Human + machine: A new era of automation in manufacturing

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New technologies are opening a new era in automation for manufacturers—one in which humans and machines will increasingly work side by side.

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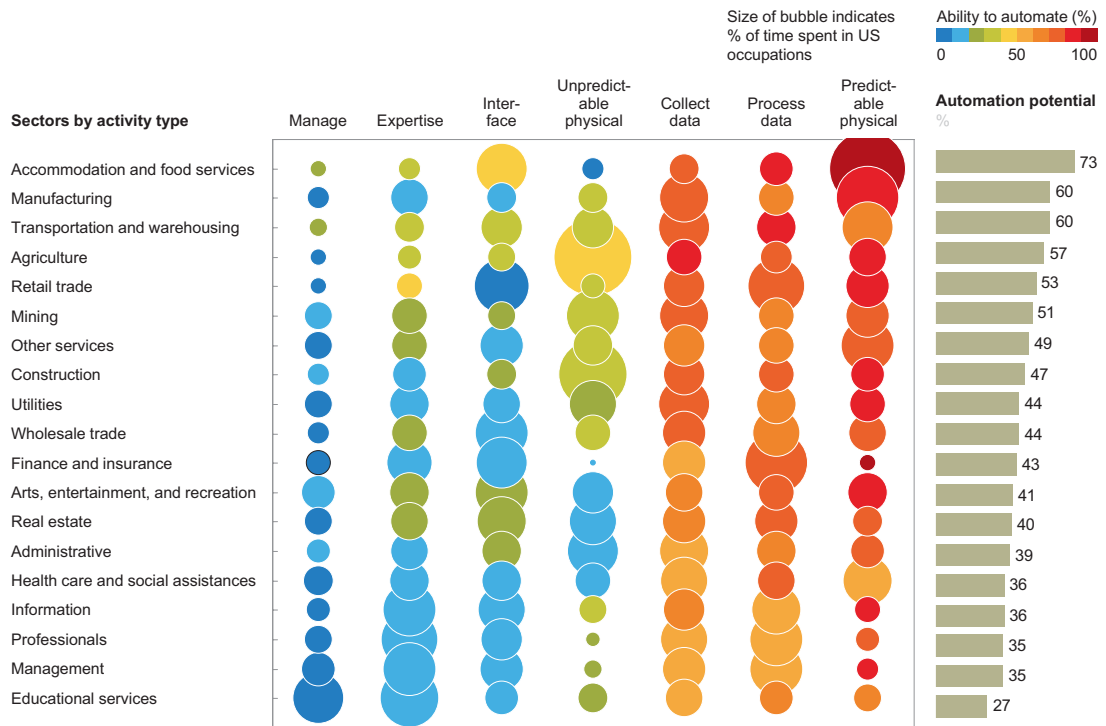
Over the past two decades, automation in manufacturing has been transforming factory floors, the nature of manufacturing employment, and the economics of many manufacturing sectors. Today, we are on the cusp of a new automation era: rapid advances in robotics, artificial intelligence, and machine learning are enabling machines to match or outperform humans in a range of work activities, including ones requiring cognitive capabilities. Industry executives—those whose companies have already embraced automation, those who are just getting started, and those who have not yet begun fully reckoning with the implications of this new automation age—need to consider the following three fundamental perspectives: what automation is *making possible* with current technology and is *likely to make possible* as the technology continues to evolve; what *factors besides technical feasibility* to consider when making

decisions about automation; and how to begin thinking about where—and how much—to automate in order to best *capture value from automation over the long term.*

How manufacturing work —and manufacturing workforces— could change

To understand the scope of possible automation in the manufacturing sector as a whole, we conducted a study of manufacturing work in 46 countries in both the developed and developing worlds, covering about 80 percent of the global workforce. Our data and analysis show that as of 2015, 478 billion of the 749 billion working hours (64 percent) spent on manufacturing-related activities globally were automatable with currently

Exhibit 1. Automation potential varies across sectors and specific work activities.

Size of bubble indicates % of time spent in US occupations

Ability to automate (%)

0   50   100

Sectors by activity type	Manage	Expertise	Inter-face	Unpredict-able physical	Collect data	Process data	Predict-able physical	Automation potential %
Accommodation and food services								73
Manufacturing								60
Transportation and warehousing								60
Agriculture								57
Retail trade								53
Mining								51
Other services								49
Construction								47
Utilities								44
Wholesale trade								44
Finance and insurance								43
Arts, entertainment, and recreation								41
Real estate								40
Administrative								39
Health care and social assistances								36
Information								36
Professionals								35
Management								35
Educational services								27

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

demonstrated technology.[1] These 478 billion working hours represent the labor equivalent of 236 million out of 372 million full-time employees—$2.7 trillion out of $5.1 trillion of labor—that could be eliminated or repurposed, assuming that demonstrated technologies are adapted for use in individual cases and then adopted. These figures suggest that, even though manufacturing is one of the most highly automated industries globally, there is still significant automation potential within the four walls of manufacturing sites, as well as in related functional areas such as supply chain and procurement. As McKinsey research has shown, manufacturing is second, among industry sectors, only to accommodation and food services in terms of automation potential (Exhibit 1).[2]

We emphasize that the potential for automation described above is created by adapting and integrating *currently demonstrated technologies*.[3] (See sidebar, "Understanding automation potential.") Moreover, it is notable that recent technological advances have overcome many of the traditional limitations of robotics and automation. A new generation of robots that are more flexible and versatile, and cost far less, than those used in many manufacturing environments today can be "trained" by frontline staff to perform tasks previously thought to be too difficult for machines—tasks such as picking and packing irregularly spaced objects, and resolving wiring conflicts in large-scale projects in, for example, the aerospace industry. Artificial intelligence is also making major strides that

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1   The baseline we used to determine which manufacturing activities are "automatable" is "current activities" as defined by the US Bureau of Labor Statistics. This includes activities that currently have some elements of automation (for example, sending email).

2   For more, see "Harnessing automation for a future that works," McKinsey Global Institute, January 2017, on McKinsey.com.

3   We define "currently demonstrated technologies" as those that have already exhibited the level of performance and reliability needed to automate one or more of 18 capabilities involved in carrying out work activities. In some cases, that level of performance has been demonstrated through commercially available products, in others through research projects.
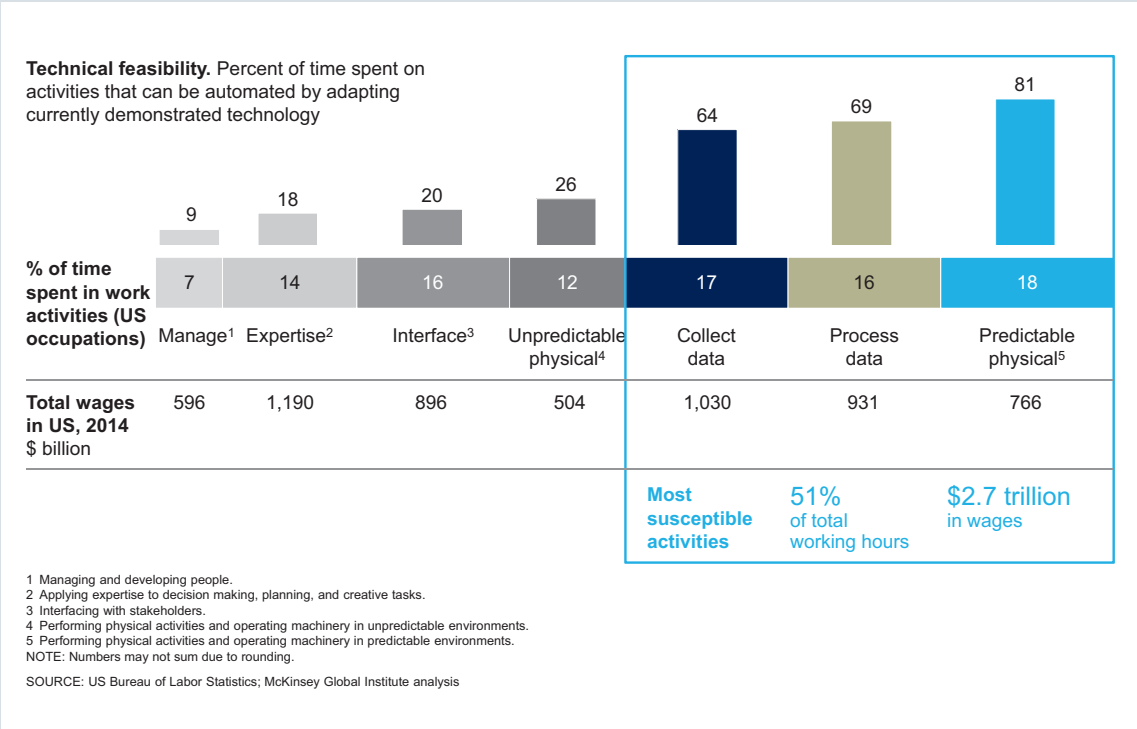
UNDERSTANDING AUTOMATION POTENTIAL

Analyzing work activities rather than occupations is the most accurate way to examine the technical feasibility of automation. Every occupation is made up of multiple types of activities, each with varying degrees of technical feasibility when it comes to automation. The figure below shows the susceptibility to automation of each of seven top-level groupings of activities as well as the time spent on each across all occupations in the United States. Just over half of all working hours in the United States are spent on activities that are the most susceptible to automation: performing physical activities and operating machinery in a predictable environment, and collecting or processing data (exhibit).

Occupations in manufacturing involve activities including, among others, collecting or processing data, applying expertise, and operating machinery (which we classify as physical work) in both predictable and unpredictable environments. Since these and other constituent activities each have a different automation potential, we have arrived at our estimates of automatability for the sector (64 percent of total working hours spent on manufacturing-related activities globally, 87 percent of hours spent on activities performed by workers in production occupations, and 45 percent of hours spent in nonproduction activities) by examining the time workers in manufacturing spend on each of them during the workweek.

Exhibit. Different work activities have different automation potential.

Technical feasibility. Percent of time spent on activities that can be automated by adapting currently demonstrated technology

	Manage[1]	Expertise[2]	Interface[3]	Unpredictable physical[4]	Collect data	Process data	Predictable physical[5]
(Technical feasibility %)	9	18	20	26	64	69	81
% of time spent in work activities (US occupations)	7	14	16	12	17	16	18
Total wages in US, 2014 $ billion	596	1,190	896	504	1,030	931	766

Most susceptible activities   **51%** of total working hours   **$2.7 trillion** in wages

1 Managing and developing people.
2 Applying expertise to decision making, planning, and creative tasks.
3 Interfacing with stakeholders.
4 Performing physical activities and operating machinery in unpredictable environments.
5 Performing physical activities and operating machinery in predictable environments.
NOTE: Numbers may not sum due to rounding.

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

are increasing the potential for automating work activities in many industries: in one recent test, for example, computers were able to read lips far more accurately than professionals.

Our study also looked at the automation potential for specific types of activities and jobs within the manufacturing sector. We found that 87 percent of the hours spent on activities performed by workers in production occupations are automatable—the most of any manufacturing occupation. Even among other occupations in manufacturing (for example, engineering, maintenance, materials movement, management, and administration), however, there is still significant opportunity, with approximately 45 percent of these working hours automatable as well.[4]

When comparing various subsectors within manufacturing, we see a wide variation of automation potential that can be explained partly by the nature of the activities themselves, and partly by differences in the skills levels required of workers and in the technological complexity of the manufactured product:

- **Low-skill labor/low product complexity.** Apparel/fashion/luxury (82 percent of hours worked are automatable), agriculture processing (80 percent), food (76 percent), beverages (69 percent). The predominance of repetitive, low-skilled activities in this group makes it highly susceptible to automation.

- **Medium-skill labor/moderate product complexity.** Furniture (70 percent), basic materials (72 percent), chemicals (69 percent), medical devices (60 percent), pharmaceuticals (68 percent), auto/assembly (64 percent), electric power and natural gas (53 percent), and oil and gas (49 percent).

- **High-skill labor/high product complexity.** Aerospace and defense (52 percent), advanced

electronics (50 percent), high tech (49 percent), and telecom (43 percent).

As for the monetary value of the automatable labor in various manufacturing subsectors, the differences can be up to threefold, depending on the mix of labor in a given subsector ($27,000 per year in apparel/fashion/luxury, compared with $75,000 per year in oil and gas). Comparing the groupings listed above, on average we see a 1.6-fold increase in wages per hour automatable increase going from low- to high skill/complexity, and a 1.4-fold increase going from low- to-medium skill/complexity.

Finally, we find that even though technical automation potential does not vary greatly across the global economy, the fact that 81 percent of the world's automatable manufacturing hours and 49 percent of automatable labor value reside in developing countries means that an upswing in automation in the developing world could have significant global impact. Considering that 68 percent of the automatable manufacturing hours in the developing world (and 62 percent of automatable labor value) are in China and India alone, we see potential for major automation-driven disruption in India and China, although how long that could take will depend, in part, on the speed with which the costs of automation solutions fall to below wage levels in these countries. A radical shift toward automation in India and China could have major employment implications in both countries and would also inject a substantial boost to economic growth there.

What to automate: Factors to consider

Technical feasibility is, of course, a necessary precondition for automating a given work activity or set of activities. Yet it is far from the only factor companies need to take into account when

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4   While management and engineering activities account for only about 2 percent of automatable working hours in manufacturing, because managers and engineers are the highest-paid workers in manufacturing, the automatable activities they perform represent about 11 percent of automatable labor dollars—behind only production and materials-movement occupations. Substantially automating these activities will likely require further technological advances, especially in natural-language understanding and generation—advances that seem entirely plausible even if they are not imminent.

deciding what and how to automate. A second factor to consider is the cost of developing and deploying both the hardware and the software for automation. The cost of labor and related supply-and-demand dynamics represent a third factor: if workers are in abundant supply and significantly less expensive than automation, this could be a decisive argument against it—or for automating only to a limited degree. For example, an automotive supplier in India has found that after introducing low-cost automation of a few steps on its production line—which reduced staffing levels from 17 to 8—its costs are now equivalent to those for a Japanese company running the same kind of

ADAPTING AND ENHANCING HUMAN CAPITAL

It is important to point out that the implications of automation for a company's workforce are not just about replacing human workers with machines. According to our analysis, fewer than five percent of occupations can be entirely automated by adapting currently demonstrated technology. However, about 60 percent of them could have 30 percent or more of their constituent activities automated. In other words, just by adapting and integrating current technology, automation could change—at least to some degree—the majority of occupations. This will necessitate significant job redefinition and a transformation of business processes and workplace cultures.

Indeed, the most vital component in successfully deploying automation over both the long and short terms may be the hard work of preparing and adapting human capital to work in tandem with technology. Almost every job will eventually change, and every workflow will eventually be transformed. Many workers will have to be continually retrained to work alongside machines as their jobs continue to evolve. This will require changes not only in skills but in mind-sets and culture as "coworkers" come to include not only other people but also machines.

As roles and processes get redefined in these ways, the economic benefits of automation will also include freeing up and repurposing scarce skilled resources. Particularly in the highest-paid occupations, machines can augment human capabilities to a high degree and amplify the value of expertise by freeing employees to focus on work of higher value. In aircraft maintenance, for example— where drones and insect-size robots could someday perform inspections, robots could deliver parts and tools, and automated tugs could move planes in and out of hangars—fewer technicians would be needed on the maintenance hangar floor, but those who remained would spend more time problem solving for nonroutine issues. These workers will, however, need continual retraining to keep up with developing technology.
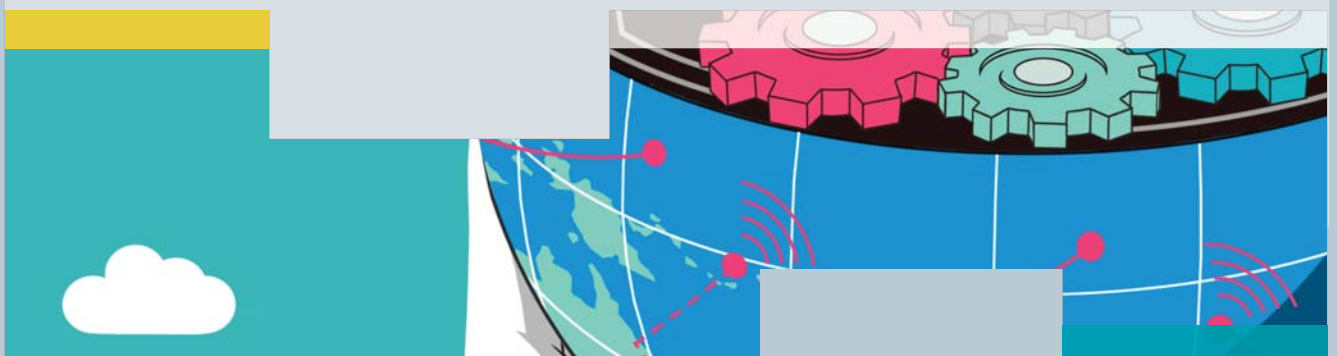
production line with a higher degree of automation and a staffing level of only two.

A fourth factor to consider is the benefits beyond labor substitution, including higher levels of output, better quality, and fewer errors (see sidebar, "Adapting and enhancing human capital"). While it is tempting for a manufacturer to view automation primarily as a labor-savings lever, these other benefits are often larger than those of reducing labor costs. Automation options should be considered and evaluated using a clear strategy focused on reducing the total cost of operations. We find that companies typically use automation to address a number of opportunities, including increasing throughput and productivity, eliminating variation and improving quality, improving agility and ensuring flexibility, and improving safety and ergonomics.

In addition to technical feasibility, cost of hardware and software, labor supply and demand, and benefits beyond labor substitution, a fifth factor to be taken into account in deciding whether and where to automate is regulatory and social-acceptance issues, such as the degree to which machines are acceptable in any particular setting, especially where they will interact with humans. The potential for automation to take hold in a given sector or occupation reflects a subtle interplay among all five of the factors we have listed and the trade-offs among them.
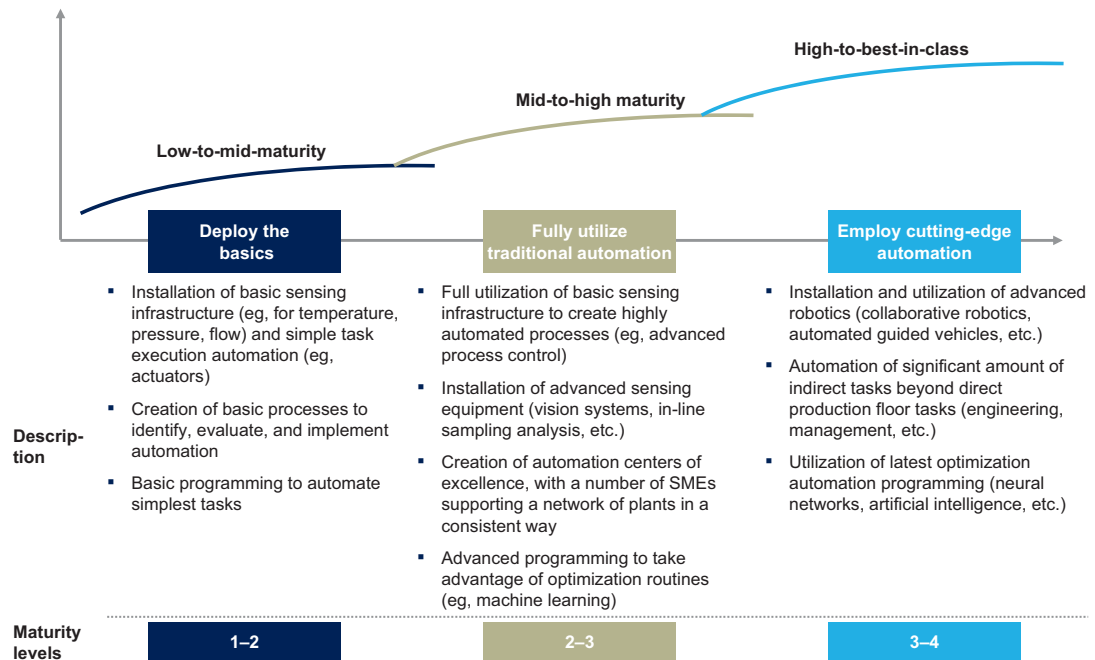
Capturing long-term value from automation

The ultimate goal for manufacturers as they weigh the various factors described above is to capture as much long-term value as possible from automation. How to go about achieving this depends, in part, on how far along the spectrum of automation maturity a given manufacturer is. We see this spectrum as having four stages:

- **Low maturity.** There is limited infrastructure for employing automation—for example, lack of robotics, sensors, and data-collection systems.

- **Mid-maturity.** There is significant automation infrastructure in place but it uses only a fraction of the potential—for example, many sensors are installed but the majority of data are not utilized; numerous data-capture systems lack interconnectedness; programming optimizes local processes but not global value streams.

- **High maturity.** There is full utilization of traditional automation infrastructure on the manufacturing floor, but not employment of cutting-edge automation technology and realization of potential of automating managerial, support-function, and back-office tasks.

Evaluating a manufacturer's operations along the spectrum of automation maturity can help determine what kind of approach will best help to capture full long-term impact.

Exhibit 2. Manufacturing companies and sites can capture more value at each stage of automation maturity.

	Deploy the basics	Fully utilize traditional automation	Employ cutting-edge automation
	Low-to-mid-maturity	*Mid-to-high maturity*	*High-to-best-in-class*
Description	▪ Installation of basic sensing infrastructure (eg, for temperature, pressure, flow) and simple task execution automation (eg, actuators) ▪ Creation of basic processes to identify, evaluate, and implement automation ▪ Basic programming to automate simplest tasks	▪ Full utilization of basic sensing infrastructure to create highly automated processes (eg, advanced process control) ▪ Installation of advanced sensing equipment (vision systems, in-line sampling analysis, etc.) ▪ Creation of automation centers of excellence, with a number of SMEs supporting a network of plants in a consistent way ▪ Advanced programming to take advantage of optimization routines (eg, machine learning)	▪ Installation and utilization of advanced robotics (collaborative robotics, automated guided vehicles, etc.) ▪ Automation of significant amount of indirect tasks beyond direct production floor tasks (engineering, management, etc.) ▪ Utilization of latest optimization automation programming (neural networks, artificial intelligence, etc.)
Maturity levels	1–2	2–3	3–4

SOURCE: McKinsey analysis

▪ **Best-in-class.** Full potential of automation is captured with latest technology across all spectrums of the operation.

Evaluating a manufacturer's operations along this spectrum of automation maturity can help determine what kind of approach will best help to capture full long-term impact. For example, lower-maturity operations will benefit more from "clean sheeting," while more mature operations can focus on fully utilizing their already robust automation infrastructure to get to best-in-class. Exhibit 2 describes in more detail the steps manufacturers can take to move along the spectrum.

Wherever a given company is on the maturity spectrum, it is essential to keep the focus on value creation. To help diagnose where automation could most profitably be applied to improve performance, business leaders may want to conduct a thorough inventory of their organization's activities and create a heat map of where automation potential is high. Business processes shown to have activities with high automation potential can then be reimagined under scenarios where they take full advantage of automation technologies (rather than mechanically attempting to automate individual activities using current processes). Finally, the feasibility and benefits of these automation-enabled process transformations can be used to prioritize which processes to transform using automation technologies. Such an approach can help ensure that automation investments deliver maximum impact for the enterprise.