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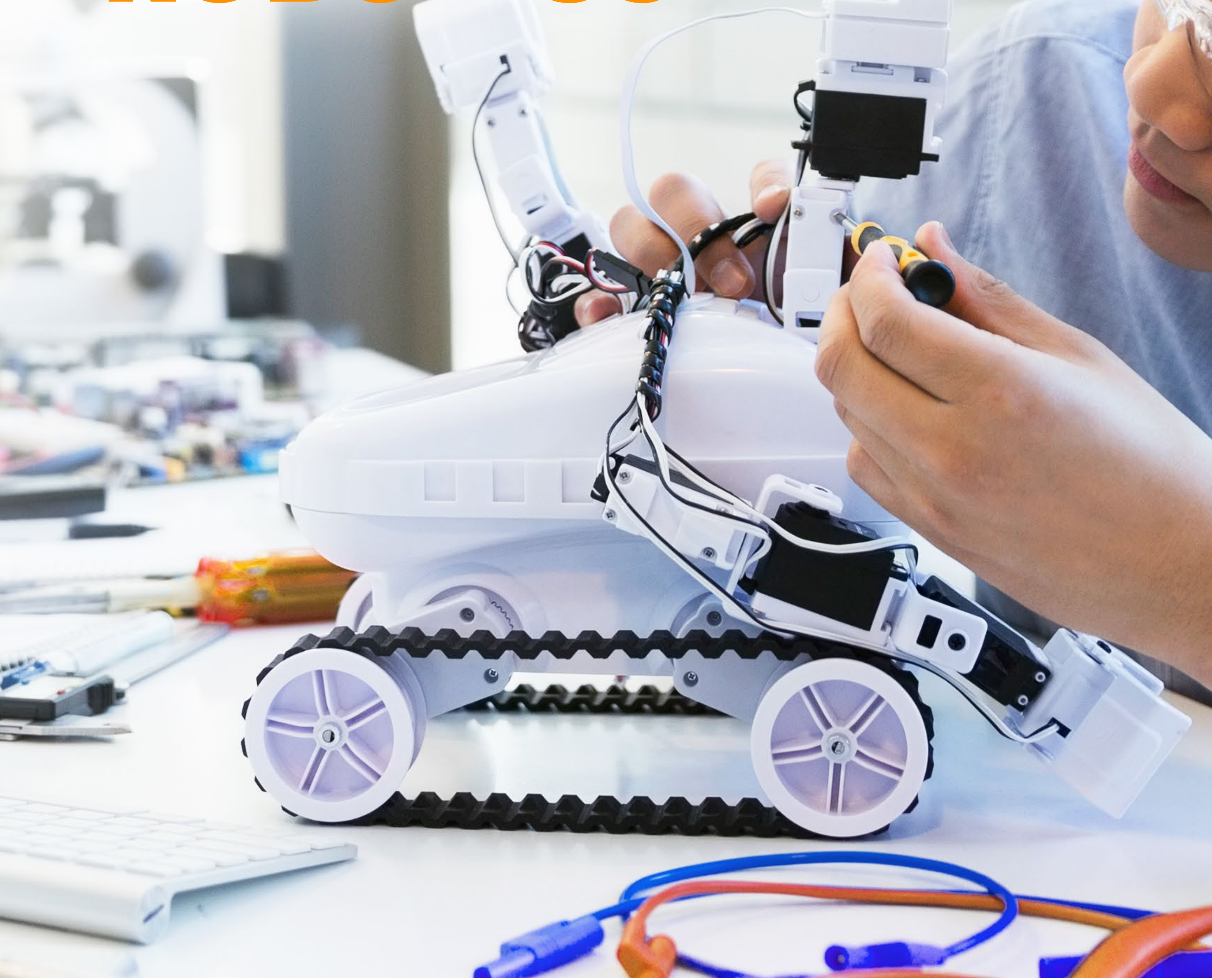
Accenture Labs

FOSTER INNOVATION WITH ENTERPRISE ROBOTICS



The sophistication with which physically embodied robots can sense, plan, act and learn will continue to increase dramatically. As robots move toward operating in semi-structured and unstructured environments, the door will open to entirely new forms of interaction with humans while reducing the complexity of implementation for companies. This means robotics will be broadly accessible and capable of executing new use cases across the enterprise.

Robotics today is following the trend of consumerization, evidenced by both acceptance and increased economies of scale. This transformation is now to the point where businesses can innovate with robots as a viable solution for a broad range of tasks in which humans and machines augment each other's strengths to increase productivity.

As the field continues to expand, leading companies in every industry must work to understand the vast potential of robots throughout the enterprise. This involves taking a multi-dimensional journey and developing a strategy to move from experimenting with robotics toward fully scaled and integrated robotics capabilities.

EXECUTIVE SUMMARY

The next stage in robotic automation is here. Over the past two decades, robots—programmable machines that have the capability to sense, plan and act in order to perform physical tasks automatically—have received a substantial boost through investments, open source contributions, consumerization and standards development, resulting in a new range of commercially viable robotic applications.

Now a new generation of robots is emerging that can handle an increasing amount of variability, which allows them to navigate and complete tasks in less structured environments with more efficiency (see Figure 1). As such, they are being used across industries including:

MANUFACTURING to handle, build, transfer, and package products and materials

LOGISTICS to track and transport goods

HEALTHCARE to monitor patients and provide transportation within hospitals

RETAIL for customer service interactions and planogram compliance

AGRICULTURE for precision spraying and automated picking

Robotics applications like these are early indicators of what is coming. According to a report published by IDC, annual robotic spending for hardware, services and software is expected to triple by the end of 2021 to $215 billion, driven by a compound annual growth rate (CAGR) of 23 percent.[1] The increased democratization of robotics and component technologies across domains will fuel innovation and cost reduction. This, in turn, will drive a faster pace of robotic adoption and ubiquity. As this cycle continues, Accenture Labs foresees some of the most effective enterprise applications of robotics will operate in semi-structured environments where a robot is integrated as a part of an overall system, and digital information helps the robot to perform more intelligently.

In addition, rapid progress in the mechanical, electrical and software components will foster the movement of robotic systems into environments that are uniquely human, where machines will intermingle fluidly with people and take on a growing range of work assignments. This will have an impact on the design of work processes and affect how humans and robots interact and ultimately collaborate.

Accenture Labs believes the full implications of these robotics trends are still a few years from realization; however, the initial opportunities are here—and the time to lead the advancement is now.

At the Labs, we are actively collaborating with clients and robotics researchers to help enable the next generation in robotics usage across enterprise. In many cases, integrating current robotics solutions into workforce processes is already providing benefits and profits. As shown in our Enterprise Maturity Model for Robotics (see Figure 3), as companies go from experimenting with robotics in specialized cases to a fully realized and optimized deployment, they will need to prepare their operations and employees for the era of advanced, flexible robotics. This requires developing a comprehensive, integrated approach with key decision points about technical infrastructure, flexible robotic process implementation, human-robot teaming, system operations and cultural implications.

This report looks at the quickly evolving robotics ecosystem, including technological, societal and regulatory advancements. It also covers potential new applications of robots across multiple industries along with enablers for powerful human and robot collaborations. Finally, it suggests steps to get started, including an Accenture Robotics Capabilities Model (see Figure 5), as companies invent their future with widespread robotics use.

ROBOTICS: FROM RIGID AUTOMATION TO FLEXIBLE TEAMMATES

Multiple advances in technology and infrastructure have allowed physical robotic technologies to move beyond stationary manufacturing applications and into dynamic, everyday environments. Put more simply, robots are increasingly able to handle variability—unlocking entirely new options to transform the ways businesses operate and people work.

Today, companies are beginning to use mobile robots to wash windows of skyscrapers and clean oceangoing ship hulls. They're deploying flying robots to inspect powerlines and pipelines, or to collect information for insurance claims. And they're overseeing wheeled robots to move goods through warehouses or to deliver amenities to hotel guests. Engineers are using robots combined with advanced analytics to automate mining processes, and doctors are using them to improve surgical procedures. And in the consumer sphere, physical robots are appearing in people's everyday lives through applications like 3D printing, drones and robotic vacuum cleaners.

Still, physical robotic technology must overcome some technical hurdles to maximize usefulness in the enterprise (see section "Technology → Structured to Unstructured Environments"). The focus of recent robotics research has been on handling environment variability—with rapid advancements in moving from structured environments like factory floors to more unstructured environments like supermarkets, office hallways and field operations.

In the coming decade, we expect to see a dramatic expansion of robotic systems in the enterprise and a major shift in how companies deploy robots. Much of this innovation will come from scenarios that are already unfolding as people increasingly transform tools into teammates by automating some portion of the work, including autonomous vehicles for driving, warehouse robots for picking and packing, and healthcare robots for monitoring patients. In time, we believe the application of robotics in these industries and others will drive even larger transformations.

The message is imminent and far-reaching: Companies must take steps now to understand the wide-ranging potential of robotics across the enterprise and develop a comprehensive strategy to introduce the technology into their operations. As outlined in our Robotics Maturity Model (see Figure 3), this will require progress in five core dimensions in bold:

1. Upgrading the technical **infrastructure** to support a robotics system

2. Modifying business processes and tasks for the **implementation** of flexible, connected robots

3. Introducing workflow changes to enable effective **human-robot teaming** and boost productivity

4. Updating **systems operations** to detect and recover from errors quickly, and manage overall execution

5. Evolving the corporate **culture** to prepare and train employees to work alongside robots

One of the key technologies that allows robots to cope with environment variation is artificial intelligence (AI) planning. Given a desired state of the environment as an input (e.g., which items to pack into a box, the level of cleanliness desired for a floor, which pipes to inspect by when), planning algorithms determine which of the robot's—or human-robot team's—basic capabilities should be used, and in what order. Because planning operates on the robot's current view of the world, it allows a system to autonomously cope with changes to that world, or its assigned tasks, online.

AI planning makes use of computational abstractions of the world called "models." A robot may have a 3D model of an object it should grasp, a kinematic model of how its arm moves, and a causal model of the effects of closing its gripper around an object and then lifting. These models can be associated with metrics such as cost (e.g., energy usage), duration and risk to allow the robot a broader understanding of their effects.

Another important tool that allows a robot to adjust to environment variation and lack of structure is learning through experience. Repeatedly performing a task, such as navigating through a busy supermarket or grasping new products, allows an AI-driven robot to improve models, like those described above, using feedback from successes and failures (e.g., by using probabilistic models to capture the inherent uncertainty in robotic operation in dynamic environments). Regardless of their internal representation, **models that are improved through learning can be exploited in the AI planning process, improving overall system behavior.**

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TECHNOLOGY → STRUCTURED TO UNSTRUCTURED ENVIRONMENTS

Creating modern robotic systems requires the integration of numerous mechanical, electrical and software components. Consequentially, the capability of state-of-the art robotic systems is, in large part, restricted by the maturity of component industries.

For example, the main requirement for traditional industrial robots is accurate positioning and the ability to follow preprogrammed paths. To operate in highly dynamic and human-centric environments, modern robots require sensor packages and perception algorithms, safe actuators with sufficient payload limits, robust planning strategies and substantial computing power.

Until recently, robots operated primarily in structured environments because they could only technologically handle limited variability. Although people can adapt relatively quickly to new situations, robotic systems can fail at tasks when even small changes in the environment occur. As just one simplistic example, a robot can be programmed to pick up a bottle of soda from a specific point on the table; however, the robot might knock over the bottle if it is moved two inches to the right or if a differently shaped bottle is substituted.

Fortunately, this example of variability is a solved problem today thanks to the progression toward unstructured environments. But the more advanced robotic applications of the future must address technical challenges related to user level of training and range of interactions, task variability, changing object sizes and positions, semantic understanding, terrain, and navigating crowded environments. By embedding machine learning algorithms into robotic systems and training robots, their abilities and performance will improve.

UNDERSTANDING TYPES OF ROBOTS

The rate of adoption of robotics will depend, in part, on the type of robot required for a specific use case. Several types of robots exist today (see Figure 1), each with a differing set of functionality and applications. While many of the component technologies overlap, each type of robot will progress at different rates based on task complexity and business viability. Examples and their potential uses include:

FIGURE 1. TYPES OF ROBOTS

INDUSTRIAL ROBOTIC ARMS—Robotic arms are the longest standing and most ubiquitous form of industrial robot. Driven by the automotive industry, they have revolutionized manufacturing and are extremely efficient at repetitive tasks that require high degrees of accuracy and repeatability.

COBOTS—Collaborative robots, better known as cobots, are robots designed to operate safely around or with humans. While they may use a robotic arm for manipulation, they enable automation outside of a rigid factory environment and provide intuitive methods for operation.

MOBILE / WHEELED UNMANNED ROBOTS—Mobile robots are capable of locomotion through an environment, typically using wheels. Wheeled robots utilize different strategies to navigate environments and can be used to transport goods through hospitals, factories and warehouses, explore outer space, and inspect pipelines and infrastructure. Some also have mechanisms for manipulating objects in their environment.

AUTONOMOUS VEHICLES—Autonomous vehicles are a specific implementation of wheeled robots that aim to revolutionize transportation and delivery. Through their development, substantial progress has been made with sensing, navigation and image recognition technology that transfers to other types of robots.

HUMANOID ROBOTS / LEGGED ROBOTS—Legged robots use bipedal or quadrupedal locomotion to traverse uneven terrain and obstacle-filled environments. While the technology is relatively expensive for companies to deploy currently, legged robots capable of running or climbing will unlock a variety of new robot applications, such as handling stairs and ladders.

DRONES/UNMANNED AERIAL VEHICLES—Drones are unmanned aircrafts that can be remote-controlled, semi-autonomous or fully autonomous. They are largely used for inspection and information gathering tasks while specialized drones are capable of transporting objects.

AUTONOMOUS UNDERWATER VEHICLES—Autonomous underwater vehicles allow for aquatic inspection, maintenance and exploration. While mechanically expensive, these systems can operate in ocean environments unsuitable for humans.

SOCIAL ROBOTS—Social robots can interact and communicate with people or other machines by following a set of social behaviors and rules. These robots allow for more natural user interaction and, therefore, are well-suited for environments involving untrained human agents.

EXOSKELETONS—Exoskeletons physically augment human performance allowing for increased stamina, consistency and/or strength. They are useful for repetitive movement of heavy objects in military, warehouse and construction environments—and can also be used for patient rehabilitation.

EVOLVING SOCIAL AND REGULATORY ACCEPTANCE

Beyond the unsolved technical challenges, the robotics industry still faces social and regulatory challenges. While many people have concerns about the potential for robots to replace human jobs, evidence suggests that automation in manufacturing has historically correlated with job creation in the US.[2] Today, physical robotic automation can help countries inshore manufacturing while remaining competitive with lower foreign labor rates, as well as fill labor shortages related to undesirable jobs and an aging workforce.

In some industries and sectors, the trend is toward human-machine teaming where robots are used to augment humans and perform "dirty, dangerous and dull" tasks, thus freeing up people to focus on higher-order tasks that require creativity, empathy and judgment. For example, security robots are designed to patrol offices and malls looking for changes in the environment. When an anomaly is detected, the robot switches over to human control (through telepresence) for decision making.

As companies evolve their work processes and environments to include robotic systems, they will need to consider the role that robots may play. How should work processes be restructured? How should work be divided, coordinated and shared within a team that includes both human and robots? Answers will vary per industry; however, it is clear there will be major impacts on everything from manufacturing to distribution, to service and maintenance.

In Accenture Labs' Enterprise Maturity Model for Robotics (see Figure 3), we outline the main decision points for companies as they consider how best to enable robotics across the organization. In the case of human-robot teams, for example, a company would establish roles and interaction models for humans and robots in the **tactical** stage, and then move toward the **scaled** stage by introducing dynamic team composition of humans and robots. When pursued strategically and in stages, human+machine teams can leverage the intelligence, dexterity and flexibility of human workers with the autonomy, consistency and reliability of robotic systems.

Employees are usually more effective at doing their jobs when working with teammates, especially with peers who have complementary skillsets. Similarly, robots can be better at their tasks when behaving as teammates among humans. Think hospitality robots that work alongside hotel front-desk or kitchen staff to deliver requested items or room service to guest rooms. In fact, leveraging the strengths of human-robot teams will provide a more productive and empowering path forward than "pure" automation.

Human-robot interaction (HRI) research is making its way from academic research labs into the real world of robotic products and services. As robots are designed for use by untrained humans instead of only by highly trained professional operators (e.g., NASA engineers), robotic technologies can be used in a variety of new domains.

As human-robot teams become increasingly pervasive, there are critical issues to be addressed in the design and deployment of these robotic systems. For example, as tele-operated robots gain bits of autonomous capabilities (e.g., obstacle avoidance), some people are more or less willing to give up control to robotic systems. This raises important issues of how much responsibility a robot operator should have in a given situation—not only credit for successes, but also blame for failures (e.g., autonomous car crashes).

Selecting appropriate roles for these robots in each workplace, designing behaviors into robots that are readily understandable for human co-workers, and enabling humans and robots to work together more fluently are all critical challenges in making these robotic systems worthwhile to businesses.

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In addition, companies must proactively address potential safety, security and privacy concerns to overcome barriers to large-scale robot adoption. Several governments have created regulatory frameworks, such as the European Union's RoboLaw,[3] to support worker safety while enabling companies to increase productivity through robotics. Likewise, institutions including Harvard Law School[4] have convened forums to discuss the implications of emerging robotic and automation technologies. Since regulation will likely lag behind quickly advancing robotic technology, leading companies should consider participating in robotics standards development, and collaborate with governments and policy makers to shape regulations.

As applications expand, robotic technology will also become increasingly democratized. This trend is already occurring through exposure to robotic toys in the consumer market, the consumerization of robotic systems like 3D printing and drones, and access to open source robotic components for development by academic institutions, business labs and individual enthusiasts. As these products become the norm, people will expect to use more industrialized versions of the same technologies to improve business processes, workflows and models in enterprise environments. Take, for example, the growth of custom manufacturing services through 3D printing or the use of drones for inspection in a range of industries. As economies of scale reduce the costs for robotic implementations, increase the talent pool and accelerate innovation, the business value proposition will continue to improve.

AUTONOMOUS VEHICLES: A KEY SIGNPOST

The modern field of robotics traces its roots back to the automotive industry where the first robotic arms transformed manufacturing. On the assembly line, robots provided physical strength, efficient operation and consistent quality, which directly translated into a substantial reduction of cost on a per-car basis.

Today's automotive robotics technology has moved well beyond the confines of the manufacturing plant—in the form of autonomous vehicles. While fully autonomous cars are not yet commercially available, test models can be seen driving some city streets. These prototypes display the maturity of robotic technology and surrounding infrastructure that is now available. They also showcase the ability of robotics to operate in increasingly unstructured and human environments.

To bring these vehicles to market, the automotive industry and multiple government agencies are working to establish regulatory policies and safety metrics necessary to let highly autonomous machines be responsible for human safety. Enacting these regulations will set a precedent for other forms of robotic systems in both business and consumer applications.

This will have a ripple effect on the industry overall. The scaled adoption of autonomous vehicles and other robots such as drones will increase accessibility to, and decrease the cost of, various software and hardware components useful across applications. These include technologies for navigation and localization, person and object identification, obstacle avoidance, human intention awareness, and much more. Through the consumerization of these truly advanced robotic systems, the pace of innovation will increase as people across disciplines are exposed to and able to experiment with robotic technologies.

ROBOTIC ADVANCEMENTS IMPACT INDUSTRY PROCESSES

Powered by advances in perception, computer vision, planning and navigation, state-of-the-art robotic automation presents opportunities to dramatically change industry processes (see Figure 2). These types of advances will fundamentally change enterprise strategies for many industries, so understanding robot capabilities and integration in a business ecosystem is pivotal.

In the near-term, early adoption of and innovation with robotic technology can give businesses a measurable edge over their competition, reduce inefficiencies and mitigate risk. In 2016, for example, Deutsche Bank estimated that Amazon would save $800 million by deploying its existing Kiva robot system to the then 110 fulfillment centers that lacked robots.[5] Longer term, the increased ubiquity of robotics will require companies to use them simply to remain competitive.

Consequently, several companies are adding Chief Automation Officers (CAOs) with responsibility for software automation of processes and, in some cases, robotics hardware. A growing number of companies are going a step further: hiring Chief Robotic Officers (CROs) to develop full-fledged strategies for robotic systems. **In fact, within the next five to 10 years, more than 60 percent of Global 1,000 companies in manufacturing, supply chain, healthcare, energy and agriculture are expected to have some form of the CRO role.[6]**

While complete automation may be a goal for some companies, the technology is only ready to tackle specific components. Take supply chain as a prime example. A major challenge for logistics companies is efficiently automating delivery from factory to doorstep through robots. Within this overall problem, robots must be able to, at a minimum, manufacture products autonomously on an assembly line; stack pallets; load and unload shipping vehicles; manage, transport and track warehouse inventory; pack and unpack boxes, including break-bulk methods; and complete last-mile delivery. Each of these tasks has varying levels of complexity and can be distilled further into component tasks with an associated difficulty for robots.

In the future, however, an advanced logistics automation solution monitored by humans and powered by a variety of mobile and warehouse robots, autonomous vehicles and drones could, in theory, handle each of these steps. Large retailers could also deploy robots in the store to manage stock, unload boxes and place items on the correct shelves with the correct price. Every stage and handoff between manufacturers, distributors, retailers, delivery companies and customers would need to be digitized. It will take continued robotics investment and collaboration for companies to realize this vision.

FIGURE 2: ROBOTIC AUTOMATION SCENARIOS BY INDUSTRY

Over the next five years, autonomous navigation will help enable robotic shipping, delivery operations, consumer transport and household assistance, while specialized manipulation solutions will improve areas such as food processing in agriculture and warehouse picking. Further in the future, more advanced manipulation capabilities will vastly improve automation flexibility and can be combined with mobile robotic platforms for more holistic and general-purpose solutions.

INDUSTRY SECTORS	EXAMPLE ROBOTIC ROLES IN FUTURE	ENABLING HUMANS TO:
MOBILE MANUFACTURING	Moving beyond the fixed robotic assembly line, mobile robots perform on-site assembly and aid in the construction of large-scale, stationery objects such as ships, buildings, roads or bridges.	Improve architectural practices, focus on higher-skill operations, oversee continual infrastructure improvements.
SMALL BATCH/ CUSTOM MANUFACTURING	Additive and flexible manufacturing techniques produce new, higher quality forms of distributed manufacturing (e.g., athletic retailer prints custom-fitted shoes at store; build custom car components via industrial 3D printer).	Design and develop new products directly with customers, enable technicians to repair items faster.
AGRICULTURE AUTOMATION	Manipulator improvements enable mobile robots to pick majority of fruits and vegetables; robots perform manual processing operations that require dexterity (e.g., shucking oysters, cutting meat).	Redefine agricultural practices to improve yield and sustainability, address global hunger problems.
HEALTHCARE TOOLS	Provide caregiver assistance to help impaired, disabled and elderly people function more independently (e.g., social robots monitor individuals, exoskeletons supplement wheelchairs, autonomous vehicles provide increased independence).	Offer personalized service and compassionate care.
DISASTER RELIEF	Fleets of drones or mobile robots quickly scan an area, measure and record damage, identify stranded or in-need people, and provide emergency goods such as food and water.	Coordinate efforts across departments, quickly help those in danger, focus on recovery and rebuilding efforts.
RESOURCES	Mobile robots monitor and mitigate asset depreciation through inspecting and repairing pipelines, transmission lines and aging infrastructure. Modern remotely operated vehicles (ROVs) and machinery will become increasingly autonomous.	Improve infrastructure and citizen safety through preemptive maintenance and repair. Move from operators to information stewards.
RETAIL	Mobile robots navigate stores and perform planogram compliance to improve product advertisement, sales and consumer satisfaction. Back-of-house robots fulfill customer orders and autonomous vehicles deliver to home.	Free up employees to provide personalized customer service, cross-sell and up-sell goods.

PROGRESSING UP THE ROBOTICS MATURITY SCALE

To help companies understand the robotics journey, Accenture Labs has created a Robotics Maturity Model (see Figure 3) that illustrates the spectrum of a company just beginning to experiment with robots, to one that is operating with a fully realized robotics system. This model can help organizations plot their current location across the four stages—specialized, tactical, scaled and optimized—and five dimensions—infrastructure, implementation, system operations, human-robot teaming and culture. In order to progress to the next stage, a company must make improvements at each dot along the five dimensions.

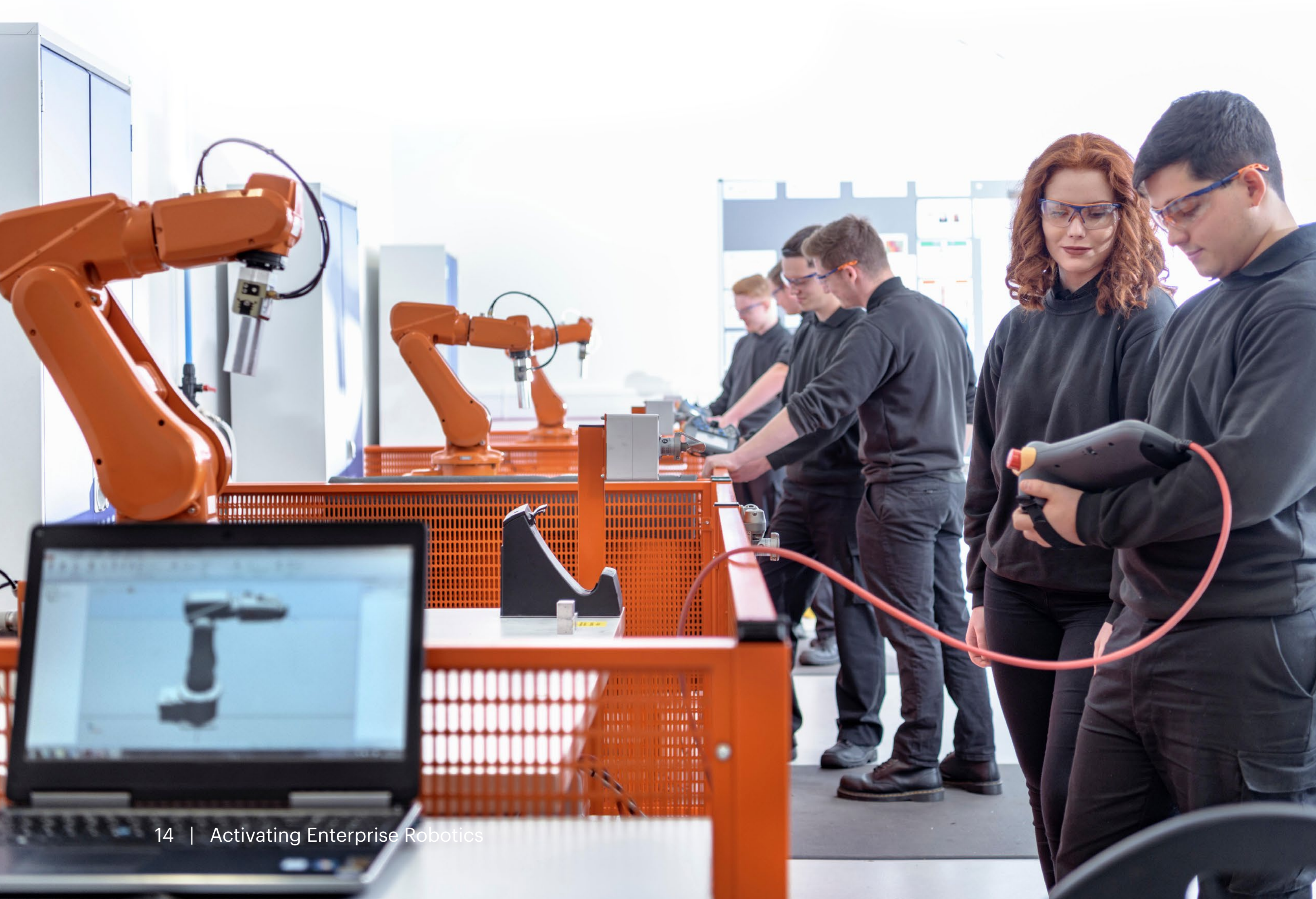
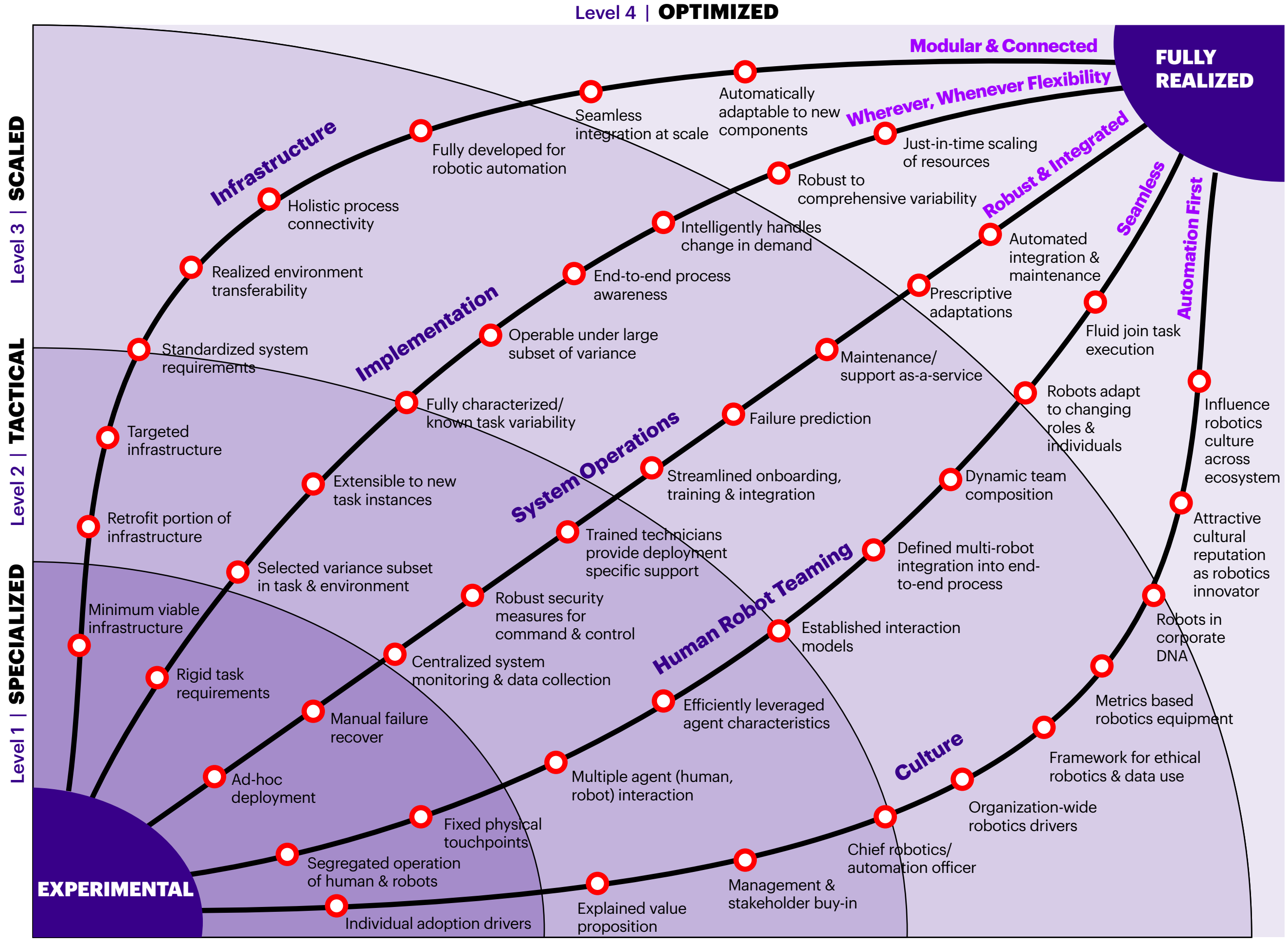


FIGURE 3: ENTERPRISE MATURITY MODEL FOR ROBOTICS



FOUR STAGES

Level 1 | SPECIALIZED
Beginning to deploy in production by using a single or few robots (segregated from humans) in ad-hoc implementations for a few rigid tasks.

Level 2 | TACTICAL
Has internal organizational knowledge of how to use robots and multiple existing deployments (e.g., oil and gas company building standards and working to expand underwater autonomous vehicles usage to discover energy sources and conduct seafloor pipeline inspection).

Level 3 | SCALED
Prioritizes robotic infrastructure and integration first when evaluating business processes (e.g., retailer or logistics company using robots in majority of warehouses for picking and packing; automotive company with robotic assembly lines manufacturing at scale).

Level 4 | OPTIMIZED
Broadly uses robotics across all feasible operations with an established plan for continued adoption of advancing robotics.

FIVE DIMENSIONS

1 | INFRASTRUCTURE
Surrounding infrastructure allows robotic systems to perform efficiently through insightful task information and meaningful task structure.

2 | IMPLEMENTATION
Robots are able to handle increasing amounts of task variability. By understanding task variance, companies can enable flexible robot systems that operate robustly across numerous deployments.

3 | SYSTEM OPERATIONS
Scaling deployment of sophisticated robotics systems requires repeatable environments, system integration, user training, operation and maintenance.

4 | HUMAN-ROBOT TEAMING
Within a business, robots serve as team members that augment human performance. Optimizing tradeoffs and interactions between humans and robots improves overall process performance.

5 | CULTURE
Stakeholder buy-in and robotics strategies are important across all levels of the organization. Company culture directly affects the adoption and performance of robot systems. Incentivized use of robots has been shown to improve performance metrics.

Thanks to widespread investment that has fueled both academic and business research, robotics has made tremendous progress in areas that involve interaction, perception and control. Robots are getting increasingly proficient at understanding commands provided via gestures and natural language, navigating safely through crowded spaces, building 3D maps of their environments, and detecting and tracking objects and people as they move through the world. This recent progress has been possible through advances in machine learning combined with novel range-sensing technologies and highly parallel computing devices such as the modern GPU.

As robotics solutions progress from navigation and observation tasks to areas that involve physical interaction with the environment and proximity to people, they will soon be able to help with more complex tasks such as asset tracking or shelving products. Continued research will enable robots to manipulate arbitrary objects in cluttered scenes, such as unpacking boxes in a fulfillment center or cleaning a desk. Further improvements in perception and reasoning algorithms will allow robots to accurately detect the actions and goals of people around them, and interact seamlessly with untrained co-workers.

Machine learning plays a crucial role in this endeavor. Advanced simulation will make it possible to feed techniques such as deep reinforcement learning with the data and experiences necessary to robustly operate robots in the real world. Photo-realistic rendering of 3D scenes along with realistic models of object dynamics and contact forces will provide the virtual training ground for the next generation of robots. It is already possible to train object detectors, grasp strategies and motion controllers via simulation. However, providing realistic simulation of people and their actions is still an open problem.

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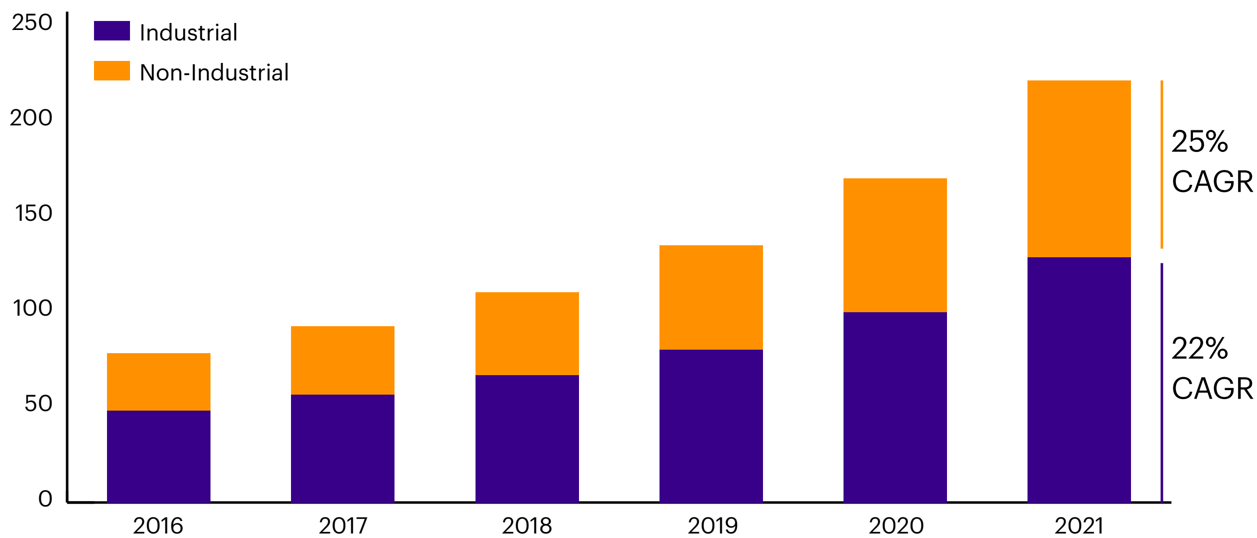
RAMPING UP INVESTMENTS IN ROBOTICS

The progression of robotics into new environments and scenarios, fueled by the democratization of hardware and software components, will increase over the coming decade. According to a report published by IDC, annual non-industrial robotic spending is predicted to grow at a 25 percent CAGR by the end of 2021 with large amounts of spending and growth coming from healthcare, transportation, construction, utilities and retail (see Figure 4).[7]

FIGURE 4: GROWTH OF INDUSTRIAL AND NON-INDUSTRIAL ROBOTICS



Many governments have recognized the potential impact that robotics can have on their economy. In 2016, Japan announced a five-year, $1 billion investment in industrial robots. Similarly, the European Commission has invested more than $600 million into robotics and cognitive systems as part of the 7th Framework Programme and another $900 million through the Horizon 2020 project for manufacturing and robotics.[8] The European Commission has stated that robotics research and innovation is, among other things, essential to productivity and competitiveness.[9] In the US, military (DARPA) and NASA funding has also led to substantial advancements in robotic technologies. Other notable government robotics investments have come from Japan, China, South Korea, Singapore, Russia and Germany.

The private sector has also been heavily investing in robotics. In 2016 alone, more than $18 billion was spent in acquisitions of robotics companies[10] with the largest acquisition being Aethon by ST Engineering for almost $6.7 billion. Other major companies including Softbank, Honeywell, GE, GM, Microsoft, Boeing, Intel and Apple have all had recent major robotics acquisitions as well. Simultaneously, venture capital firms invested over $2.8 billion in robotics startups over a 2.5-year period from 2015 to 2017.[11] A breakdown of startup funding reveals substantial investments in healthcare, manufacturing, drones, consumer goods and education applications.

With exponential growth in robotics spending and decreasing cost through economies of scale, the pace in innovation for robotics applications across industries will rapidly accelerate.

ACCENTURE INNOVATING WITH ADVANCED ROBOTICS NOW

At Accenture Labs, we are working to merge advanced robotic technology with current business processes and enable the next generation of robots. To better understand and predict future robot capabilities, we are conducting technical research with multiple robotic platforms/technologies and are collaborating with a cohort of robotics professionals and university faculty members. Our research includes methods and best practices for:

Improved systems and platforms for the easy enterprise integration of robotics, including autonomous navigation capabilities and multi-robot control.

Optimizing human-robot teams and interactions, including augmented reality for easier communication with robots, virtual reality for tele-operating robots, and telepresence to enable humans to provide on-demand expertise in any location at any time.

Advanced perception and artificial intelligence, such as deep learning to enable robots to operate in varying environments, and simulators for testing and providing transferrable experiences at scale.

As we explore specific areas of robotics implementation, Accenture Labs refers to our Robotics Capability Model (see Figure 5), which represents a high-level view of a fully functioning robotics system in the enterprise and illustrates the relationships of various components of complex systems. By modularizing and tracking different aspects of robotics technology, companies can efficiently and holistically design and integrate robotic systems. Possible uses of this model include:

IDENTIFYING
the components of a comprehensive solution and approaches for specific robotics capabilities

SELECTING
the various interaction, perception and control component(s) needed to meet system requirements

EVALUATING
robotics vendors and identifying potential gaps in their offerings

APPLYING
industry expertise to help ensure the robotics system works in the business setting

STRUCTURING
the overarching security and governance models to support a fully functioning system

APPLYING THE ROBOTICS CAPABILITY MODEL

Introducing robots and making them functional in a business setting requires a host of surrounding components and knowledge.

FIGURE 5: ROBOTICS CAPABILITY MODEL

HARDWARE forms the basis of a robotic system and will either limit or empower the overall performance of the robot. It is important to make sure hardware matches a given task and interacts appropriately with the environment to maximize efficiency and cost-effectiveness of the solution (e.g., robot equipped with industrial-strength grippers to pick up 50-pound boxes versus hand-like grippers to move 16-ounce bottles).

CONNECTIVITY (WiFi coverage, bandwidth, etc.) is a critical component across a system with special considerations necessary to navigate in enterprise environments (e.g., robots can get stuck in elevators). Robotic systems leverage connectivity to integrate robots and edge devices into an overarching enterprise system and are able to improve performance by offloading compute, data, and system orchestration to cloud or server-based resources.

INTERACTION, PERCEPTION AND CONTROL represent the core capabilities of a robotics system in terms of how a robot interacts with other humans and robots, perceives the surrounding environment, and is controlled through methods for planning and actuation. When the capability subcomponents have access to all the surrounding components and knowledge, it is possible to create robust, reusable software instances that transfer more easily to other robotic hardware solutions in the enterprise.

DATA MANAGEMENT, LEARNING AND ADAPTATION are important across the interaction, perception and control capabilities—and allow a robotics system to perform intelligently and adapt over time. Data management includes services like data orchestration, acquisition and storage. A common data layer enables learning algorithms that can improve and optimize robot behavior.

CONTEXT AND SEMANTICS are additional methods for improving and abstracting robot behavior across the three core capabilities. Context includes a robot's awareness of operations across multiple tasks and data streams thereby informing decisions about how to act; ideally this context uses common programmatic methods of communication between the capability subcomponents. Semantics provides a structure that enables this shared knowledge.

Three areas span all system components and are vital for a successful robotics implementation:

DOMAIN-SPECIFIC KNOWLEDGE—
Even with supervised and unsupervised learning through deep neural network technology, out-of-the-box "robot intuition" is not yet fully realized. It will be important to apply industry-wide practices, proprietary knowledge and employee experience across various aspects of a robotics solution.

SECURITY, SAFETY AND POLICY—
In factory or industrial scenarios, these components are already largely in place. However, as robotics moves toward unstructured environments and direct interactions with people, companies will need to pay special attention to implementing these in business and consumer settings. It is essential to ensure the security of enterprise assets and data, to protect the safety of employees and the public, and to formulate policies using robotic ethics and data ethics.

GOVERNANCE—
Human-machine teams introduce new roles and responsibilities for robots, operators and support personnel. The people and process governance considerations for new technology must be considered, especially for at-scale implementations.

START THE JOURNEY

Using the Robotics Maturity Model and Robotics Capability Model as guides, companies can start the robotics journey with these steps:

1

IDENTIFY
manually operated tools and machinery as potential low-hanging fruit for robotic automation

2

EVALUATE
business processes and look for repetitive or simplistic tasks. Determine each task's susceptibility to automation (both robotic and otherwise)

3

DEVELOP
a strategy for gradually introducing robotics into the work environment across the five dimensions: infrastructure, implementation, human-robot teaming, systems operation and culture

4

CREATE
a roadmap to design and integrate the various components of a robotic system based on business need

5

CONSIDER
developing the necessary robotics capabilities in-house, evaluating specific robotics vendors, or relying on a third-party provider experienced in robotics strategy and implementation

CONCLUSION

The increasing capabilities that robotics can offer to businesses show no sign of slowing. Given the myriad opportunities available, companies must work to activate their enterprise robotics journeys now, innovate with flexible robots in semi-structured or unstructured environments, and prepare their people for human-robot teaming.

The consumerization of robots is already propelling early adopters to experiment with new robotics technology and pioneer its implementation in various industries. Focusing on solutions in which robots can be used safely for a broad range of process improvements at-scale unlocks reduced costs and increased throughput. It will be equally important to emphasize the corresponding social and cultural changes within the enterprise so that employees can transition into safer, more rewarding and higher-skilled roles.

As more companies move toward using robots in unstructured environments, there will be further advents into robotic form factors, peripheral hardware and greater acceptance in enterprise. This pervasive future will continually push the boundary of automation—providing the boldest innovators with unprecedented opportunities for productivity improvement and growth as they invent their futures.

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