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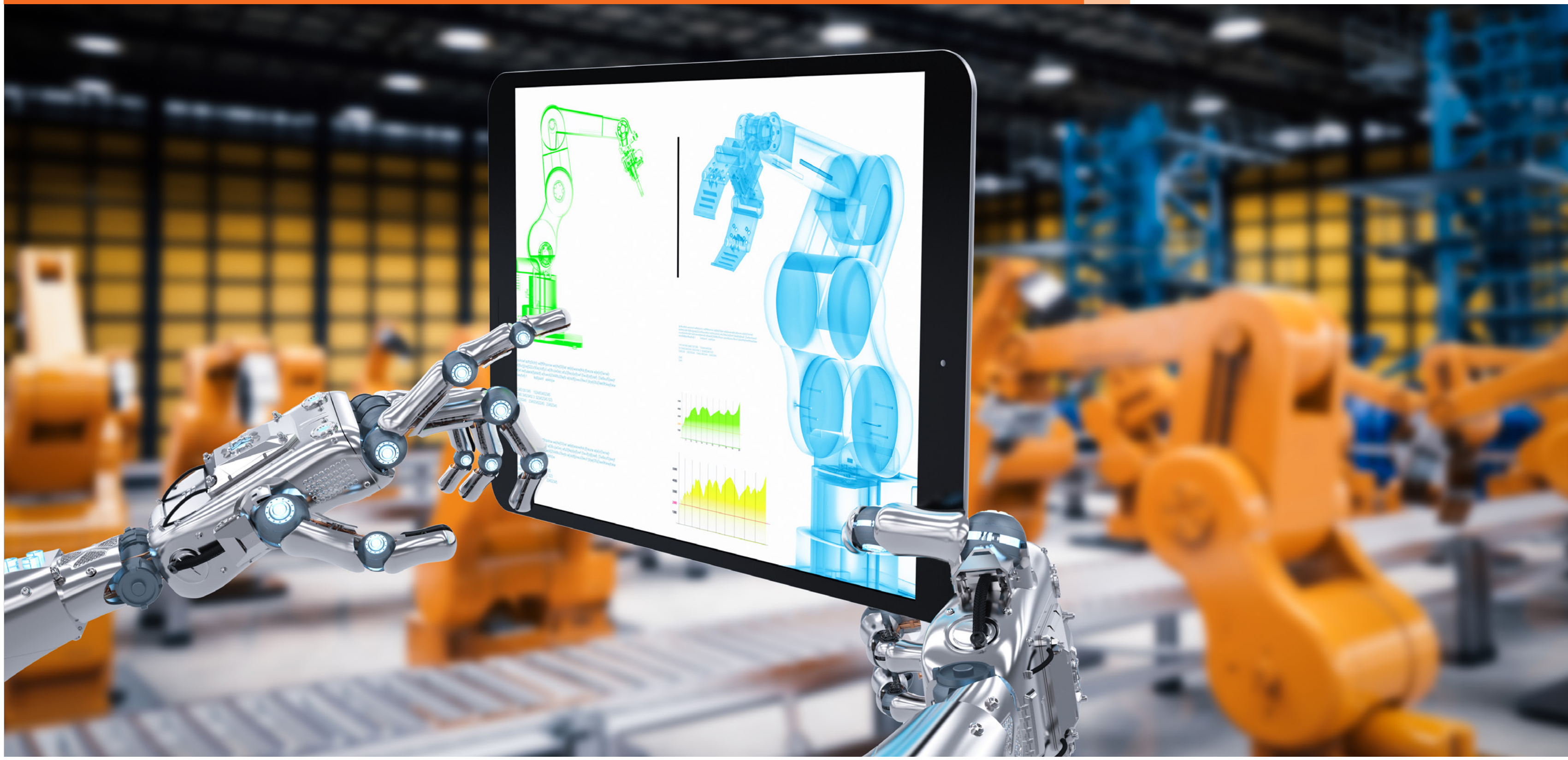
Robot-ready:
Adopting a new generation of industrial robots

June 2018



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Introduction

A new era—and new value—for industrial robots

It's time to retire stock footage of an industrial robot as a fixed machine repeating a few moves to complete a task in time with a production line. Today's industrial robots have literally stepped out of the frame. They're going places where industrial workers cannot go without great risk to safety and doing things with great dexterity such as soldering microchips. As robots take on more, and promise more—and as adoption costs continue to decline—a wealth of options for manufacturers are opening that did not exist even a few years ago.

Today's industrial robots have literally stepped out of the frame.

The climate surrounding adoption of robotics and automation is also shifting. US manufacturers are grappling with challenges that are likely to incent greater investment in technologies, including those technologies on the data frontier like artificial intelligence. These challenges include rising global competitiveness as trade policy uncertainties mount; and those at home, given a tightening labor market. For many manufacturers, these trends have effectively shifted the value equation of robotics automation.

We remain far from an age of the "lights-out factory," where robots toil alone 24/7 in autonomous factories. And, successfully integrating automation technology in manufacturing operations on a significant scale—while meeting the workforce needs to make that happen—will likely be much easier said than done. However, there should be no doubt that we are on the way to greater automation.

This report focuses on the automation of physical tasks as opposed to information-driven processes, or robotics process automation (RPA). We discuss capabilities and strategies companies need to harness to best optimize returns on investments in—and deployment of—robotics technology.

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Industrial robotics: today's imperatives

Apart from the perennial pursuit of increased productivity and cutting production costs, US manufacturers may well see, in the current climate, added incentives to invest in industrial robotics. We see three principal drivers accelerating robotics adoption.

US Tax reform incentivizes technology investment. The 2017 overhaul of the US tax code, lowering statutory corporate income tax rate from 35% to 21%, will likely free up cash for manufacturers that they can, in turn, deploy for automation technology investment. In addition, the tax reform allows full expensing of equipment expenditures, although this provision is set to phase down from 2023-2026 and phase-out completely by the end of 2026. This comes at a time when the average price for an industrial robot has dropped about 40% in the last decade and is forecast to drop by a further 65% to about $11,000 by 2025.[1] It is too early, however, to know how capital spending by manufacturers will be affected amid the new tax environment (and how much of that spending will be earmarked to robotics and automation technology). US orders of manufacturing equipment, though, have been rising steadily since mid-2017 and spiked by 27% in the first two months of 2018 (compared to the same period in 2017), according to the Association of Manufacturing Technology.[2]

As robotics technology matures and expands, so, too, should manufacturers' expectations of the value they can extract from that technology.

New values are being unlocked. As robotics technology matures and expands, so, too, should manufacturers' expectations of the value they can extract from that technology--values extending beyond merely reducing labor costs. Robotics are part of a wave of new technologies including 3D printing and the Industrial Internet of Things (IIoT), opening new paths of production, real-time machine performance monitoring and preventive maintenance. Working in concert with other technologies, robotics adds a new set of values—including producing higher-quality products with more innovative designs, shortening delivery cycles, introducing flexibility (just-in-time assembly) and customization (Lot Size 1 production).

Robotics also diminishes reliance on human labor at a time of a deepening talent shortfall and historically low unemployment. Four in 10 manufacturers, for instance, cited the shortage of skilled workers as their top challenge for 2018, a recent survey found.[3] And according to a recent PwC study, an estimated 45% of existing manufacturing jobs (and 53% of current transportation and storage jobs) globally could potentially be supplanted by automation by the mid-2030s. At the occupational level, at least 60% of existing machine operator and assembler jobs could be supplanted through automation technology over the period, the study found.[4]

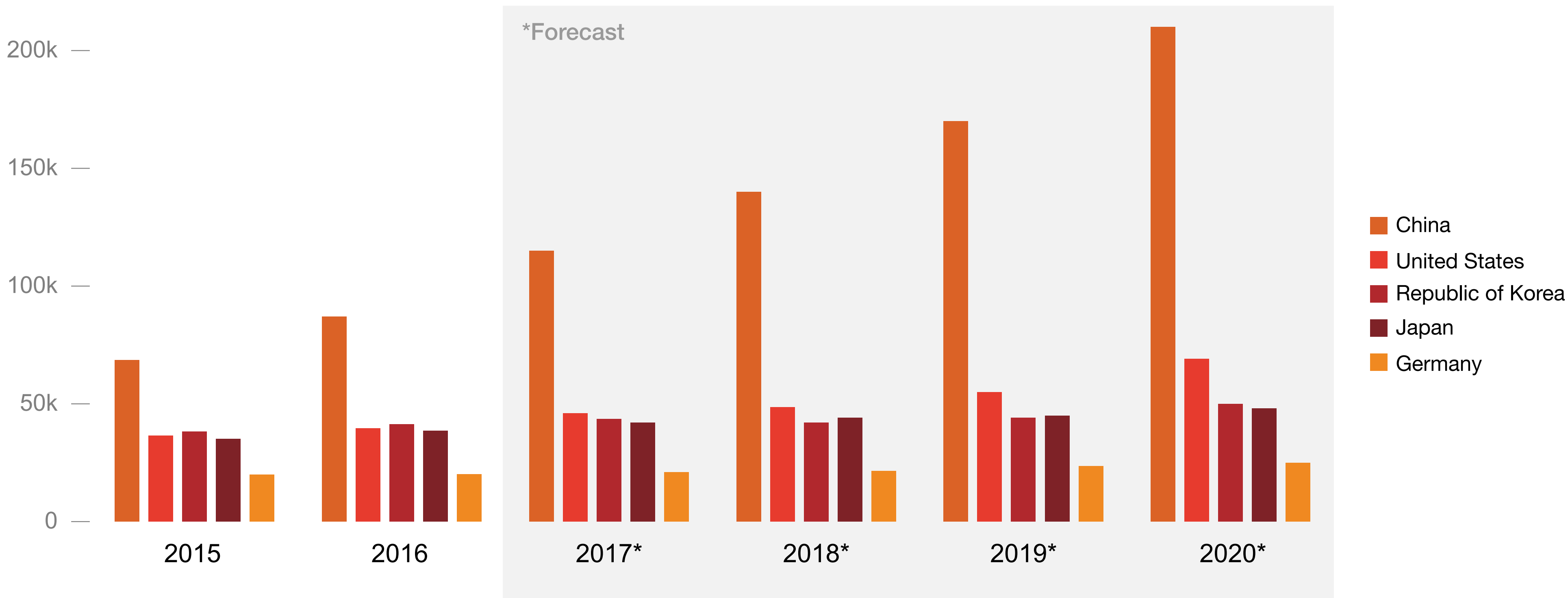
Automation offers a path to greater global competitiveness. Whether or not some US manufacturers see a need to develop a robotics strategy, it is likely their competitors are—both domestically and globally. The US ranks seventh in the world in "robot density," lagging far below Korea (see sidebar). China's 2017 shipments of industrial robots are estimated at 115,000, more than tripling those in the US, according to the International Federation of Robotics (IFR) (see following table). Despite this lag, the US has steadily increased its installed base of industrial robotics since 2010, driven, according to the IFR, by "the ongoing trend to automate production in order to strengthen American industries on the global market and to keep manufacturing at home, and in some cases, to bring back manufacturing that had previously been sent overseas."[5]

The global trend in automation is in the cross-hairs of US venture capitalists, too, who, in 2017, invested $937 million in US robotics technology start-ups, increasingly steadily since 2013, when it stood at $209 million (see following chart).

US ranked seventh in robot density

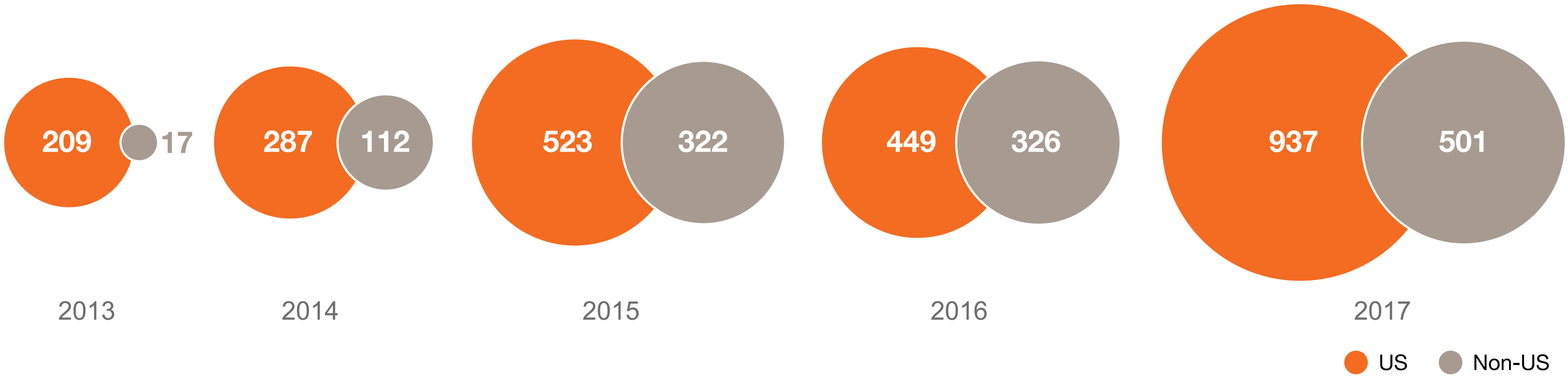
Industrial robots now working in the US number at least 230,000.[6] A record-setting 19,331 robots were sold in North America in the first half of 2017, up by one-third over the same period a year earlier.[7] The US is ranked seventh globally in "robot density," with 189 installed robots for every 10,000 employees in the manufacturing industry, compared to top-ranked Republic of Korea, with density of 631 units.[8] In the US, the auto industry is the largest adopter of industrial robots. Consider the Detroit area, which is, unsurprisingly, the nation's most robot-dense city with some 15,000 robots installed, working amid the city's 250,000 humans in the manufacturing sector.[9,10]

Estimated annual shipments of multipurpose industrial robots in selected 2015-2020 countries: *(Number of units)*



Source: Executive Summary World Robotics 2017 Industrial Robots", International Federation of Robotics, 2017.
*reported and estimated sales which could not be specified by territory

Venture Capital investment in US robotics tech start-ups more than quadruple since 2013 *(in $US million)*
Venture capital investment in US and non-US robotics start-ups: 2013-2017



Source: PwC analysis based on CB insights data

Strategies around robotics integration

Any new advanced manufacturing technology requires a well-informed and scalable strategy. Industrial automation can be a considerable investment. Based on PwC's experience in working with manufacturers integrating robotics automation, there are three main areas new adopters (and those expanding their current adoption) would do well to think through before committing to investments in time and capital:

1. Building a "no-surprises" business case

Identifying how robotics automation will yield the most value involves more than identifying tasks well-suited to automation. Indeed, a robotics automation solution that succeeds for one manufacturer may not translate well to another. It just may be that a mobile robot transporting materials may bring more value than a more expensive one doing assembly work on the line. Or, a collaborative robot might bring greater value than a robot which essentially replaces a worker (or even another machine).

Assess all costs (especially the hidden ones) to avoid surprises. First, it is critical to make a clear, fact-based assessment of total costs of automating compared to not automating. When assessing the value proposition, adopters need to consider the net value. This is the increase in benefits (such as cost savings from higher productivity yielded in both increased throughput and reduced waste in time and material), net the time and resources required to configure and maintain the robots and any idling of the robot due to breakdown, malfunction or dis-use. And, conversely, in some cases, deciding not to automate a task or process could, in the long run, create greater value versus adopting automation predicated on faulty or misinformed assumptions.

Some foundational questions which help yield a realistic and accurate ROI estimate include:

- What are all the realistic costs and feasibility of acquiring a certain robot (configuration, operation, maintenance, repair, new software, training workers)?
- Is the robot future-proofed (easily updated with software/hardware) or is it vulnerable to emerging disruptive technology?
- Will the robot pay for itself, and, if so, over what period?
- Are you assessing the right needs and estimating the right amount of value?
- Are there alternatives to robots or automation that can create value?

The art of assessing performance targets. Before selecting a technology for any use-case, it's important to set a target for a preferred outcome. Improving outcomes can cover a wide range, naturally, and could be as varied as streamlining palletizing, making assembly more efficient or transporting goods more swiftly (and safely).

Some companies err in estimating an accurate (or realistically attainable) technology performance target—either too low or too high. Often this happens as a result of fast-improving technology, effectively rendering the performance target…a moving target. For example, if a company aspires to a ten-percent increase in workflow on the assembly line through industrial robotics, is that outcome too ambitious, or not ambitious enough? Scalability of the technology is also important to assess, especially if, as is the experience of some companies, an unexpected spike in product demand outstrips the operational ability to meet it. Getting the math right around such scenarios at the outset is a foundational step.

Figuring in the potential of obsolescence, too, is important when setting performance targets based on technology—especially investments that are long term (at least five years out).Take autonomous mobile robots as an example. With vision and motion recognition systems and embedded artificial intelligence constantly advancing, choosing a model that is not scalable or easily updated could leave an adopter lagging in the technology curve much sooner than expected. Once a performance target is set, then the process of identifying the right technology to hit that target follows.

Generally speaking, then, any operational improvements—and competitive advantage—a company may gain through industrial automation may likely be short-lived as competitors follow suit and catch up—or even get ahead of the pack through novel robotics use cases.

Hedging your bets. Manufacturers can hedge their bets against getting technology performance targets wrong by leasing automation technology. Take for example, robots-as-a-service (R-a-a-S) or even drones-as-a-service (D-a-a-s), where third-party vendors not only offer short-term leases on the technology but also offer data collection and analysis to extract greater value from that technology. Leasing (while it may carry higher costs per unit) could, for some manufacturers, avoid the problem of technology obsolescence, and may also offer flexibility in piloting automation technology before making substantial commitments that may fall short of expectations or even efficacy.

Leasing could, for some manufacturers, avoid the problem of technology obsolescence, and may also offer flexibility.

And, in some cases, outsourcing automation to a third-party may make a stronger business case than attempting to automate a given task in-house, for example in the case of sub-assembly work. Or, final assembly could be transferred to the end-user, as in IKEA's model.

Streamline budget approval for swift adoption. Another complication some companies encounter in adopting robotics is that of slow budgetary approval. At a time when the technology is moving so swiftly up the maturity curve, taking six months to approve a capital expense may result in missed opportunities to exploit the most recent functional advancements available in the market. Therefore, while clearly it's key to have a sound automation strategy, it's perhaps just as important to create a streamlined budget approval process that doesn't hamper the quick adoption of technology that supports that strategy.

2. Know your automation know-how

There are numerous touted benefits of robotics—including speedy ROI rates, plug-and-play capabilities and ease of "training", to name a few. Yet, no matter how simple a new technology may be described, all adopters need to ask themselves the same question: How ready are you to incorporate the technology into your operations? To what extent does your operations have modern automated systems in place?

How ready are you to incorporate the technology into your operations?

Indeed, it is not unusual for new robotics adopters to encounter any number of set-backs along the road. Assessing the available in-house experience in automated systems is necessary in order to determine what might need to be outsourced.

A few areas of skill and demonstrated experience in managing automated systems—and robotics specifically—include:

- Configuring and programming for production jobs, especially for tasks needed for quick, infrequent runs
- Analyzing data collected from machines for insights such as condition-based maintenance, or rate and quality variability
- Managing the integration of robotics into workflow (at the right place and at the right pace of automation) and scheduling to prevent bottlenecks
- Monitoring, maintenance and repair of automation equipment and associated tooling

Without such fundamental automation knowledge and experience, new adopters will require a higher level of guidance, training and service from robot vendors or by a third-party automation integrator. Underestimating such out-sourced support is a common miscalculation of early robot adopters.

Now, companies need to be comfortable with rapidly maturing technology and be careful not to over-commit in spending and in time.

- How will people and robots work together in the first year?
- How could that change in subsequent years?
- How will the robots "grow" in their contributions, in the same way employees grow and extend their value?
- Could robots change assembly in a way that could accommodate new product designs, lower-cost products—and even altogether new product offerings?
- Can robots "teach" factory managers and operators (e.g., by providing data about their performance, the performance of the products they touch, or the environment in which they work)?
- Are you prepared to capture new values that extend a robot's capabilities (e.g., AI-based task prioritization by the robot).

3. Choosing the right robotics technology for the right job

The types of robots and the range of capabilities are ever-expanding, with more manufacturers looking to robot functionality far beyond just heavy-lifting or welding car bodies. Increasingly, robots are enlisted for complex, sophisticated tasks—soldering micro-chips, or other increasingly tiny and complex components difficult for humans to work on. Or, they're interacting should-to-shoulder with humans as a collaborative worker, or "co-bot".

As the very definition of robots expands, we will see new technology curves take shape—and new types of adopters.

Meanwhile, robots are increasingly fitted with greater sensory abilities—and artificial intelligence—via cameras, vision recognition, motion and thermal sensors and software driving an inexorable march toward greater flexibility, learnability, dexterity, precision and autonomy. And, as the very definition of robots expands, we will see new technology curves take shape—and new types of adopters.

Consider, for example, that the largest commercial purchaser of unmanned aerial vehicles (UAVs, or drones) over the next five years will be the construction sector, pegged at $11.2bn globally.[12]

Identifying what can be automated…and why. The growing lists of tasks assigned to robots are wide and varied, including: assembly, machining (especially those requiring high levels of precision and dexterity), materials handling/packaging, and materials transport—just to name a few. Taking an inventory of all processes that are repetitive, difficult (or even impossible) is an important first step in identifying prime candidates for automation. Human skills which are in short supply (or may be more difficult to secure in the future) are also prime candidates. Such an appraisal would especially include tasks critical to quality, (e.g., inspection of machines or products in unsafe or uncomfortable environments)

It's also important to consider which processes might be considered unattractive (i.e., manual labor) to a new generation of employees, who might well be more interested in managing automated technology than in toiling at physically onerous labor.

The following "at-a-glance" table highlights a selected list of industrial robotics technologies, their common use cases and domains of use, as well as first and secondary adopters, by industry.

A selective taxonomy of robotics technology: what they are, what they do, and where they work

Main categories	Common tasks	Typical domain	Established industry adopters	New and future industry adopters
Fixed and caged industrial robots *Designed to operate within physical barriers (includes Articulated arm, SCARA, Cylindrical and Cartesian)*	Assembly Welding Riveting Drilling Fastening Die casting Picking/packaging/sorting Painting/coating	Industrial manufacturing plants and factories	Industrial products manufacturing Retail and consumer Food and beverage Electronics Pharmaceutical	Oil and Gas, pipeline distribution Construction All industries adopting robotic additive (3D printing) manufacturing
Collaborative robots *Designed to work side-by-side with humans*		Industrial manufacturing plants/factories Warehouses Distribution centers Pipe networks Drilling operations Construction sites	Industrial products manufacturing Retail (warehouses) Medicine (assisted surgery) Semi-conductor Electronics Oil and gas industry Healthcare Law enforcement Agriculture Online retailers Retail and consumer	Service industries (e.g., hotels, hospitals, restaurants, retailers) Retail (product scanning and assembly) All industries adopting robotic additive (3D printing) manufacturing Construction
Collaborative stationary robots *Quickly programmable to augment/supplant manual tasks with humans at a stationary site*	Materials handling In-plant transportation Product and asset inspection Assembly Robotic 3D printing Picking/packing/sorting Point-of-sale assembly			
Collaborative Autonomous Mobile Robots (AMRs) *(designed to work closely with humans) and automated guided vehicles (AGVs)*	Materials handling In-plant transportation Automated palletizing Product/shelf scanning (in warehouse and retail environments) Brick-laying			

A selective taxonomy of robotics technology: what they are, what they do, and where they work

Main categories	Common tasks	Typical domain	Established industry adopters	New and future industry adopters
Unmanned Aerial Vehicles (UAVs) for surveillance *Low payload industrial aerial drones (under 15lb)*	Asset management Asset inspection (e.g., power plants, wind turbines) Product/part scanning capability Autonomous data mapping Contaminant detection Inventory tracking/management (RFID-reading) Aircraft inspection Construction site illustration	Locales of large-area environmental surveillance (mines, forests, oil rigs, pipe-lines, construction sites, farms, etc.) Warehouse/fulfillment centers Airports Energy assets (oil rigs, wind turbines, power plants)	Aerospace Construction (illustration of sites) Real estate Oil &Gas	Agriculture (e.g., crops surveillance) Power utilities (plant, transmission/ distribution network inspection) Mining Industrial products manufacturing
Unmanned Aerial Vehicles for transport *High payload capacity 15lb+ (Note: 55 lb-payload is highest permitted by FAA, as or August 2016, for commercial delivery applications)*	Retrieval and delivery of parts/packages	Private plants and premises All other airspace permitting UAV use	Military Construction Emergency medical supplies/ food delivery	All industries requiring delivery of low pay-load items Last-mile delivery of parts or end-user product In-plant/warehouse inventory management and materials handling Low payload tasks now carried out by airplanes/helicopters (e.g., spraying crops)
Robotic Exoskeletons *Wearable robotics systems designed to augment human physical performance*	Assists manual human labor (e.g., lifting, gripping, carrying)	Manufacturing assembly lines Warehouses	Industrial manufacturing (especially auto sector) Retail & Consumer (in warehousing operations)	All other industries requiring heavy manual labor, especially in the handling of materials)

Robotics and its role in the factory of the future

In an age of rapid digitalization, today's (and tomorrow's) automation technology will inevitably become integrated. Robotics are at the heart of a larger network of digitally-connected operations that are made possible through Industrial Internet of Things technology (IIoT). Consider an outsized example: GM has connected at least one quarter—or 30,000—of its robots to the Internet and collects performance data that yields information towards predictive maintenance, which has helped the automaker reduce breakdowns and assembly-line disruptions.[12]

Manufacturers are finding value not only in the instrumentation of machines on the shop floor, but also from data captured in other parts of the operations, including materials, parts, labor and workflow records. Such data, when aggregated with other data (customer, financial, environment, etc.) can serve as the basis for insights and actions.

New adopters need to think through their preparedness to systematically build robotics into the fabric of operations.

New adopters need to think through their preparedness to systematically build robotics into the fabric of operations. When information flows matter as much as task automation, these three particular considerations arise for manufacturers who are expanding automation capabilities or just beginning:

Speed and customization: Robotics, along with 3D printing, are also ushering in a new age of product customization. The march towards a "lot-size-1" capability requires manufacturers to carry out faster set-up times to meet the mandate of customization, and to apply these capabilities to continually shrinking product life cycles. Manufacturers are under pressure to be at once more highly automated (for production speed) and flexible (to accommodate customized and differentiated products). Increasingly, then, manufacturers on both regional and global levels recognize the importance of adopting flexible industrial robotics to stay competitive.

Adopt with an eye to the digital future: While first-adopters of robots—and those already deploying them—may focus squarely on automating discrete tasks needed today, keeping an eye on how scalable the technology will be in the future is just as, or even more, important. As robot technology advances, enabling easier and faster "training" of a wider variety of tasks, adopters will likewise see wider opportunities for their integration into workflows. And, as operations become "digitally tethered," new abilities and insights will likely emerge (especially when IoT-derived data and insights from robots are integrated into existing IT systems). The integration, ideally, will also come about through leveraging data derived from robots' performance, machine-to-machine communication and even self-learning. Such a real-time monitoring across operations opens new opportunities to improve workflows and better understand where, how and why automation works best.

As operations become "digitally tethered," new abilities and insights will likely emerge.

Integrating the robotics into an overall smart factory technology and functional ecosystem will become increasingly vital as pressures mount for plants to increase flexibility and meet quick-turn requirements. Presently, this typcially means assigning robots tasks in concert with other machines (and people). Looking ahead, however, manufacturers will increasingly benefit by arming its systems with greater artificial intelligence and machine-learning to create more connectedness and independent decision-making. This requires robots discerning historical “big data” to make algorithm-driven decisions (e.g., assigning themselves tasks). But, just as with humans, decisions are only as good as the information (and data) that supports them. As such, the more (and most relevant) data supplied to robotics systems—delivered through an integrated reference architecture—will yield better, and more sound decisions.

Planning around safety/workforce issues: Adopting robots can introduce a new layer of risk and liability considerations. For example, in the event of accidents connected to robotics systems (e.g., caused by malfunctioning hardware, software, communications or misuse by a human, or even natural disaster), it is important to ascertain which party is responsible and liable. Additionally, new adopters of robots need to be well-versed in relevant safety standards, particularly those offered by The US National Institute for Occupational Safety and Health (NIOSH) and Robotic Industries Association (RIA). Another workforce consideration is data privacy. Companies are under increasing scrutiny to protect personal data that may be captured by robotics systems (such as via cameras, microphone and sensors).

Businesses mulling integrating robotics technology also need to be mindful of relevant labor laws, which may apply in the event workers are replaced by robots. They also need to have the capacity, resources and capital needed for worker re-training (or talent hiring or outsourcing) to operate/repair their new robotic colleagues.

Cyber-proof for today…and tomorrow: Whether you are integrating robots in-house, with a vendor, or leasing the technology, it’s important to understand the inherent risks—both malicious and unintentional—that it carries. An idle robot of course could result in stalled or aborted production and other business disruptions. And, in the case of a fleet of robots on the same network that also share the same configuration, an attack on one robot could become an attack on all. All other IoT-connected technology (computers, smart phones, etc.) could also be compromised. The entries of attack are many and varied and, unfortunately, rise in number as the world becomes more and more digitally connected. Some vulnerabilities cyberattacks target include: remote control apps, operating systems, connection ports, installation of malware in firmware, hacked autonomous robots, microphones, and cameras, for example. There are a number of fronts on which companies (and robot makers) can cyberproof robots, yet the overarching lines of defense include constant software security from the outset (and updated through the life of the robot), encryption of communication and software updates, and verification that technology vendors up and down the supply-chain follow strict cybersecurity protocols.

The Takeaway

Indeed, manufacturing has never been strangers to adoption of automation technology—from Henry Ford's mass-production assembly lines to the deployment of industrial robotics more than four decades ago. More recently, industrial products manufacturers have also been early adopters of a wide range of advanced manufacturing technologies (from 3D printing to augmented reality) and, most notably of a fast-expending new generation of robotics.

A perfect storm arguing for adoption… Today, however, there exists a confluence of conditions making investment in robotics technology now particularly attractive and momentous. Robotics is opening a new era in not only quicker production runs, but also customized products—and even products that would be impossible to produce through traditional methods. The technology is also leaving the heavy lifting and other dangerous tasks to machines at a time when the industry is aging and finding it difficult to lure the next generation of makers. Additionally, US recent tax reforms could present some manufacturers with freed-up cash to invest in automation. And, in a larger and more forward-looking context, well-considered bets placed now could help manufacturers future-proof their production and processes.

Yet, buyer beware. Adoption of any technology, however, could seem much more easily said than done. As the robotics market matures, manufacturers can run the risk of making commitments to automation solutions that are not based on well-informed strategies, running the risk of choosing the wrong task for automation, the wrong robot for the wrong job or, worse, getting stuck in the valley of technological obsolescence. Adopters of robotics, then, need to be mindful of twin aims: 1. be agile and swift in acquiring automation solutions (because your competitors likely are) and 2. Be careful in deciding what needs to be automated what technology is best to carry out those selected automation tasks.

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