governments and companies that lead international infrastructure projects have powerful influence on setting regional, global, and geopolitical standards. China's multibillion-dollar Belt and Road Initiative is the source of massive investment in infrastructure development, including roads, rail, sea, and air travel. The vast extent of the investment and partnerships with Asian, East African, European, and developing countries has helped make China the preferred financier and producer of transport and power infrastructure on the global geopolitical scene.

EXAMPLES

China's Belt and Road Initiative began in 2013 and has primarily focused on investment in infrastructure, education, construction, rail, highway, auto, and the electrical grid. The effort is enormous—roughly 12 times larger than the U.S.'s Marshall Plan, which helped Europe rebuild after World War II. In 2017, the Belt and Road Initiative involved an estimated 68 countries, 65% of the world's population, and 40% of global gross domestic product.

DISRUPTIVE IMPACT

Critics worry that the debt created by the project will cause an imbalance of leverage in geopolitical relations. Many of the countries involved are developing nations that urgently need the infrastructure, but may have limited ability to handle the debt sustainably. While China is offering a moratorium on debt servicing during 2020, the debts will eventually come due and require potentially long-term global partnerships to address.

EMERGING PLAYERS

- Asian Infrastructure Investment Bank
- New Development Bank
- National Development and Reform Commission

Application

STRATEGY

Information technology, supply chains, transportation, and network connectivity are becoming more complex, which will require strategists to be more agile in near-term planning. Savvy corporate strategists will consider how this complexity could lead to a broad range of possibilities. Rather than waiting for further developments, organizations should continually identify signals to inform strategic decisions, monitor outcomes, and determine where they can play—and win.

INNOVATION

Network upgrades, decreased latency, automated transportation, and new delivery options unlock a wide swath of new products, businesses, and opportunities to grow. The next several years will be dynamic, with continual improvements across many sectors. Innovation teams must be prepared to monitor development and anticipate change.

R & D

R&D leaders are playing a larger role in identifying businesses of the future, with some asked to present their ideas to their executive leadership and boards. Going forward, R&D leaders will need to consider a broader range of trends. For example, in what ways will 5G lead to new business growth in agriculture and finance? An organization's ability to think beyond existing business units will deliver stronger outcomes as the trends described in this volume mature.

RISK

Trends in networks, transportation, logistics, robotics, and transportation are complex and involve a tech stack that many organizations don't yet have. Chief risk officers should consider developing a strategy to optimize risk to deliver stronger business models—rather than using governance to slow the adoption of emerging technologies and standards.

Key Questions

We recommend using this report to support your strategic foresight activity in the coming year. Every executive team should begin by asking these questions:

1

Are we actively developing and testing new ideas related to the trends explored in this volume?

In what ways could our logistics, supply chain, or communications systems be improved?

2

What parts of our business make us vulnerable to disruption in networks, logistics, or transportation? When was the last time we audited the systems that keep those parts of our business safe?

3

Are we adequately planning for the longer term?

What assumptions must hold true for our current strategy to succeed? How will we make needed changes?

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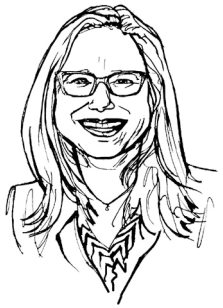

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- What scenarios describe our futures?
- What's happening outside my industry that I should know?
- What companies, startups, and partners make up our future value network?
- What new products, services, or businesses should we build?
- Which tech trends should we monitor? When should we act?
- How can we build an early warning system to see the next disruptive event?
- How do we reduce uncertainty about our futures?

We support executive leaders and their teams.

The Future Today Institute works closely with executive leadership and management teams to transform their strategic thinking on the future. Advisory services include signal mapping, trend identification, scenario development, risk modeling, visioning, and strategic planning.

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