Exponential manufacturing

A collection of perspectives exploring the frontiers of manufacturing and technology
EXPONENTIAL MANUFACTURING: A COLLECTION OF PERSPECTIVES
EXPLORING THE FRONTIERS OF MANUFACTURING AND TECHNOLOGY

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Foreword

Thank you for attending the 2017 Exponential Manufacturing Summit, an ongoing collaboration with Singularity University and Deloitte that brings together the world’s brightest executives, entrepreneurs, and investors for three intensive days.

Our hope is that, by attending, you’ll learn from and interact with business leaders seeking answers for how they can own their disruption, while working to find insight to a number of complex questions.

Manufacturing as we know it is changing. Today, many manufacturers find themselves on the cusp of a fundamental transformation driven by the continued convergence of the digital and physical worlds. The pace of this convergence continues to accelerate—exponentially—and is ushering in the next industrial revolution. Many refer to it as Industry 4.0.

As a result, manufacturers are increasingly facing disruption and opportunities that are impacting both their core and emerging businesses. Business leaders are also increasingly seeking answers for how they can own their disruption, and are working to find insight to a number of complex questions.

Singularity University and Deloitte have been at the forefront of exploring the convergence, disruption, and opportunity facing manufacturers. Through events like the Exponential Manufacturing Summit and programs like the Innovation Partnership Program, our organizations are working with manufacturers, technology companies, and other organizations to examine how manufacturers can best capitalize on the convergence of machines, technology, and data.

The business of making things continues to transform and evolve. In the following pages, we provide insight and highlight perspectives across a number of topics impacting manufacturers, including:

- Cyber risks impacting manufacturers
- Advanced technologies creating competitive advantages
- Human cognition and machine mimicking
- Science and technology innovations on the horizon, including robotic process automation and block chain
- Americans’ views and perceptions of careers in manufacturing and the impact on finding skilled talent

Singularity University and Deloitte are excited to unite the manufacturing leaders at the forefront of the next industrial revolution at the 2017 Exponential Manufacturing Summit, and present the insights provided in these articles to further inform and augment the conversations and perspectives shared throughout the conference.

Sincerely,

Rob Nail
CEO and associate founder
Singularity University

Andrew Vaz
Global Chief Innovation Officer
Deloitte Touche Tohmatsu Limited
Exponentials watch list
Science and technology innovations on the horizon
FROM TECH TRENDS 2017: THE KINETIC ENTERPRISE
UNLIKE other trends examined in this report that demonstrate clear business impact in the next 18 to 24 months, the exponentials we are discussing appear a bit smaller on the horizon. These are emerging technology forces that will likely manifest in a horizon 3 to 5 timeframe—between 24 and 60 months. But when they manifest, the speed with which they impact markets will likely grow exponentially.

For businesses, exponentials represent unprecedented opportunities as well as existential threats. As such, an analysis of exponential forces is a time-honored part of our annual discussion of emerging technologies. In our Tech Trends 2014 report, for example, we collaborated with faculty at Singularity University, a leading research institution, to explore artificial intelligence, robotics, cybersecurity, and additive manufacturing. At that time, these emerging technologies were outpacing Moore’s law—that is, their performance relative to cost (and size) was more than doubling every 12 to 18 months. Just a few years later, we see these same technologies are disrupting industries, business models, and strategies.

In each force, we seek to identify precursor uses or breadcrumbs of adoption for early application to business uses. Some if not all of these exponentials may disrupt industries in 24 months or more, but there can be competitive opportunities for early adoption. At a minimum, executives can begin contemplating how their organizations can embrace exponentials to drive innovation.

Don’t let yourself be lulled into inaction. The time to prepare is now.

Focus: Nano-engineered materials

The word nano is often used to describe something unusually small. For example, Tata Motors developed a compact automobile primarily for the Indian market it calls the Nano. But beyond its diminutive descriptive usage in product marketing, nano has a much more precise definition. Using one meter as a measuring stick, a nanometer is defined as one billionth of a meter (that’s 1/1,000,000,000). If this is hard to imagine, try using a single carbon atom as a measuring stick. A single nanometer is about the size of three carbon atoms placed side by side. In comparison, a single human hair is 80,000 to 100,000 nanometers wide.

Nano-manufacturing—the process of making things at nano-scale—represents an important emerging capability. To create things smaller than 10 nanometers, we typically turn to advanced chemis-
Tech Trends 2017
The kinetic enterprise

ROB NAIL, CEO AND ASSOCIATE FOUNDER
SINGULARITY UNIVERSITY

We live in tumultuous times. As we have seen during the past year, political landscapes are shifting beneath our feet. News, signals, and random information come at us in torrents. At the same time, exponential technologies such as synthetic biology, advanced energy storage, nanotechnology, and quantum computing, among others, are poised to disrupt every part of our lives, every business model and market, every society. Eventually, they may even redefine what it means to be human.

What are we to make of all this? Change is happening all around us at a pace that will only accelerate. Particularly in the realm of exponentials, when you see seemingly radical innovations emerging, we often experience it emotionally. We feel anxious about change. Our first reaction is often to cling to something that feels stable—the past.

At Singularity University, we are trying to understand where all this change is heading. Contrary to what some may see, we see a future that is hopeful and full of historic possibility. By leveraging exponentials, we could have a future in which cancer no longer afflicts our families. Everyone—even the most pessimistic—can agree that this is a desirable goal. This is the lens through which we should all view exponentials. By harnessing the power of quantum optimization, nano-engineered materials, or synthetic biology to eliminate scarcity and uplift humans, we can tackle problems that have traditionally seemed so daunting that we’ve never imagined a world without them. Exponentials are an opportunity driver, not something to fear.

As use cases for exponentials emerge and technologies mature over the next three to five years, it will not be enough for the technology, science, academia, and business sectors to focus solely on their own goals. Collectively, we must also help build understanding throughout society of what these technologies are and where they can take us.

The future is already here. The world around is changing every day, and will continue to do so. Unless we equip ourselves with a new vision of the future and tools to navigate it, we will wake up every morning and be surprised. At Singularity University, we believe a better path is to come together to build an awareness of where we are going and, with some rigor, talk about how exponentials can help us all build a future of abundance.

MY TAKE

“EXPONENTIAL TECHNOLOGIES MAY EVEN REDEFINE WHAT IT MEANS TO BE HUMAN.”

ROB NAIL, CEO AND ASSOCIATE FOUNDER
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try; to some degree, one can attribute the pharmaceutical industry’s achievements to its ability to create precise molecules at these length scales. More traditional manufacturing technologies, such as machining, can get down to features that are close to the size of a human hair, but that leaves a thousand-fold gap in length scales from making molecules to machining. Nano-manufacturing is a set of technologies and techniques that enables making things at this range of size.4

The drive to develop nano-manufacturing capabilities comes from a variety of different challenges and opportunities that emerge at this scale. Perhaps the most visible driver has been the demand for cheaper and higher-performing computers. Moore’s law, the periodic doubling of transistor density—the number of transistors that can fit on a chip—is a direct result of the development of machines that can create ever-finer patterns of semiconductors. In 2014, Intel shipped chips with 14-nanometer resolution. The smallest features on these chips were spanned by fewer than 50 silicon atoms.5

Medicine also drives demand for nano-manufacturing. Life emerges at nano-scale through a complex set of molecular “machines” that copy DNA and synthesize proteins; the molecules that carry out these processes are 10–100 nanometers in size. Nano-manufacturing could be used to make objects that either mimic this process—for example, to manufacture proteins that can then be used as drugs—or inhibit it directly to treat disease.6

A third area driving the development of nano-manufacturing is the role of nanostructures on surfaces, in the form of coatings, lubricants, and adhesives. Nanostructures can prevent water from wetting a surface, making water-resistant fabrics and mirrors and windows that don’t fog. In a similar way, nanostructured surfaces can prevent the formation of ice—for example, on the wings of an airplane, making it much safer to fly and eliminating the need for the repeated application of liquid de-icing agents.7 An important business application today addresses wear and friction. These physical factors, as well as adhesion, are a product of the interaction between surfaces at the nano-scale.

Reality check

So what are some current examples of nano-engineered products that are likely to impact businesses today or in the near future?

In addition to integrated circuits, examples of products made through nano-manufacturing include nanoparticles of silver that kill bacteria and are integrated into clothing and medical devices to prevent infection; nanoparticles of titanium that block UV light and when integrated into a lotion or spray and applied to the skin prevent sunburn; and nanoparticles of pigment that make brighter paints and coatings that prevent corrosion.8
Manufacturing asperities—imperfections remaining on surfaces after modern milling and machining techniques—are commonly at micron scale, but lubricant molecules are still larger than that. By changing the surface features at nano-scale, or by introducing nanostructured materials between surfaces, friction can be reduced to provide super-lubrication or can be enhanced to provide super-adhesion.9

NanoMech makes a nanostructured lubricant designed to mitigate these effects for critical mechanical components such as gears, bearings, valves, and chassis points. It is designed to address issues like performance under extreme pressure, anti-wear, anti-friction, corrosion protection, and extreme temperature stability in order to enable extension of service life and reduce maintenance cost of mechanical systems. Beyond the fact that the lubricant or coating is engineered and manufactured for specific business use cases, rather than inventing wholly new ways to make nanostructured materials, the company uses off-the-shelf manufacturing technology and includes both top-down fabrication and bottom-up assembly in its process.

However science-fiction-like nanotechnology’s capabilities might sound, applications are becoming evident today. For example, NanoMech’s AtomOil and AtomLube are self-replenishing, which means as friction rubs the nano-manufactured lubricant molecules apart, additional molecules are drawn into the interface. Applications may include equipment for oil and gas production; engines and other machines used in the marine, agriculture, and mining sectors; and macro-manufacturing techniques, including die casting and machining.10
Focus: Energy storage

As the world addresses its reliance on carbon-based energy, the sun is shining brightly and the wind is blowing at our backs. In 2014, wind and solar sources accounted for roughly 1 percent of energy consumed globally—only a tiny part of overall consumption but one that is growing rapidly. Wind capacity has doubled every four years and solar every two for the past 15 years. And with generation costs continuing to fall, this exponential trend is expected to continue, with these renewable sources projected to provide two-thirds of new generation capacity additions over the next 25 years.

However, the achievements of renewable energy sources also herald a challenge that ultimately may limit their further adoption. Unlike many traditional modes of electricity generation, wind and solar are at the mercy of nature’s vagaries—without wind or sunshine, no power is produced. There are ways to alleviate this challenge. For example, because wind production is typically greater at night than in the daylight hours, there may be opportunities to deploy wind and solar capabilities synergistically. Yet even if we embrace this approach, a fundamental challenge persists: aligning energy production with energy consumption. The challenge of storing energy on a massive scale until it is needed by consumers is hardly new. One solution, pumped hydroelectric storage, has applications dating back to the 19th century. In a pumped hydro storage facility, water is pumped uphill when electricity is abundant (and cheap) and then released to flow downhill to power generation turbines when electricity is scarce (and valuable). By some measures, the pumped hydro approach is wildly effective: This technology represents an estimated 99 percent of bulk energy storage capacity worldwide.

But while pumped storage is a useful and relatively efficient storage mechanism, it is constrained by access to water and reservoirs as well as by topography. Therefore, the dominance of pumped hydro speaks less to its advantages than to the historic absence of credible alternatives targeted toward centralized large-scale storage on the electric grid. And this is a real problem: With the massive expansion of power sources such as wind and solar, and the increasing decentralization of energy production, we will need more energy storage capacity overall as well as the ability to deploy it flexibly in different geographies, unit sizes, and industrial and consumer applications.

Reality check

The good news: The last decade has seen an explosion of new and improving storage technologies emerge, including more efficient batteries, compressed air, and molten salt. Utilities are deploying these approaches at or near sources of generation. The following examples highlight some notable developments:

• Favored with sunshine but facing high costs to import fuel, the Hawaiian island of Kauai is a leading consumer of renewable energy. On sunny days, solar contributes 70 percent of energy generation, which decreases with the arrival of cloud cover. What’s more, peak energy demand is in the evening. To close the gap, the Kauai Island Utility Cooperative is working with power systems provider SolarCity to build a new solar farm and storage facility, with energy stored in lithium ion batteries supplied by automaker and energy storage company Tesla. The plant will generate capacity during the day, store the entire amount of energy generated, and then release it during the high-demand evening hours.

• In Lake Ontario, Canadian start-up Hydrostor has launched a pilot program using compressed air. In this approach, air is compressed and pumped into a series of underwater balloons. When energy is required, the air is released, expanded, and used to create electricity.

• In commercial operation since 2015, Solar-Reserve’s 110 megawatt-hours Crescent Dunes Solar Energy Project in the Nevada desert has deployed a solar thermal system in which a large field of mirrors concentrates the sun’s rays to heat molten salt. The hot salt is then stored at a temperature of over 1,000 degrees Fahrenheit in a 140-foot-diameter insulated storage tank until needed. At that point, the hot salt is used to create steam to power turbines, just like a
conventional fossil or nuclear plant. Using this method, each day the Crescent Dunes facility can store up to 1,100 MWh of energy generated by concentrating solar array within salt.18

Perhaps more significantly, energy storage technologies may soon offer more options for the end consumer, allowing consumers to store power at or near the point of consumption. The following examples highlight some notable developments:

- In Japan, the government has set a goal for all newly constructed public buildings to be able to generate all their energy needs by 2020, with the same zero-energy standard for private residences by 2030, providing a strong incentive for development of residential-scale storage.19

- In the United States, several utilities are offering energy storage products to customers, and with the growth in solar panel installations, energy storage innovators such as Tesla, Orison, and SimpliPhi Power are marketing their battery technologies directly to end consumers. While the cornerstone of disruption may be exponential improvements in both energy generation and storage, the keystone may well be a coming business-model revolution, as new models supplement the traditional model of centralized power generation and one-way distribution to multiple distributed points of consumption. With such a broad and growing set of emerging energy storage technologies—each with different performance and economic characteristics—business and retail consumer adoption patterns will likely remain difficult to predict for the foreseeable future. But regardless of which technologies emerge as leaders, both consumers and producers of energy will be presented with more choice and more complexity, transforming the traditional supply, demand, and economic relationships between many parties.

If your business consumes large amounts of energy, what is your innovation response to this disruption force?
Focus: Synthetic biology

The Convention on Biological Diversity defines biotechnology broadly as any technological application that uses biological systems, living organisms, or derivatives thereof to make or modify products or processes for specific use. This definition makes clear that biotech’s potential disruptive impact is not limited to big players in health care and agriculture. Indeed, as it ramps up in exponential impact, biotech has relevance for industrial products, energy and natural resources, high tech, and other industries.

This year we are focusing on one area of biotech—synthetic biology—and an imminent precursor technology for gene editing and repair. Asif Dhar, principal and chief medical informatics officer at Deloitte Consulting LLP, succinctly describes synthetic biology as “bio-engineering a thing that then creates a substance.” An example might be engineering algae to produce alcohols for fuels, polymers, or building materials such as paints and coatings. Much of the progress in synthetic biology is not about editing basic cell behavior but about adding code to the cell to make it respond differently to signals in a manner that cell will accept. This is a targeted redirection of a cell’s intent, which requires a deep understanding of the specific cell to do with confidence.

The implications reach beyond the science and into business models across industries. Genetic diseases are relatively rare but usually severe—lifelong care or long-term therapeutics can be required. Chronic care today often seeks to push physiology back into place with ongoing pharmaceutical regimens. Synthetic biology could conceivably offer one-time therapy with no need to revisit treatment. In such a case, what is the best approach to payment and reimbursement when a lifetime of benefit comes from one treatment?

Understandably, there is controversy surrounding medical applications of biotechnology. Is environmental engineering possible? Will some part of society determine that germ-line or in utero engineering is acceptable? Will people start clamoring for other changes in their genome? Will ethics vary by country or culture? Those are big questions.

Regardless, the prospect of permanently correcting inherited genetic disorders such as cystic fibrosis, sickle cell anemia, and certain cancers can incite optimism for those suffering from the conditions and, potentially, fear for those imagining manipulation of the human genome in malicious ways. Regulatory and ethical debates have been just as vibrant as the scientific research, and these issues are far from settled. Nevertheless, understanding the medical, industrial, and synthetic biology applications of this disruption force is an important step toward sensing important business considerations that may shape our future.

Reality check

Currently, there is a flurry of synthetic biology inventions, patents, and IPOs, with one area in particular crackling with activity: gene editing with CRISPR.

CRISPR—clustered regularly interspaced short palindromic repeats—is a genomic editing technology. Rather than focusing on creating new capabilities or behaviors, the CRISPR enzyme acts as molecular scissors, cutting the DNA at the specified point to allow editing and correction of genetic code to work as originally intended. Tom Barnes, chief scientific officer of Intellia Therapeutics Inc., refers to the process of genome editing as “correcting typos in the Book of Life.” Biologists have had the tools to edit the genome, but CRISPR represents a more efficient, accurate, and malleable technique than the other tools at their disposal.

To understand this process more clearly, imagine a factory that produces a single component for a large, complex machine. This component is but one of the machine’s numerous parts, but it is critical nonetheless. Yet, due to a small error in the manufacturing software, this component tends to fail soon after the machine begins operation. Luckily, the company identifies the error and patches the software, and the component becomes a reliable part of the greater machine.
A human cell is like a tiny manufacturing facility, with DNA acting as software instructions for cellular function. The human cell possesses several checks and balances to ensure its genomic integrity, and while it is efficient in its task, errors do sometimes happen. In some cases, environmental damage or genetic inheritance causes errors in these instructions. Before CRISPR, there was

**Figure 1. How does CRISPR/Cas9 work?**

The CRISPR/Cas9 system is derived from the bacterial immune system, a process used to defend against viruses. The CRISPR regions are composed of short DNA repeats and spacers, as well as upstream regions that encode for the machinery required to edit the genome (Cas proteins). The bacterial CRISPR immune system effectively edits the genome using the following basic steps:

1. **Adaptation**
   DNA from a previously unseen invading virus is processed into short segments that are inserted into the CRISPR sequence as new spacers.

2. **Production of CRISPR RNA**
   CRISPR repeats and spacer DNA undergo transcription, the process of copying DNA into RNA. The resulting RNA is a single-chain molecule that is cut into short pieces called CRISPR RNAs. A Cas9 enzyme and second piece of RNA latch on, forming a structure that will unwind and bind to DNA that matches the spacer’s sequence.

3. **Targeting**
   Because CRISPR RNA sequences are copied from the viral DNA, they are exact matches to the viral genome and thus serve as excellent guides. When a matching strand of DNA is found, the enzyme opens the double helix and cuts both sides, disabling the viral DNA.

4. **Editing**
   Researchers are re-engineering the bacterial system to enable it to edit more than just viral DNA. They use the CRISPR/Cas9 tools to target regions of the genome, disable genes, or cut it and insert new DNA, effectively editing the DNA sequence.

no inexpensive, efficient, and precise synthetic mechanism for identifying a target gene repair location and manipulating the code toward a positive therapeutic outcome—that is, no reliable synthetic method of “patching” errors in the human genome across the broad array of known genetic defects that result in disease or chronic conditions.24

While advances in synthetic biology may make it possible to turn any living system into one we can manipulate genetically, few systems are sufficiently well understood today to be amenable to that manipulation. The tools and tricks currently used to manipulate fruit flies, for example, were developed over the course of 100 years. There is currently little comparable knowledge or experience base that can be used to similarly manipulate other potentially valuable cell lines.

Current CRISPR use cases focus on repairing cells back to the intended function. That allows a less complex starting point and potentially a less controversial set of capabilities.

Similarly, the agriculture industry is using CRISPR techniques to move faster than selective breeding and hybridization could in the past. For example, button mushrooms engineered with CRISPR do not go brown with handling and shipping.25

Today CRISPR is ready to advance from a bench tool into therapeutics. Academics are collaborating with business to address the regulation, scale, and rigors of development. Developments and applications of CRISPR technology will continue to be reported and debated as they advance, but it's not too soon for businesses to begin considering impacts.26 With the National Institutes of Health projecting cancer costs to hit $158 billion by 2020,27 CRISPR's potential as a treatment for cancer offers hope for health care consumers and providers buckling under the increased cost and complexity of new treatments. Pharmaceutical, oil and gas, and chemicals manufacturers are carefully following the potential of synthetic biology to engineer organisms to produce complex chemicals and other compounds.
Focus: Quantum optimization

Quantum technology can be defined broadly as engineering that exploits properties of quantum mechanics into practical applications in computing, sensors, cryptography, and simulation.28

Quantum mechanics, a branch of physics dealing with the nature of matter at an atomic or sub-atomic level—can be counterintuitive. Particles behave like waves, experience quantum uncertainty, and show the non-local entanglement phenomena that Einstein famously called “spooky action at a distance.” Given that most quantum phenomena are confined to the scale of atoms and fundamental particles, nontraditional materials and methods are required to explore and exploit them.29

As a result, efforts to harness quantum technology for computing are hardware-driven, using exotic materials, and focused on the goal of achieving durable quantum states that are programmable—that is, pursuing a general-purpose quantum computer. Difficult engineering hurdles remain. Nonetheless, there is an active race under way to achieve a state of “quantum supremacy” in which a provable quantum computer surpasses the combined problem-solving capability of the world’s current supercomputers—at least for a certain class of problem.

Currently, the Sunway TaihuLight supercomputer in Wuxi, China, can run 10.6 million cores comprising 40,960 nodes, and can perform 93 peta floating-point operations per second (FLOPS). That’s roughly 10,000 times faster than a high-end GPU today. By contrast, a single quantum gate chip with around 60 quantum bits (qubits) would, theoretically, be more powerful than the TaihuLight computer.30

Any companies that win the race for “quantum supremacy” will harness some key quantum effects into their architectures, including superposition, tunneling, and entanglement.

Superposition allows a quantum bit to hold zero and one values simultaneously, and in quantum tunneling, particles behave like waves to cross certain energy states. These unintuitive facts allow quantum computers to solve complex discrete combinatorial problems that are intractable for classic computers in practical timeframes. For example, machine learning leverages pattern recognition—comparing many instances of large data sets to find the learning model that effectively describes that data. Applying superposition and tunneling allows handling many more patterns in many more permutations much more quickly than a classic computer. One key side effect is cracking current data encryption and protection schemes.31

Fortunately, the entanglement effect supports quantum cryptography, using the “shared noise” of entanglement to empower a one-time pad. In quantum entanglement, physically distant qubits are related such that measurements of one can depend on the properties of the other. Measuring either member of an entangled pair destroys the shared entanglement. This creates a business use for senders or receivers to more easily detect “line tapping” in digital communications.32

Large-scale quantum computing, whenever it occurs, could help address real-world business and governmental challenges. Peter Diamandis offers examples from several disparate disciplines. Toward personalized medicine, quantum computers could model drug interactions for all 20,000-plus proteins encoded in the human genome. In climate science, quantum-enabled simulation might unlock new insights into human ecological impact. Finally, quantum simulations seem to better model many real-world systems such as photosynthesis. Addressing such processes with quantum computers may lead to biomimetic advances and discoveries across many industries and use cases.33

Reality check

As companies wait for a commercial gate model quantum machine with lots of qubits and high coherence—that is, a general-purpose quantum computer—they can experiment with certain applications using quantum simulation and quantum emulation. These approaches are in use today and can show both the path to and the potential of full quantum GPC (general purpose computing).
Quantum simulation implements the exact quantum physics (as we know it today) with the hardware and tools we have today. That is, quantum simulation directly mimics the operations that a quantum computer performs, using classic computing to understand the exact effects of every quantum gate in the simulated machine.

Quantum emulation targets quantum-advantaged processes without the exact physics, using mathematical shortcuts that don’t compromise the computational results from classic hardware.

As an example, Kyndi leverages quantum emulation to handle the combinatorial complexity of inferencing complex data, putting the result to work as part of a broader machine-intelligence approach in places where the volume of data overwhelms human experts. The intent is not to replace the expert—rather, it is to automate the routine parts of large-scale analysis and free humans to focus on high value add. One Kyndi proof of concept delivered analysis in seven hours of processing that the client estimated would have taken a full year using human analysts alone.

Both quantum simulation and quantum emulation approaches are backed by formal proof theory—math results from theoretical computer scientists and physicists who have done the work to show what quantum computations can be done on classic computer architectures. Those theories, though, generally do not specify algorithm design or emulation abstraction.
In the slightly longer term, quantum optimization solutions—such as the tunneling or annealing mentioned earlier—don’t provide full general-purpose compute, but they do address hard discrete combinatorial optimization problems, such as finding the shortest, fastest, cheapest, or most efficient way of doing a given task. Familiar examples include airline scheduling, Monte Carlo simulation, and web search. More current uses include image recognition, machine learning and deep learning pattern-based processing, and intelligence systems algorithmic transparency (in which an algorithm can explain itself and how it came to its conclusions).

Quantum optimization addresses limitations with both rules-based and traditional case-based reasoning in which multiple case examples are used to show levels of relationships through a commonality of characteristics. A practical problem for quantum optimization would be not only recognizing the objects in a photo but also making inferences based on those objects—for example, detecting a dog, a ball, and a person in a photo and then inferring that the group is going to play ball together. This type of “frame problem” is combinatorically large in classic rules engine approaches.

As for quantum optimization’s longer-term future, the ability to harness computing power at a scale that, until recently, seemed unimaginable has profound disruptive implications for both the private and public sectors, as well as for society as a whole. Today, we use statistical methods to mine patterns, insights, and correlations from big data. Yet for small data that flows in high-velocity streams with low repeat rates, these statistical methods don’t apply; only the human brain can identify and analyze such weak signals and, more importantly, understand causation—the reason why. In the coming years, expect quantum computation to break the human monopoly in this area, and to become one of the most powerful models of probabilistic reasoning available.
It may be several years before viable, mainstream business use cases for synthetic biology, advanced energy storage, quantum computing, and nanotechnology emerge. But even in these early days of innovation and exploration, certain risk and security considerations surrounding several of these exponential technologies are already coming into view.

For example:

**Nanotechnology:** The health care sector is developing many groundbreaking uses for nanotech devices, from microscopic tools that surgeons can use to repair damaged tissue, to synthetic molecular structures that form the basis for tissue regeneration. Yet like medical devices, nanotech carries with it significant compliance risk. Moreover, the microscopic size of these innovations makes them nearly impossible to secure to the same degree one would other technologies. In some cases, nano-related risk will likely need to be managed at nano-scale.

**Energy storage:** Batteries and grid-storage technologies do not, in and of themselves, carry significant levels of risk. However, the digital components used to control the flow of electricity, and the charge and discharge of batteries, do. As storage components become denser, more compact, and weigh less, new digital interfaces and energy management tools will emerge, thus requiring new approaches for securing them.

**Synthetic biology:** At the crossroads of biology and engineering, synthetic biology stands poised to disrupt agriculture, medicine, pharmaceuticals, and other industries that deal with natural biological systems. Yet its seemingly limitless potential will be bounded by formidable regulation that will, in turn, raise its compliance risk profile.

**Quantum computing:** With the kind of algorithms and data models that quantum computing can support, predictive risk modeling may become an even more valuable component of risk management. The difference between modeling with a few hundred data attributes, as one might today, and running the same models with 20,000 or more attributes represents a potentially game-changing leap in capacity, detail, and insight. Due to the growing complexity of managing cyber risk, platforms such as quantum will likely be essential cyber components in the future.

As we begin thinking about exponential technologies and their disruptive potential—however distant that may seem—it is important to consider not only how they might be harnessed for business purposes but also the potential risks and security considerations they could introduce upon deployment. Will they make your ecosystems more vulnerable? Will they expose your organizations to additional financial compliance or reputation risk? Or, as in the case of quantum computing, might they turbocharge your existing approaches to security by revolutionizing encryption, predictive modeling, and data analysis?

Though we may not be able to answer these questions with certainty today, we do know that by adopting a “risk first” approach to design and development now, CIOs will be putting in place the foundational building blocks needed to explore and leverage exponential technologies to their fullest potential.
Where do you start?

While the full potential of the four exponentials examined in this report may be several years in the future, there are relevant capabilities and applications emerging now. If you wait three years before thinking seriously about them, your first non-accidental yield may likely be three to five years beyond that. Because these forces are developing at an atypical, nonlinear pace, the longer you wait to begin exploring them, the further your company may fall behind.

As you embark on your exponentials journey, consider a programmatic lifecycle approach involving the following steps:

- **Sensing and research:** To begin exploring exponential forces and their potential, consider, as a first step, building hypotheses based on sensing and research. Identify a force—nanotechnology, for example—and hypothesize its impact on your products, your production methods, and your competitive environment in early and mid-stage emergence. Then perform sufficient research around that hypothesis, using thresholds or trigger levels to increase or decrease the activity and investment over time. It is important to note that sensing and research are not R&D—they are preliminary steps in what will be a longer effort to determine an exponential force’s potential for your business.

- **Exploration:** Through sensing and research, you have identified a few exponentials that look promising. At this point, you can begin exploring the “state of the possible” for each by looking at how others are approaching these forces, and determining if any of these approaches could apply broadly to your industry. Then convene around the “state of the practical.” Specifically, could these same approaches impact or benefit your business? If so, you can begin developing use cases for evaluating the “state of the valuable” in the experimentation phase.

- **Experimentation:** The move from exploration to experimentation involves prioritizing business cases and building initial prototypes, doing in-the-workplace studies, and putting them into use. When the value proposition of the experiment meets the expectations set forth in your business case, then you can consider investing by moving into incubation. Be cautious, however, about moving too quickly from incubation to full production. Even with a solid business case and encouraging experiments with containable circumstances and uses, at this stage your product is not proven out at scale. You will likely need an incubator that has full scaling ability to carry out the level of enhancement, testing, and fixes needed before putting this product out into the world.

- **Be programmatic:** Taking any product—but particularly one grounded in exponential forces—from sensing to production is not a two-step process, nor is it an accidental process. Some think of innovation as nothing more than eureka! moments. While there is an element of that, innovation is more about programmatic disciplined effort, carried out over time, than it is about inspiration.

Finally, in your exponential journey you may encounter a common innovation challenge: The investment you will be making often yields less—at least initially—than the day-to-day approaches you have in place. This is part of the process. To keep things in perspective and to help everyone stay focused on end goals, you will likely need a methodical program that guides and accounts for the time and money you are spending. Without such a blueprint, innovation efforts often quickly become unsustainable.

**Bottom line**

Though the promise that nanotechnologies, energy systems, biotechnology, and quantum technologies hold for business is not yet fully defined, some if not all of these exponentials will likely create industry disruption in the next 24 to 60 months. As with other emerging technologies, there can be competitive opportunities for early adoption. CIOs, CTOs, and other executives can and should begin exploring exponentials’ possibilities today.


4. Ibid.


9. Ibid.


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The future of manufacturing
Making things in a changing world
MANUFACTURING is no longer simply about making physical products. Changes in consumer demand, the nature of products, and the economics of production and the supply chain have led to a fundamental shift in the way companies do business. Customers demand personalization and customization as the line between consumer and creator continues to blur. Added sensors and connectivity turn “dumb” products into “smart” ones, while individual products increasingly become platforms—and even move into the realm of services.

As technology continues to advance exponentially, barriers to entry, commercialization, and learning are eroding. New market entrants with access to new tools can operate at much smaller scale, enabling them to create offerings once the sole province of major incumbents. While large-scale production will always dominate some segments of the value chain, innovative manufacturing models—distributed small-scale local manufacturing, loosely coupled manufacturing ecosystems, and agile manufacturing—are arising to take advantage of these new opportunities.

Meanwhile, the boundary separating product makers from product sellers is increasingly permeable. Manufacturers are feeling the pressure—and gaining the ability—to increase both speed to market and customer engagement. And numerous factors are leading manufacturers to build to order rather than build to stock, making intermediaries that create value by holding inventory less and less necessary.

Together, these shifts have made it more difficult to create value in traditional ways. And, as products become less objects of value in their own right and more the means for accessing information and experiences, creating and capturing value has moved from delivering physical objects to enabling that access.

These trends can affect different manufacturing sectors at different rates. To determine the speed and intensity of the coming shifts in a particular sector, companies should consider factors including the extent of regulation, product size and complexity, and the sector’s level of digitization.

In addition, large manufacturers should focus more tightly on serving in roles likely to lead to concentration and consolidation, while avoiding those prone to fragmentation. The good news is that three roles driven by significant economies of scale and scope—infrastructure providers, aggregation platforms, and agent businesses—offer incumbents a solid foundation for growth and profitability. Due to competitive pressures, large manufacturers may be pushed to focus on just one role, shedding aspects of the business that might distract the company from becoming world class in its chosen role. The likely result is a significant restructuring of existing product manufacturers.

The growth potential of adopting a scale-and-scope role can be further enhanced by pursuing leveraged growth strategies. Rather than focusing solely on “make vs. buy” options, large players will have opportunities to connect with and mobilize a growing array of new entrants, many of which will target fragmenting portions of the manufacturing value chain. Two emerging business models, “product to platform” and “ownership to access,” seem particularly promising in terms of driving leveraged growth strategies.

Finally, given the emergence of more complex ecosystems of fragmented and concentrated players across a growing array of manufacturing value chains, businesses that understand emerging “influence points” will have a significant strategic advantage.

When deciding where to win and how to play in this new environment, there is no master playbook—and no single path to success. But by understanding these shifts, roles, and influence points, both incumbents and new entrants can give themselves the tools to successfully navigate the future of manufacturing.
The shifting manufacturing landscape

The first of these shifts is the end, for all intents and purposes, of a manufacturer’s ability to create and capture value solely by making “better” products. For decades, manufacturers have been pursuing “more for less,” focusing on delivering increasing product quality and functionality to consumers at lower and lower prices. But while this model served manufacturers well when improvements were relatively few and far between, accelerating technological change—and the consequential shortening of the product life cycle—has reduced the window of opportunity for capturing value from any given improvement to a sliver of what it once was. And in an era of global competition, most of the already small gains in margin from product improvement are often competed away, with the consumer as the beneficiary.

With delivering more for less no longer a sustainable strategy, forward-thinking manufacturers are looking for alternative ways to create and capture value. It is no longer just about selling the product, but about gaining a share of the value it generates in its use. Consider the value that Netflix generates through the use of televisions as a conduit for streaming entertainment—or the value that businesses such as Zipcar and Uber create through the use of cars for on-demand mobility. Manufacturers are waking up to possibilities such as these and, in the process, starting to transform the way they do business.

Against this backdrop, a second, parallel shift is taking place. It arises from a confluence of factors moving scale upstream and fragmentation downstream in the manufacturing supply chain. Advances in technology and changes in consumer expectations are making it possible for relatively small manufacturers to gain traction and thrive in an industry where scale was once a virtual imperative. Indeed, in the race to find new ways to create and capture value, their smaller size and agility may give many market entrants an advantage over larger, older organizations, if only because incumbents may find it difficult to change entrenched business models and practices to accommodate new marketplace realities. Moreover, the new entrants are not necessarily manufacturing companies in the traditional sense. The growing popularity of “smart” products, for instance, has prompted some technology companies to make forays into the manufacturing space, either by developing software to run the products or by producing the products themselves.

Incumbents may, of course, choose to meet new entrants on their own ground, finding ways to create and capture value that rely more on capitalizing on a product’s value-creating attributes than on selling the product itself. But there’s another option. Some incumbents, viewing the proliferation of fragmented smaller players as a market in itself, may opt to support niche manufacturers by providing them with products and services for which scale still provides an advantage—platforms for knowledge sharing, components upon which niche manufacturers can build, and the like. Due to competitive pressures, large incumbents will likely consolidate further, providing the foundation for a large number of fragmented smaller players dedicated to addressing the increasingly diverse needs of the consumer. The result is an ecosystem that includes both niche players and large scale-and-scope operators.

Facing these two macro shifts, manufacturers—both incumbents and new entrants, from both traditional and nontraditional backgrounds—need to understand the forces driving the industry’s evolution in order to choose their path forward. How can large incumbents take advantage of emerging tools, techniques, and platforms? What lessons can new
entrants and incumbents learn from other industries that have staked a claim in the manufacturing space? And how can organizations find profitable and sustainable roles in the future manufacturing landscape?

With these questions in mind, we take a deeper dive into four areas where changing dynamics underlie both of the shifts we have described (figure 1), exploring the trends and factors that influence each and laying out steps both entrants and incumbents can begin to take to effectively navigate this landscape of the future.

- **Consumer demand:** Consumers’ rising power and unmet needs around personalization, customization, and co-creation are causing niche markets to proliferate.
- **Products:** Technological advances enabling modularity and connectivity are transforming products from inert objects into “smart” devices, while advancements in materials science are enabling the creation of far more intricate, capable, and advanced objects, smart or otherwise. At the same time, the nature of products is changing, with many transcending their roles as material possessions to become services to which consumers buy access.
- **Economics of production:** Technologies such as additive manufacturing are making it

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**Figure 1. Four shifts in manufacturing**

![Diagram of four shifts in manufacturing](source: Center for the Edge)
possible to cost-effectively manufacture products more quickly, in smaller and smaller batches.

- **Economics of the value chain:** Digital technologies are narrowing the distance between manufacturer and consumer, allowing manufacturers to bypass traditional intermediaries.

Each of these shifts contributes to an increasingly complex economic environment that makes value creation more challenging and value capture more crucial. After exploring the evolving landscape, this report lays out steps both entrants and incumbents can begin to take to effectively navigate this landscape of the future. When navigating the path to enhanced value creation and value capture, large incumbents, especially, should determine the urgency of change in a given market, focus on the most promising business types, pursue leveraged growth opportunities, and identify (and, where possible, occupy) emerging influence points. The path to success is specific to each business, and executives should envision their organizations in new ways if they want to make the most of the available opportunities.
The changing nature of consumer demand

More and more, consumers are embracing product personalization, customization, and co-creation, generating an abundance of niche markets and new opportunities for manufacturers.

Personalization and customization

Personalization—adding to or changing a product to fit the individual—can be as simple as monogramming a towel; customization involves creating products attractive to specific niche markets. But the current rise in both personalization and customization is more than cosmetic. It’s the difference between adding your name to a mass-produced object and generating a product made for your unique body, between buying a pair of drugstore reading glasses and receiving chemotherapy optimized for your particular tumor.

Historically, personalization (to the individual) and customization (to a niche) have been the provinces of the wealthy, with offerings such as custom tailoring and high-performance automobiles. No longer. Digital technologies, especially the Internet, are making tailored products for niche markets increasingly available and accessible, raising consumers’ expectations of being able to get exactly what they want versus to settling for mass-produced items. This, in turn, is fragmenting the broad consumer marketplace into numerous niche markets, each of which represents an opportunity for manufacturers capable of cost-effectively delivering the desired goods and creating and capturing value through economies of scope rather than economies of scale.

Consumers as creators

Beyond their rising interest in personalization and customization, consumers are also increasingly apt to engage in the creation, or at least the conceptualization, of the products they buy. At base, this phenomenon represents a shift in identity from passive recipient to active participant—a blurring of the line between producer and consumer.

One manifestation of this trend is the growing popularity of the maker movement—a resurgence of DIY craft and hands-on production among everyone from Lego-obsessed kids to enthusiastic knitters and electronics geeks. Those involved in “making” see themselves in a different light in relation to the products they use. Some actually assume the mantle of maker, taking pride in creating rather than

Figure 1a. Four shifts in manufacturing

Source: Center for the Edge.
consuming. Others, while not producing objects themselves, become collaborators, engaging with maker culture to support and shape the products they buy, and deriving identity from that engagement. As more and more makers begin selling their creations and customizations, it has given rise to a thriving ecosystem of platforms and niche providers, including learning tools, digital repositories, service bureaus, tool shops, kit manufacturers, crowd platforms, and online and off-line retail outlets. Most of these niche providers are small startups and microbusinesses, though several have grown to a point where they’re challenging incumbents—and redefining how demand is both expressed and satisfied.

As consumer demands shift toward personalization, customization, and creation, we will see an increasing proliferation of niche markets where, rather than “settling” for mass-market products, consumers will be able to find or even create products suited to their individual needs. In this environment, manufacturers fully leveraged to produce large volumes of limited numbers of products will likely be at a disadvantage, forcing them to rethink their place in the manufacturing landscape and the value they bring consumers. Fortunately, amid the fragmentation, new roles and new sources of value can emerge for large players.
The changing nature of products

In parallel with, and in response to, shifts in consumer demand, the nature of products is changing. “Dumb” products are getting “smarter”—more connected, intelligent, and responsive. Concurrently, how consumers view and use products is changing, redefining both the factors that determine product value and how companies can capture it.

As clothing becomes “wearables,” cars “connected cars,” and lighting “smart lighting,” will the majority of the benefits accrue to the product manufacturer, the software platform owner, the creator of the “killer app” that makes the product come alive, or the company that generates insights from the resulting big data? The questions raised go far beyond the technical challenges of manufacturing. As products create and transmit more data, how much value will be located in the objects themselves, and how much in the data they generate, or the insights gleaned from it? And what of the option to rethink products as physical platforms, each the center of an ecosystem in which third-party partners build modular add-ons? These questions envision a change in the nature of products—and a much larger shift in how value is created and captured.

From dumb to smart

Smart watches and health and fitness trackers are good examples of the quantified “self movement,” in which participants use technology to track and analyze the data of their daily lives. As yet, most are still stand alone tools. The next generation of these devices, however, is likely to be integrated into our clothing and accessories so seamlessly that they become “wearables.”

The emergence of technologically enabled products such as activity trackers is one facet of a looming transition in physical goods. In the near future, many, if not most, “dumb” products will become “smart”—falling under the umbrella of the Internet of Things (IoT). The pervasive expansion of sensors, connectivity, and electronics will extend the digital infrastructure to encompass previously analog tasks, processes, and machine operations. Gartner analysts predict that by 2020, the IoT will include nearly 26 billion devices, adding $1.9 trillion in global economic value. In a recent survey, nearly 75 percent of executives indicated that their companies were exploring or adopting some form of IoT solution, with most seeing integrating IoT into the main business as necessary to remain competitive.

The evolution of “smart” products presents manufacturers with challenges on multiple levels. Some
of these products incorporate complex software or interact with users’ smart devices, while others use cutting-edge materials—such as electroactive polymers and thermal bimetals—that continually adapt to users’ changing needs. Further, not all products will be smart in the same way and, as smart products become more complex, it will be increasingly difficult for any single manufacturer to develop an entire hardware/software stack in house.

To capture value in a world where products are as much about software as about physical objects, manufacturers should consider their business models in light of four factors that play into generating value from smart products: integrated software, software platforms, the applications (apps) that run on those platforms, and data aggregation and analysis. While integrated software handles all the performance functions needed by the hardware housing it, software platforms act as translators, managing the hardware based on new instructions delivered through easily updatable apps. This platform-plus-app model allows for a greater range of customization and personalization, and makes it easier to update products in response to shifting needs and contexts.

From product to platform

We often think of “platforms” in terms of software, with the most recent example being the massive success of the iOS and Android app platforms. These platforms use a leveraged growth model that relies on simple mathematics: The greater the reach and value of the extensions created, the greater the number of base-module sales. However, platforms can also exist outside the digital world. A platform is any environment—including a physical product—with set standards and governance models that facilitate third-party participation and interactions. Successful platforms increase the speed and lower the cost of innovation, as they reduce entry costs and risks through common interfaces and plug-in architectures. Participants can join in and collaborate, extending the platform’s functionality. The more participants a platform has, the richer its feedback loops and the greater the system’s learning and performance improvements.

Aftermarket add-ons—one example of a physical platform—have a long history. Thriving aftermarkets exist to customize and personalize automobiles for both utility and aesthetics, for example. Most aftermarket products are manufactured and installed by third parties that have no affiliation with the original equipment manufacturers (OEMs). What is new is the upsurge of products designed from the start as bases for third-party extensions from partners and others. The aftermarket has become a premarket.

The view of products as platforms—as starting points for customization and personalization—has been embraced by the maker movement. These platforms’ successes are directly and intentionally tied to that of the extensions that consumers build on them. Forward-thinking product manufacturers are approaching such movements, not as fringe activities, or even as threats to the brand, but as marketing opportunities—a chance to embrace a passionate, highly invested community, offering opportunities for engagement and loyalty in products designed and manufactured for hackability. They are extending the concept of the product as platform into an explicit business strategy: Introduce a product platform then invite multiple third parties to create modular add-ons that extend the value to the customer.

From product to service

Where does the product end and the service begin? In one sense, this is an old question; business strategists have long advised companies to focus on the problem solved rather than on the product that solves it. Today, however, the expanding digital infrastructure—low-cost computing and digital storage, ubiquitous connectivity, and a multiplying number of connected devices—has created many more opportunities to fundamentally rethink the product as a service. This trend is most evident where the “product” is virtual, with Adobe, Autodesk, Microsoft, and others offering software suites via monthly subscription. In the enterprise software market, onsite IT hardware and software is being eclipsed by cloud-based software-as-a-service (SaaS) offerings.
Opportunities to re-conceptualize physical products as services are growing, as well. For instance, digital infrastructure has spurred the “sharing economy”—a broad term used to describe businesses that commoditize sharing of underutilized goods and services. By moving the focus from ownership to access (collaborative consumption), this model shifts the economics of usage from product to service, giving rise to billion-dollar companies including Uber (crowdsourced transportation) and Airbnb (crowdsourced housing). Lesser-known startups have arisen to share tools, kitchen appliances, and other rarely used or underutilized products. The value created by sharing these goods is not, for the most part, being captured by product manufacturers. There is a largely untapped opportunity for manufacturers to reconfigure their own business models, re-envisioning the nature of their products in a way that helps them take advantage of the product-as-a-service concept.

As products become “smart,” connected, co-created, and even transformed into services, the whole notion of creating value solely by making and selling more items becomes obsolete. With this change in the nature of products comes a shift in value creation. In the manufacturing future, value will come from connectivity, data, collaboration, feedback loops, and learning—all of which can lay the groundwork for new and more powerful business models.
The changing economics of production

MANUFACTURING, until recently, was a daunting space with relatively few players. Barriers to entry were high and initial capital investments hefty; products had to navigate multiple intermediaries in the supply chain before reaching the consumer. Today, however, huge advances in technology and plummeting computing costs have eroded barriers that once impeded the flow of information, resources, and products, making previously cost-prohibitive tasks and business models more available to more players and weakening the value proposition for traditional intermediaries. Meanwhile, rapid advances and convergences in technology, including additive manufacturing, robotics, and materials science, further expand what can be manufactured and how. All of these developments are combining with changing demand patterns to increase market fragmentation, supporting a proliferation of product makers further down the value chain with more direct consumer contact. Upstream, larger manufacturers will likely consolidate, taking advantage of scale to provide components and platforms used by smaller players.

Exponential technologies

Modern computers continue to become exponentially smaller, faster, and cheaper. And as more and more technologies become digitally empowered, this pattern of growth has expanded beyond microprocessors. Emerging fields with potential for exponential growth include additive manufacturing, robotics, and materials science. The convergence of these and other technologies has the potential to generate huge improvements in capability, utility, and accessibility.

ADDITIVE MANUFACTURING

Additive manufacturing (AM), better known as 3D printing, encompasses manufacturing technologies that create objects by addition rather than subtraction (through milling, for example). While 3D printing technologies were developed more than 30 years ago, this decade has seen a rapid advancement in tools, techniques, and applications in both commercial and consumer arenas.

Today, while additive manufacturing is used mostly in prototyping, it is expanding to other stages in the manufacturing process. Tooling—the production of molds, patterns, jigs, and fixtures—is traditionally one of the most time-consuming and costly portions of the process, far outweighing unit costs for each additional part, and leading manufacturers

Figure 1c. Four shifts in manufacturing

Source: Center for the Edge.
to spread the upfront cost across large production runs. In contrast, the initial capital outlay for AM is typically much lower, not only because AM obviates the need for tooling, but also because the cost of AM equipment has been decreasing rapidly.

AM is becoming increasingly price-competitive with conventional manufacturing due to differences in fixed vs. variable costs. Even though the variable cost for AM is currently higher, reduced upfront investment often makes the total cost of AM less for small production runs—a potential game-changer (figure 2).

In addition, complexity is free with additive manufacturing—the material cost of printing a complex design is less than that of printing a solid block, since it requires less time and material. When the burden of production is transferred from the physical world to the digital world, engineers can design intricate, previously un producable shapes. And manufacturers can produce stronger, more lightweight parts that require less assembly time, reducing the overall cost of production or increasing the value of the final product.

While AM technology is still developing in terms of speed, material, and precision, many industries are already using it to create high-value, low-volume parts. In coming years, we may expect the range and scale of AM deployments to extend to lower-value, high-volume items.

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**Figure 2. Breakeven analysis comparing conventional and additive manufacturing processes**

![Breakeven analysis](https://example.com/breakeven.png)

ROBOTICS

Industrial robots historically have been used in large-scale manufacturing for tasks requiring exceptional strength and precision—for example, moving heavy items, welding, and semiconductor fabrication. They required heavy upfront investment and programming, and were usually bolted to the ground and caged as a safety measure for humans working in the vicinity. Until recently, low labor costs plus the high price of industrial robots posed little incentive for low-wage countries to invest in automation, particularly for tasks that require relatively little training and production lines that change frequently. Now, however, rising global labor costs and a new generation of cheaper, more capable, more flexible robots are changing the equation.

Some analysts estimate that, by 2019, per-hour labor costs in China will be 177 percent of those in Vietnam and 218 percent of those in India. Given such projections, it’s not surprising that in 2014, China became the largest buyer of industrial robots, buying more than 36,000—more than either the United States or Japan. While Japan still has the largest total number of active robots, China is well on pace to become the automation capital of the world.

Though robots will not replace human labor in manufacturing in the immediate future, they are poised to take up an increasing share of the manufacturing floor. This is likely to reduce the number of low-wage, low-skill human manufacturing jobs while generating a relatively small number of specialized higher-wage jobs in programming and maintenance.

MATERIALS SCIENCE

Since the 1960s, the term “space-age” has been used to describe new materials that enable previously impossible engineering tasks. The first generation of these materials—memory foam, carbon fiber, nanomaterials, optical coatings—has become ubiquitous. As new materials are created, older ones, once inaccessible to all but the most advanced, price-insensitive manufacturers, have begun to trickle down to the mainstream.

Take carbon fiber. While the energy costs associated with its manufacture still prevent use in many low-end applications, recent technological improvements have allowed manufacturers to produce higher volumes of carbon fiber products at lower prices. As a result, it has found utility in a slew of premium products such as bicycles, camera tripods, and even structural automotive components such as drive shafts and A-pillars. Lexus, for example, has developed a carbon fiber loom that, rather than forming two-dimensional sheets into three-dimensional shapes, can weave seamless three-dimensional objects. As manufacturing improvements lower costs and other barriers to access, we can expect to see such materials used in more mainstream applications. In fact, lower costs and streamlined manufacturing processes are slated to double global carbon fiber production by 2020.

The effects of such gains extend far beyond making it cheaper to manufacture high-tech items. Battery technology, for instance, has seen dramatic performance improvements over the past decade as a result of materials science innovations. It has been predicted that advancements in chemistry and materials science will result in an eight to nine percent annual increase in the energy density of batteries. Other nascent technologies have the potential to vault past the capabilities of commonly used materials—even the first generations of space-age materials—by orders of magnitude. Carbon nanotubes, for example, have one of the highest tensile strengths of any material and are one of the best conductors of both heat and electricity. They can carry four times more energy than copper while retaining the physical characteristics of a piece of thread. Researchers have envisioned applications including composite materials stronger than carbon fiber, advanced water filters, syringes that can inject genetic information into cells, solar panels, and artificial muscle fibers.

Meanwhile, materials are being developed from new sources. MycoBond offers a flame-resistant Styrofoam alternative grown from Mycelium fungus. Hobbyists can now make thermoplastic at home using simple online instructions and the starch from a grocery store potato. And researchers are making surgical-grade plastic from silk. Like carbon nanotubes, these materials have potential in higher-performance settings. Nanocrystalline cellulose,
a renewable material abundant in wood fiber, has potential applications ranging from plastic and concrete reinforcement to conductive paper, batteries, electronics displays, and computer memory.\textsuperscript{19}

Other high-performance materials adapt to their environments. Dynamic materials such as electroactive polymers (polymers that change shape when exposed to an electric charge) and thermal bimetals (metals that change shape as temperatures change) have demonstrated potential for use in adaptable architecture. When used as the outer skin of a building, these materials can expand when it is hot to cool structures, and close when it is cold to preserve heat.

While not everyone will have immediate access to newly developed materials, the barriers to entry for advanced, customized manufacturing will be reduced as advancements in materials science progress—opening up space for new players in cutting-edge manufacturing.

Finally, no technological development exists in a vacuum. As more and more technologies reach a stage of aggressive growth, they are more likely to intersect, generating growth greater than the sum of their parts. When discussing the impact of converging exponential technologies on the manufacturing landscape, bear in mind that each technology will compound the capabilities of others, enabling previously unforeseeable innovations.

Eroding barriers to learning, entry, and commercialization

One of the strongest effects of the exponentially developing digital infrastructure is its ability to break down barriers to produce design, production, marketing and sales, opening the manufacturing world to newcomers. As knowledge and information are digitized, it’s easier than ever to learn a new skill or connect with experts in any field, to enter a market that once required high investment capital, and to commercialize an opportunity from a product to a business. These benefits, first evident in the digital world, are now reaching physical manufacturing and are likely to spur both growth and change.

LOWER BARRIERS TO LEARNING

What does a Millennial (or at this point, anyone) do to learn something new? Google it. Or, in broader terms, search online. How-to videos on pretty much any topic can be found on YouTube. Websites such as Instructables, Hackster, and Makerzine feature thousands of step-by-step projects in text and video. Discussion forums in communities of interest deepen learning with conversations—often mixing amateurs and experts—that address specific problems. Such online discourse is then extended to “real life” via tools, like Meetup, that make it easy to gather a group around a topic or “learning/hacking” session. Communities form around institutions such as TechShops and Fab Labs or events such as MakerFaire, MakerCon, SOLID, and the Open Hardware Summit, all of which include hands-on learning sessions. In short, the transfer of tacit knowledge—knowledge gained by doing—has become easier with the ready availability of both online and real-world events, each of which enhances the other.

The resulting influx of makers and startups drawn from these communities, and the ease of acquiring design and production skills, fuels the number of market entrants. While entrants generally are unequipped to challenge incumbents directly, they are both the sign and the result of rapid innovation; the areas where they innovate will be loci of change and growth in the nature of manufacturing. From desktop tooling to freelance engineering talent, crowdfunding to business incubators, a whole ecosystem has arisen to help budding manufacturers learn the ways of designing, manufacturing, and selling a product.

LOWER BARRIERS TO ENTRY

The digital infrastructure-based benefits that supported the rise of software startups at the turn of the century have now extended to hardware startups. In addition to pay-per-use models that allow for access to high-end computing power through offerings such as Amazon’s AWS service, an array of boutique agencies, freelance creative and technical consultants, and service marketplaces give prospective hardware entrepreneurs access to programming, design, and engineering talent on an as-needed basis.
At the low end, sites such as Fiver.com offer ad hoc services for as little as $5 an hour. And support for small providers of first, services, and now products, is growing rapidly. Coworking spaces such as Hub and Citizenspace provide shared office space and ancillary support, reducing the initial investment and effort needed to launch a business.

Both tooling technology and tool access have also been democratized. TechShop offers members access to complex design and tooling equipment for roughly the cost of a monthly gym membership. A slew of desktop manufacturing modules, from 3D printers and CNC milling machines to printed circuit board (PCB) printers and pick-and-place machines, have hastened the speed of prototyping and small-scale manufacturing. As former Wired editor and 3D Robotics founder Chris Anderson put it, “Three guys with a laptop used to describe a Web startup. Now it can describe a hardware startup as well.”

LOWER BARRIERS TO COMMERCIALIZATION

Barriers to initial funding and commercialization are also falling, making it easier than ever to enter a market, commercialize a creation, and build a business. Crowdfunding of hardware projects has become both popular and lucrative, reducing reliance on financing through bank loans and venture capital. Initial capital often covers tooling costs, requiring only enough revenue to cover production. Crowdfunding sites such as Kickstarter and Indiegogo have also allowed startups to identify early adopters, develop a loyal customer base, and establish demand prior to producing a single item. Venture funders have taken notice, increasing their funding of hardware startups, while numerous hardware incubators and accelerators help startups move from idea to prototype to business.

Traditional large-scale manufacturers are playing a role here, as well. FirstBuild, the GE subsidiary, launched its first crowdfunding campaign on Indiegogo for the Paragon Induction Cooktop, a Bluetooth-enabled tabletop cooker—and the test case for the company’s new manufacturing model. Foxconn, the world’s largest contract manufacturer, sectioned off a portion of one of its factories to house Innocconn, a startup incubator and microfactory targeting initial product runs of 1,000 to 10,000—a dramatic shift for a firm once accessible only to blue-chip brands with multimillion-unit orders. While Innocconn represents only a tiny fraction of Foxconn’s total production volume, it demonstrates the willingness of even the largest firms to learn small-batch manufacturing and support the growing small-company segment of the manufacturing landscape. By appropriating formerly small-scale funding and production practices like crowdfunding and small-batch manufacturing, big manufacturers can reap the benefits of both their size and the new methods’ agility.

Emerging manufacturing models

Responding to the growing opportunities presented by niche markets, and drawing on technologies that make it possible to cost-effectively manufacture small batches or even single instances of many items, manufacturing is shifting from a predominantly scale-driven sector to one characterized by multiple production models. Large-scale production will always dominate some segments of the value chain, but three other manufacturing models are arising to take advantage of new opportunities: distributed, smaller-scale local manufacturing; loosely coupled manufacturing ecosystems; and an increased focus on agile manufacturing methods at larger operations.

While each of these models reduces costs, they also reimagine and restructure how products are made, with a deep long-term effect on value creation. The emergence of business models centered on niche markets and smaller-scale production makes it easier for new entrants to establish themselves, attract customers—and, potentially, eat into the mass markets traditionally served by large-scale manufacturers, on whose platforms they may very well rely.

DISTRIBUTED LOCAL MANUFACTURING

In the twentieth century, an intense focus on cost reduction and efficiency led manufacturers to decamp to countries with low labor costs and to maximize efficiencies gained through mass production. In
the United States and Europe, what little domestic manufacturing remained served premium or craft markets. But a recent rise in local manufacturing is bucking that trend, relying on technology and community to keep costs down.

The digitization of manufacturing, along with the exponential growth of subtractive and additive digital fabrication technologies and robotics, has made manufacturing more repeatable and portable. Individual designers and small businesses now have the ability to produce high-quality goods locally at low cost. Increased digitization is likely to further lower the cost of customization, giving more advantage to distributed small-scale local manufacturing that captures consumer needs.

LOOSELY COUPLED MANUFACTURING ECOSYSTEMS

Shenzhen, a city in southern China, was established in 1979; today, it is the anchor city of China’s Special Economic Zone, the global epicenter of consumer goods manufacturing.22 While the zone’s largest manufacturers are known worldwide, some of the more interesting players in this ecosystem are part of a network of smaller factories, called Shanzhai, which evolved around the giants, originally manufacturing gray-market or pirated products but now entering legitimate commerce. These smaller manufacturers’ size, plus their network of interconnections, enable them to perfect small-lot manufacturing while iterating at incredible speed. Their operators—many former factory workers who have branched out into ownership—have mastered the ability to build high-quality products at low volumes and low cost, at extreme speed, using an ecosystem of loosely coupled small- to medium-sized factories and individual experts. The result is a system that can take on the larger Shenzhen factories—and one that is extremely well-suited to emerging modes of supply. The beneficiaries are any designers or brands, large or small, established or new, that want to jump in, iterate quickly and cheaply, and scale as needed to meet demand. One highly visible outcome is the plethora of inexpensive, high-quality mobile phones dominating the Chinese market. As newer trends such as IoT, wearables, and robotics gain momentum, the Shanzhai are likely to respond with equal alacrity and range.

The geographic density of Shenzhen, and its ability to encompass the entire value chain from raw material suppliers and industrial equipment
manufacturers to designers, product manufacturers, and assemblers, is unlikely to be replicated exactly. However, similar hubs have appeared elsewhere in China, with footwear manufacturing in the Fujian region and motorcycle manufacturing around Chongqing. Other, more traditional global manufacturing hubs have the potential to spawn similar loosely coupled networks, mirroring the Shanzhai’s system and success.

AGILE MANUFACTURING

For larger manufacturers, renewed interest in agile manufacturing is helping them remain competitive while staying responsive to increasingly fickle and unpredictable market signals. The key to this increased agility: a digital infrastructure that provides access to near-real-time point of sale (POS) data, rather than lagging monthly or quarterly sales reports.

The more accurate such forecasts are, the more sense it can make to choose highly efficient large production runs. However, when introducing a new product with less certainty of market acceptance, or making upgrades or changes to a product design, manufacturers may instead choose to focus on producing “minimal viable batch quantities,” matching agile manufacturing practices with agility in the supply chain. Overseas production and freight shipping will force minimum manufacturing quantities to compensate for long lead times from production to customer. For smaller items, the cost of air freight and short fulfillment cycles may trump the cost of holding inventory, cost of capital, and obsolescence.

As technology advances exponentially and barriers to learning, entry, and commercialization continue to decrease, product development and commercialization will further fragment. New entities may find it increasingly easier to enter the landscape and to create products addressing specific consumer niches. These businesses will proliferate, though each will be limited in size by “diseconomies of scale”—the larger they get, the less relevant they will become. Meanwhile, as consumer demand fragments, so will addressable markets, making the notion of “mass market” more and more irrelevant. In this manufacturing environment—with the downstream fragmenting as scale moves upstream—businesses seeking growth will need to rethink the ways they participate in the manufacturing landscape.
The changing economics of the value chain

The lines between manufacturers (which make things) and retailers (which sell things) are blurring. This softening of roles has significance not just for the companies undergoing a transformation, but also for any intermediaries holding inventory along the way.

While a few companies are vertically integrated across the value chain, most traditional manufacturers are a few steps removed from their products’ end consumers. In a world where information travels ever more freely, and where cycle times are collapsing, traditional players can struggle to communicate with consumers and to receive—and act on—timely, meaningful feedback. Consumers feel this disconnect as well, and many are opting to engage more directly with the makers of the products they consume.

Figure 1d. Four shifts in manufacturing

These disconnects can have multiple implications for how value is created and captured. As the distance between manufacturer and consumer narrows, intermediaries whose sole value is to hold inventory are likely to be squeezed out. The most likely survivors will be those that create more value for consumers, perhaps by providing useful information, helping people make choices, or allowing buyers to experience products in new ways. For the same reasons, successful manufacturers will be those that can engage directly with consumers, narrow the gap between prototype and product, and move their business models from build-to-stock to build-to-order.

While no single small company can have a major impact on large incumbents, numerous agile start-ups taking market share from the incumbents can create significant change. Entrants are using three approaches to gaining a toehold in the new manufacturing landscape, each at a distinct point in the value chain: engaging the consumer directly, increasing speed from idea to market, and favoring build-to-order models over build-to-stock.

Eroding value proposition for intermediaries

In a traditional value chain, the manufactured product goes through a series of wholesalers, distributors, and retailers before reaching the consumer. Inventory is held at each of these intermediary stops to buffer for variable demand. Capital is held hostage for a few months, tied up in shipping and inventory until products are sold. It’s no surprise that the manufacturer’s suggested retail price (MSRP) is usually four to five times the ex-factory cost of a product: A lot of money (and, traditionally, value) is stuck in intermediaries. But as the digital
infrastructure continues to cut the distance between manufacturer and consumer, this model, and its conception of value, will most likely be questioned and restructured.

When search cost was high, a retail outlet providing multiple side-by-side options had value. Convenience also dictated having as many items as possible available in one location. But then online sales brought consumers not just a near-infinite number of options, but reviews and feedback that helped buyers choose among them. Meanwhile, quick (even overnight or same-day) shipping has become cost-effective when substituted for the cost of multiple intermediaries. While choice and convenience alone may not be adequate value drivers for intermediaries, as consumers are retrained in new behaviors (online purchasing and ship-to-door), retailers’ traditional sources of power, geographic spread and physical shelf space, are slowly slipping away.

In this environment, many hardware startups are forgoing traditional brick-and-mortar retail channels, going directly to consumers via online platforms, such as Amazon, eBay, and Etsy, which offer advantages to both buyers and sellers. While getting on the shelves of a brick-and-mortar retailer can boost sales, it can also create a cash crunch when most of a small firm’s revenue is stuck in inventory or held hostage to long payment terms. As the value captured by controlling access erodes, retailers that want to stay relevant as value chain players will have to reevaluate and reconfigure their business models. Eyeglass manufacturer Warby Parker, for example, has been growing at a rapid pace in an industry historically closed to outsiders, largely due to its ability to bypass traditional distribution and retail channels. As a result, the company is able to offer high-quality frames at lower prices, unlocking value otherwise taken up by intermediaries.

Direct consumer engagement

Traditionally, the consumer has been a few steps removed from the product manufacturer. Today’s hardware startups, however, are using the digital infrastructure to connect directly with the consumer, building affinity for both product and company. As technology evolution accelerates, these startups focus on brand affinity rather than traditional intellectual property (IP) patent filings and protection.

While consumer engagement is not usually seen as part of the supply chain, it is testament to the power of direct engagement that it can be redefined as a very early point in that chain—which may today be more aptly called the value chain. Many of these startups are using crowdfunding platforms not only to raise initial capital, but to build a community of fans and supporters around their products—engaging demand in a way that ties it inextricably to supply. In shifting the power balance for market entrants, this stance strikes at the heart of the question of how to capture value, and which entities (new entrants or incumbents, small businesses or large) will do so.

In crowdfunding campaigns, consumer engagement does not end with the campaign; rather, businesses continue to connect and communicate with supporters throughout the manufacturing process, offering detailed updates on both successes and challenges.

Faster speed to commercialization

While small manufacturers embrace a measured pace of development informed by community engagement, larger players are more likely to distinguish themselves through speed. And with ever more rapid shifts in consumer demand, speed to market is increasingly important. “Fast fashion” sellers such as TopShop, for example, credit their success in large part to optimizing manufacturing and the value chain to address changes in consumer tastes and demands.

With the success of such models, manufacturers have inevitably followed suit, working to compress time from idea to market. One major draw of manufacturing consumer electronics in Shenzhen is “Shenzhen sudu” (Shenzhen speed), which allows sellers to capture market value almost as fast as it can be identified. For the Solowheel, this resulted in development of dozens of lower-priced substitutes only weeks after the initial product was
released. Today, such rapid speed to commercial-
ization is poised to become the rule rather than the
exception.

Build-to-order vs.
build-to-stock

Traditional manufacturing practices are still built
around a “build-to-stock” model—demand is fore-
cast, and then the product is manufactured to fit that
forecast, taking into account multiple lead times
along the value chain. But with the ability to engage
the consumer directly online come new “build-to-
order” models driven by online promotion and
preorders. In many respects, crowdfunding for new
products is a kind of preorder. While build-to-order
manufacturers may still use forecasting to optimize
manufacturing efficiency, preorders are even better
at gauging consumer demand.

As consumer preferences shift toward personaliza-
tion, customization, and creation, direct access to
consumers will become critical. Intermediaries re-
duce speed to market and require capital to build
up inventory; they can also make it more difficult
for manufacturers to access valuable consumer in-
sights. However, many large manufacturers today
rely heavily on intermediaries, weakening their
connection to the consumer. This puts them at a
disadvantage when compared to smaller players
with direct consumer relationships that make them
more responsive to changing consumer needs. Large
manufacturers should consider how they might use
their scale to enable these smaller players instead of
competing with them directly.
Navigating the future manufacturing landscape

The world of manufacturing is shifting exponentially. Not only is it becoming more difficult to create value, but those who do so are not necessarily those best positioned to capture it. Value resides not just in manufactured products, but also in the information and experiences that those projects facilitate. For example, today’s televisions, despite being many times more powerful than those of just a decade ago, are priced so competitively that neither manufacturers nor retailers can maintain anything more than the smallest margin on their sales. Rather than delivering value in their own right, televisions have become a vehicle for the locus of value—the content that viewers watch on them. With this fundamental shift in value from object to experience—or more specifically, from device to the experience facilitated by that device—comes the need for manufacturers to redefine their roles, and hence their business models.

The same trends that have pushed manufacturing in the direction of delivering more value for lower cost—and that have made it about far more than producing physical products—will become more pronounced over the next few decades. To succeed, products will have to be smarter, more personalized, more responsive, more connected, and less expensive. Manufacturers will face increasingly complex and costly decisions about where and how to invest in order to add value.

When assessing the future manufacturing landscape, there is neither a single playbook for incumbents nor a single path for new entrants. Instead, companies should consider these recommendations when navigating the path to enhanced value creation and value capture:

• Determine the urgency of change in your specific market
• Focus on the most promising business types
• Pursue leveraged growth opportunities
• Identify and, where possible, occupy emerging influence points

Determine the urgency of change in your specific market

As lowered barriers to forming a business intersect with increasing consumer demand for personalization, the manufacturing landscape will begin to fragment in ways that touch the consumer. We’ll likely see a wide range of individual players, each focusing on a small, addressable market around a specific niche; both niches and players will proliferate over time. Collectively, these businesses can address a broad spectrum of consumer and market needs, with no single player having enough market share to influence the long-term direction of its domain. This situation will be sustained by the need for only modest investment to enter and maintain one’s position, combined with “diseconomies of scale” that make it more difficult for larger players to compete at this level.

Fragmentation will occur mostly around specialized product and service markets, with a wide range of small players either designing and assembling niche products or serving as supporting domain experts or contractors. We see this pattern now in the growth of small hardware startups associated with the maker movement, as well as with sellers on websites such as Etsy.

However, accelerated technological change is likely to have a markedly different effect on this era of
manufacturing than it has had in the past. Where before, new industry segments consolidated into a few dominant players as their industries matured, the future manufacturing landscape is poised to experience rapid, ongoing disruption leading to continuous fragmentation.

Fragmentation will occur at varying rates and to varying degrees across regions, manufacturing subsectors, and product categories. All segments of manufacturing will eventually be affected, with timing and speed of disruption varying based on the industry’s exposure to shifting trends. Barriers to entry in the form of factors such as regulation, design complexity, product size, and digitization will affect which subsectors first experience disruptive shifts. However, the speed of the shift will vary greatly even within industry segments—for example, electronic toy manufacturers will have very different experiences from makers of board games, stuffed animals, or building toys. Understanding the timing and speed of change in their industries and subsectors will help businesses assess when and where to play in these changing times.

The factors at play aren’t static. The regulatory environment is constantly evolving in response to market needs. Product complexity, size, and digitization are all affected by exponentially evolving technologies. When considering these factors, it is important to evaluate not just the current placement of your product category, but also potential shifts that could accelerate fragmentation in parts of the business landscape.

THE REGULATORY ENVIRONMENT

Public policy and regulation play a profound role in the current and future structure of the manufacturing ecosystem. Trade agreements, labor relations, consumer safety and environmental regulations, and privacy and security restrictions all have the power to shape and shift dynamics and economies. In a survey of 400 CEOs in all major industries, respondents listed the regulatory environment as their top concern, with more than 34 percent reporting spending an increasing amount of time with regulators and government officials. Industries with complex supply chains spanning multiple geographies can struggle to change practices developed in response to regulatory requirements. In general, the greater an industry’s regulation, the greater the barriers to entry and the slower the pace of fragmentation. Governments can speed the transition to a more fragmented manufacturing ecosystem by relaxing regulation and encouraging new entrants and innovation. For example, tax treatments in China’s Special Economic Zones spurred many foreign and domestic companies to relocate, quickly expanding the country’s manufacturing sector.

PRODUCT COMPLEXITY

The more complex the product—measured by the number of components, the intricacy of component interactions, and the extent of product novelty—the more the parties designing parts of the final product must interact. In general, this factor matters most during design and prototyping. This means that, the more complex the product, the greater the value of in-house R&D or collaboration by a few tightly coupled players, and the more resources a manufacturer should have in house—and the more difficult disruption in the form of fragmentation becomes.

However, this is not always the case, as exemplified by the first Apple iPod. Faced with an incredibly tight timeline, the designer, Portal Player, tightly defined boundary conditions for each product component, then invited multiple players to compete for the best design in each category. This approach allowed for greater innovation in the final product—as specialists worked on each part of the player—but led to more work for the engineers designing and testing how all the parts came together.

Product complexity is also changing as a result of exponential technologies such as 3D printing. The advent of the 3D-printed car took the car from 20,000 parts to 40, significantly reducing product complexity—and enhancing the potential for smaller players to enter the design and final assembly market, leveraging the capability of a few large-scale component providers. 3D-printed parts are also agnostic as to design complexity; complex geometries can be printed just as easily as a solid block.
PRODUCT SIZE

Regardless of product complexity, physical product size matters. The larger the physical product the more costly it is to prototype, manufacture, store, and ship. The equipment and space needed to tinker with a small consumer electronics device is much less than that required for a home appliance. And such requirements amplify as a product moves from tinkering to prototyping and on to production. Across the board, categories including larger products will be slower to fragment, in part because their shipping costs make up a significantly higher portion of the final delivered cost to the consumer. As Local Motors CEO Jay Rogers puts it, “For local to go big, big needs to go local.”

Note, however that increasing product modularity plus new manufacturing processes can drive shifts in product size from large to small. The Tata Nano, India’s $2,000 “affordable car,” was designed to be flat-packed and shipped for assembly close to the delivery point. Local Motors’ Rally Fighter can be purchased either as a fully assembled car or as a kit for self-assembly. Size, it turns out, is not always a static measure.

DIGITIZATION

The “more digital” a product or industry is—the more sensors and electronics it incorporates, or the more digitized its processes—the shorter its product cycles. Technology is evolving at a faster pace each year—Products contain more and more digital technology, and so become obsolete more and more rapidly. With the greater use of digital manufacturing tools, an increasing number of physical objects being digitized, and a growing number of processes digitally transmitted and managed, the speed of evolution and collective learning increases, in turn speeding the fragmentation process. Consumer electronics and mobile phones have experienced this acceleration, facing ever-shorter product life cycles as a result. One counterpoint: If the software and applications on a product add more value that the product itself, it lengthens the product life cycle, since the software helps keep the product relevant.

As more “dumb” products become “smart,” digitization is reaching once-dumb manufactured products. The advent of categories such as wearables, connected cars, and smart lighting is likely to speed obsolescence as the technology in these products ages faster than the products themselves.

Considering regulation, size, complexity, and digitization, and the movement of these factors in an industry, can help companies estimate the speed and intensity of coming shifts (see figure 3). The resulting estimates can help companies choose the best ways to participate in, and influence, the shifting manufacturing landscape. How fast is your industry or product segment fragmenting? Which factors—from regulatory environment to digitization—are driving that evolution? In the face of constant change, companies tend to step back and take a “sense and react” approach, watching the factors driving change and preparing themselves to react to new market conditions. Now, however, leaders have the opportunity to use deep understanding of these drivers to anticipate potential changes. They can then move their business in a direction both congruent with market forces and designed to position their company favorably.

Focus on the most promising business types

The ability to create and capture value will vary depending on the business type. As discussed previously, the increasing demand for personalization and customization is poised to increase market fragmentation, while making it increasingly difficult for any single company to sustainably meet all of a consumer’s needs. The companies that do the best job of capturing value will be those that figure out how to work with, and use, fragmentation rather than fighting it. Scale will move upstream to components and platforms, while scope (via a greater diversity of assemblers) will move downstream, owning the “last mile” to the customer.

We delve into these structural elements in much more detail in our paper *The hero's journey through the landscape of the future.* Here, we present an overview of the coming landscape with a focus on manufacturing, in order to help participants...
determine which business roles might be most appropriate for them.

Both incumbents and new entrants should be aware of possible roles in this system, and each business should determine the best fit based on its assets, strengths, and core DNA. In general, large companies are well-suited to take on infrastructure management or customer relationship roles, while smaller companies are well-positioned to play as niche product and service businesses. Entities looking for sustained growth may not be able to achieve it in the more fragmented, downstream landscape; they may need to shift upstream to achieve their growth goals.

As product innovation, design, and assembly fragment, other parts of the business landscape will consolidate where scale and scope make it easier to support the niche operators. Areas of concentration will be marked by players, tightly focused on a single business type or role, that can muster the

**Figure 3. Industry fragmentation assessment framework**

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<th>Industry segment</th>
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<td>Aviation</td>
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<tr>
<td>Other industries</td>
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**Drivers of fragmentation apply to a variety of contexts**

While change is inevitable, not all industry segments will be affected at the same rate. As industries fragment, value creation and value capture become more and more challenging. As a result, new roles and business models begin to emerge, often challenging or disrupting the status quo. This chart offers a simplified analysis of a set of industry segments; readers can extend these ideas to evaluate their own segments, companies, and even products.

**Limitation of categorization**

This chart presents an overview assessment for illustrative purposes only. Many of the segments shown are quite broad and nuanced. For example, Toys includes everything from electronics to board games; each driver may apply differently to each subsegment.

**Additional factors also matter**

Many other factors may impact the speed of fragmentation in a particular industry. For example, the high cost and low utilization of cars has contributed more to the rise of “sharing economy” companies such as Zipcar and Uber than have any of the factors shown here. Additional industry-specific factors should also be considered by companies conducting this analysis.

Source: Center for the Edge.
significant level of investment required to enter or sustain marketplace position in that role, and that generate value by leveraging resources such as large-scale technology infrastructure or big data to provide information, resources, and platforms to more fragmented businesses. Because these areas of concentration are driven by significant economies of scale and scope, early entrants that can quickly achieve critical mass are likely to gain a significant competitive advantage. Businesses that choose to focus on one of these roles are advised to be early movers rather than fast followers.

We anticipate scale-and-scope operators to fall into three broad business roles:

- Infrastructure providers
- Aggregation platforms
- Agent businesses

**Infrastructure providers** deliver routine high-volume processes requiring large investments in physical infrastructure, such as transportation networks (e.g., UPS and FedEx) and scale manufacturing plants (e.g., Flextronics and Foxconn). Infrastructure providers also exist in digital technology delivery (e.g., Amazon AWS and Cisco) and scale-intensive business processes (e.g., Infosys and Wipro).

In the second category are **aggregation platforms**—virtual and physical platforms that foster connections, broker marketplaces, or aggregate data. For example, online marketplaces such as eBay and Etsy connect buyers and sellers; Kickstarter delivers financing by connecting artists, makers, and innovators with their fans; and Facebook connects people socially to share knowledge or information.

The third category encompasses the role of **agent**. The consumer agent, a trusted advisor that helps consumers navigate an array of possible purchases, is the agent type most relevant to the manufacturing landscape. While agent businesses have always existed—from wealth managers to personal shoppers—their primary customer base has been the affluent. Now, however, technology is making such services more widely available to the general population. In manufacturing, fragmentation in the area of final product assembly will give rise to agents that guide retail consumers to the right options for them.

The retailers most likely to survive and thrive are those that embrace this role, becoming experts dedicated to supporting each consumer’s unique needs.

The three roles above are based on scale and scope, making them attractive positions for companies looking to achieve significant and sustained growth. Businesses in these roles collaborate closely with the fragmented but focused niche players.

In the resulting ecosystem of niche players supported by scale-and-scope businesses, “mobilizers” are the connective tissue that organizes an ecosystem to move in specific directions. Mobilizers can add value by framing explicit motivating goals, providing governance that enhances interactions, and facilitating collaboration. Maker Media’s Maker Education Initiative (slogan: “Every Child a Maker”) is a good example of a mobilizer framing an explicit goal. In addition to its rallying cry to increase maker education, the group publishes programs and playbooks designed to provide governance and facilitate collaboration.

It is not surprising for these roles to emerge in response to the shifts in the manufacturing landscape described earlier. Each role represents an essential business type. For example, fragmented niche operators are **product** businesses, focused on designing and developing creative new products and services, getting them to market quickly, and accelerating their adoption. This business type is driven by the economics of time and speed to market. It requires skills and systems focused on rapid design and development iteration, supporting the quick identification and addressing of market opportunities. The culture of this type of business prioritizes creative talent and is oriented toward supporting creative stars.

**Infrastructure providers** and **aggregation platforms** are examples of **infrastructure management** businesses. This business type is driven by powerful scale economics. It requires skills to manage routine high-volume processing activities, and has a culture that prioritizes standardization, cost control, and predictability. In this business culture, the facility or asset trumps the human being.
The agent role is an example of the **customer relationship management business** type, which is driven by economics of scope—building broader relationships with a growing number of customers. The more this business type knows about any individual customer, the more accurately it can recommend resources to that customer. Simultaneously, the more it knows about a large number of customers, the more helpful it can be to any individual based on its ability to see larger patterns. To succeed, such businesses need to understand the evolving context of each customer based on carefully structured interactions, plus a growing data set that captures context and history. The culture of this business type is relentlessly customer-focused—seeking to anticipate needs before they arise, building trust, and positioning the business as an advisor rather than a sales-driven vendor.

Aiming to become infrastructure management or customer relationship businesses can help large companies leverage existing economies of scale and scope to occupy the concentrating portions of the business landscape. Smaller companies, in contrast, are best served by aiming to become a product/service type of businesses, filling in the more fragmented portions of that landscape.

Today, most large companies operate multiple types of businesses (and thus play multiple roles). Given the uncertainty of a rapidly changing world, such diversity is often viewed as a strategic advantage; a portfolio is comforting. However, when a company participates in too many business types at once, it can lack focus. Diverse groups compete for resources, chafe under inappropriate economics or metrics, and clash culturally. The reality is that the three business types bundled into today’s large enterprises have very different economics, skill sets, and cultures.

In the past, large companies bundled these business types together because of the high cost and complexity of coordinating activity across independent companies. However, today’s ever more powerful digital infrastructure makes it far less expensive, and far easier, to coordinate activity across a growing number of independent entities. As competitive pressure intensifies, companies that keep the three business types tightly bundled will likely reduce performance as they seek to balance the competing demands of these business types. Such businesses can become more vulnerable to companies that, by focusing on a single business type, become world-class in their chosen activities.

Further, as the pace of change accelerates, the imperative to learn faster becomes more pronounced. A company that focuses on a single business type is likely to learn much faster without the distraction of multiple competing businesses within its walls. It is more likely to attract and retain world-class talent, gaining employees seeking to be the heroes of the organization rather than take on second-class support roles. Its learning potential can be further enhanced by the ability to connect and collaborate with trusted top-tier companies of the other two types.

To flourish in an increasingly competitive environment, a company should resist the temptation to do everything. Instead, it should put its energies into one primary role. Given the divergent drivers, cultures, and focuses of the three business types, an organization that contains more than one can benefit from first separating them operationally within the firm. Then, over time, it can choose a primary type to prioritize as its company’s core DNA, ultimately shedding operations in the other two business types completely. Perhaps paradoxically, such unbundling can set the stage for much more sustained and profitable growth.

Large incumbents may be understandably reluctant to let go of their current positions in the value chain. But failing to adapt to the new landscape is missing a powerful opportunity to own an influential new position in that chain—a foundational platform on which a large number of smaller players build. If this role is played out correctly, a new ecosystem of smaller, specialized niche providers will form around the large incumbent to customize and personalize products (through physical products, software, or services). All of these will be tied together by an entirely new set of players—mobilizers, data platforms, and connectivity platforms.
Pursue leveraged growth opportunities

Historically, to achieve growth, entities had two options: buy or build. Advances in digital technology and connectivity allow for a third option, “leveraged growth,” in which a business can connect with and mobilize a growing array of third parties in the fragmenting parts of the manufacturing landscape to create and capture value for its customers. Companies occupying the platform, infrastructure, and agent roles, which are inherently positioned for growth, can accelerate that growth and gain flexibility by leveraging trusted resources from outside their organizations. In addition to financial resources, such players can leverage the capabilities of third-party partners. By doing so, they reduce risk, broaden their perspective to maximize learning and performance, and cut costs by taking advantage of existing resources. Just as important, they build a network of trusted relationships, a factor becoming more and more crucial in navigating the future manufacturing landscape.

This level of transformation is very much in the domain of larger businesses—whether incumbent or entrant—with the resources to influence market factors. These businesses will be doubly successful if they develop strategies—and platforms—that allow them to attract and support a large number of smaller, more fragmented players. Leveraged growth can also help the larger business sense the shifting environment more accurately, and continue to shape it.

In turn, smaller firms can leverage platform businesses for financing, learning, and prototyping, reducing capital investment while increasing speed to market. They can address surges in demand by relying on infrastructure providers, and can more effectively connect with relevant customers through agent businesses. Though they may have little power to move the market individually, they can maximize their influence as part of a broader ecosystem.

Two potentially promising business models emerging in the manufacturing landscape can enable leveraged growth for large incumbents: the shift from **products to platforms** and from **ownership to access**.

As digital and physical products become platforms, they enable a wide variety of participants to join, collaborate, and innovate. Platforms have a tremendous network effect, growing in importance as more participants join and extend their functionality. They are also a cheaper, more flexible, and less risky way for participants to enter a space. Once platforms gain traction and achieve a critical mass of participants, they become hard to replace.

The shift from ownership to access allows manufacturers to transform their focus from making products to developing deep, long-term customer relationships. At the core of this shift is a platform that aggregates resources and enables consumer access. With it, consumers can access products as they need them. Manufacturers can use data collection and product feedback to continually grow and improve. And as access providers gain a deeper knowledge of customers and their needs, they can identify and mobilize a broader range of third parties to enhance the value provided to customers.

Identify and, where possible, occupy emerging influence points

There are still more ways to capture value in the rapidly shifting manufacturing landscape. With eroding barriers to entry and continued exponential growth of the digital infrastructure, many companies are seeing their positioning weaken. Strategic positions in the value chain—or influence points—are shifting. These positions are often key to enhancing value-capture potential. Power once derived from harboring stocks of knowledge now arises from an organization’s position in the flow of knowledge. While patents and IP remain valuable, their strategic significance is declining as the pace of innovation increases and product life cycles shrink. New influence points are emerging around flows of knowledge. Privileged access to these flows makes it possible to identify and anticipate change before others do, and to shape them in a way that strengthens future positioning. Access to these diverse flows can also speed up learning—the key to competitive advantage in a quickly evolving market.
So how do influence points emerge and evolve? They attract participants through the value they provide, and inspire action with positive incentives. Influence points are most likely to emerge where they can provide significant and sustainable functionality to the broader platform or ecosystem, where their functionality can evolve rapidly, where network effects drive consolidation and concentration of participants, and where they can encourage fragmentation of the rest of the platform or ecosystem.

For example, in the early days of the personal computer industry, development of de facto standards for microprocessors and operating systems encouraged significant fragmentation in other aspects of the technology. These standards also created concentrations in knowledge flows as companies sought to connect with makers of the standard technologies to understand how they were likely to evolve.

Another example of shifting influence points is the ongoing value shift from physical products to digital streams created by smart products. Here the greatest knowledge flows may have little to do with specific products; instead, they become part of the emerging IoT infrastructure. Such shifts tend to create new influence points further from the core capabilities of current manufacturing incumbents—points that favor large external players such as Google, Facebook, Apple, and Amazon. Google’s acquisition of home IoT device company Nest and Facebook’s acquisition of virtual reality startup Oculus VR make sense in this context—as do Google’s Android, Apple’s iPhone and iPad, and Amazon’s Kindle devices.

As the manufacturing landscape and value chain evolve, old influence points will erode and new ones emerge. For established incumbents, doing nothing in this area is likely to lead to loss of influence and an erosion in the ability to capture value. To maintain or extend current levels of influence, manufacturers should assess their value chains, identifying current influence points and possible changes that could affect their position. Next, they should identify potential new influence points where they might establish strongholds. This may mean releasing elements once central to a firm’s value, and reimagining value in the context of potential positioning in the value stream.

Big firms—both incumbents and new entrants—have an advantage here, as they tend to have resources valuable to a large number of fragmented players. Patent portfolios can be seen as a means to increase and focus knowledge flow, rather than as a static stock of knowledge or barrier to entry. GE took this path when it gave Quirky community members access to GE patents, encouraging innovation outside the initial patent domain.

Clearly, not everyone can target and occupy influence points; by definition, there are only a few to be had, and doing so is not required for success. But businesses that control influence points can create more sustainable advantages and get advance information about evolving markets.

When navigating the path to enhanced value creation and value capture, a business should first determine how these ideas apply to its particular industry and its position within it, as well as to its organization and the products it produces. The next step is to determine the roles with the greatest potential for growth, exploring how it might shift to occupy one or more of those roles. Finally, the company should look for opportunities to collaborate with other players, large and small, in the relevant ecosystem—and determine how it might occupy emerging influence points. Given the ever-changing nature of manufacturing, such exploration and evolution are an ongoing process, one that businesses must continually follow if they want to stay relevant.
Conclusion

The manufacturing landscape is undergoing a massive collective shift. Consumer demands, the nature of products, and the economics of production and distribution are all evolving. Boundaries are blurring between manufacturing and technology on one hand and manufacturing and retail on the other. While more value is being created, manufacturers are under increasing pressure. In this environment, capturing value requires fundamentally rethinking business models—remapping a company’s strategic positioning based on internal capabilities, external shifts, and emerging influence points.

Several large incumbents are making moves in these directions. GE Aviation moved from selling jet engines to selling power by the hour, as a utility company would. And savvy startups are developing business models in alignment with the new manufacturing landscape. Xiaomi started with a direct-sales model that prioritized consumer relationships, then eventually expanded to include traditional retail channels. The company knew that the influence point was closeness to the consumer; owning that space allowed it to develop good terms with retailers.

Creating and capturing value in the new manufacturing environment will require understanding the factors driving change in specific sectors, focusing on activities that convey a structural advantage, leveraging the skills and capabilities of third parties, fundamentally rethinking business models, and identifying influence points. There is no one path to success; instead, we offer a set of pointers and guideposts. Take this opportunity to define your own success—and blaze your own trail.
ENDNOTES


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John Hagel III (co-chairman, Deloitte Center for the Edge), of Deloitte Consulting LLP, has nearly 30 years of experience as a management consultant, author, speaker, and entrepreneur, and has helped companies improve performance by applying technology to reshape business strategies. In addition to holding significant positions at leading consulting firms and companies throughout his career, Hagel is the author of bestselling business books such as Net Gain, Net Worth, Out of the Box, The Only Sustainable Edge, and The Power of Pull.

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High-performing manufacturers
Where they play and how they win
A report by the Deloitte Center for Industry Insights
ABOUT THE STUDY

As part of Deloitte's ongoing collaboration with the US Council on Competitiveness on the Global Competitiveness in Manufacturing Initiative, we conducted a global study of manufacturing CEOs in 2010, 2013, and 2016. Together, these three studies received a total of over 1,600 CEO responses.

On a broad list of capabilities, we asked CEOs to rate their companies' current competitiveness in each capability relative to their closest global rivals, as well as rate how important they thought each capability would be to staying competitive in the future. In order to remove the variations in rating among countries (due to culture), industry subsectors, and company revenue sizes, we normalized the data by country, industry, and size, and calculated current and future index scores for each of the capabilities on a 10–100 scale for both current competitiveness and future importance.

We separated the respondents' companies into “high performers” and “other companies” (all other companies studied). High performers were identified on the basis of four parameters: the company's actual profitability, its profitability when compared to its peers, whether the company met or exceeded its profitability goals, and the company's performance on return on assets.

This classification methodology for selecting high performers showed that 30 percent of the high performers were in the top 10 percent of profitability relative to their primary global industry competitors, and four-fifths (81 percent) of the high performers were in the top third. Among the other companies, only 1 percent were in the top 10 percent of profitability, and only 9 percent were in the top third, relative to their primary global industry competitors. In addition, 25 percent of the high performers were in the top 10 percent on return on assets (ROA) relative to their primary global industry competitors; 74 percent of the high performers had ROAs in the top third. Among the other companies, only 1 percent had ROAs in the top 10 percent and only 5 percent had ROAs in the top third relative to their primary global industry competitors.

About the Deloitte Center for Industry Insights

The Deloitte Center for Industry Insights (DCII) is the research division of Deloitte LLP’s Consumer and Industrial Products practice. The DCII’s goal is to inform stakeholders across the consumer business and manufacturing ecosystem of critical business issues including emerging trends, challenges, and opportunities. Using primary research and rigorous analysis, the DCII provides unique perspectives and seeks to be a trusted source for relevant, timely, and reliable insights. To learn more, visit www.deloitte.com/us/cb and www.deloitte.com/us/manufacturing.
An in-depth study of high performance

No one has to tell manufacturing company executives that it’s getting tougher to differentiate themselves and compete successfully—they feel the pressure every day. Rapid globalization, technological advancements, changing consumer preferences, and evolving government policies are reshaping the manufacturing industry, exponentially accelerating the pace of competition and continually raising the bar on company performance.

Still, some manufacturers consistently and convincingly outperform their peers (see sidebar “Why study high-performing manufacturers?”). How are they doing this? And what can “the rest” learn from “the best” to improve their own performance? This report provides executives with clear direction on what companies need to do to be high-performing manufacturers—now and in the future.

For more than 25 years, we’ve been studying manufacturers to identify what sets apart high-performing companies (defined in the section “About the study”) from their competitors. We found that high performers focus carefully on the development of specific but evolving sets of manufacturing capabilities to differentiate themselves and succeed in the marketplace. These capabilities, when coupled together, are difficult for their competitors to replicate, and when executed well, they create long-term competitive advantage by generating greater customer loyalty, higher market share, and superior profitability.

To dig deeper into the attributes of high-performing manufacturers, Deloitte collaborated with the US Council on Competitiveness to conduct a global survey of over 500 manufacturing C-suite executives
WHY STUDY HIGH-PERFORMING MANUFACTURERS?

High performers outpace, by a significant margin, other manufacturing companies in many dimensions of revenue performance. To understand the importance of being a high performer, Deloitte conducted an in-depth financial analysis of global manufacturing firms. We divided the top global manufacturing companies (the top 2,000 global manufacturing firms by FY 2014 sales) into top and bottom quartiles based on their average gross margin for the period 2004–2014, and compared the financial performance of the bottom quartile with the top in seven categories.

In all categories, manufacturing firms in the top quartile (the high performers) had much higher profitability or provided superior returns compared to firms in the bottom quartile (figure 1).

Figure 1. Financial performance of the top quartile versus the bottom quartile firms (2004–14)

- Net incoming margin: 398% larger (5.0x)
- Gross margin: 357% larger (4.6x)
- EBIT margin: 340% larger (4.4x)
- EBITDA margin: 217% larger (3.2x)
- Return on assets (ROA): 145% larger (2.4x)
- Return on capital (ROC): 121% larger (2.2x)
- Return on equity (ROE): 96% larger (2.0x)

Note: The graph shows the median of the top quartile versus the median of the bottom quartile.

Source: Deloitte analysis based on data from CapitalIQ.

The differences between high performers and all other manufacturers in our study are striking. High performers are operating with such strength that their impact on the future of the manufacturing industry is likely to be substantial. Understanding which manufacturing capabilities high performers consider to be important to their current and future competitiveness can provide important lessons—and a potential strategic advantage—to all companies.
in 2016. This report, which draws on the survey’s results, builds on the 2010 and 2013 editions of this survey and further extends the story of manufacturing competitiveness in the 21st century.

Even for high performers, it isn’t easy to continually excel in the dynamic, hypercompetitive global manufacturing industry. However, this study provides an operating framework to help C-suite executives decide “where to play and how to win.” Becoming a high performer requires a keen focus on acquiring needed capabilities, which not only change with time but also vary based on where a company chooses to play: in which markets, with which customers and consumers, in which channels, and in which product categories and services the company wants to compete. To determine how to win, company leaders should consider which capabilities will enable the organization to create unique value and consistently deliver that value to customers in a way that is distinct from competitors’ offerings.

This year’s study suggests that high-performing manufacturers share several common attributes that distinguish them from the rest:

- Brand, reputation, and managing customer perceptions are the top priority among high-performing manufacturers to pursue current and future competitiveness.

- Talent remains a key capability among high performers, while the gap is closing on leadership capabilities.

- High performers are focused on improving their price competitiveness while setting their sights on new markets and new customers.

- High performers are aggressively applying new, advanced technologies to help drive innovation while protecting intellectual property with an enhanced emphasis on cybersecurity capabilities as key differentiators for future competitiveness.

We found that high performers focus carefully on the development of specific but evolving sets of manufacturing capabilities to differentiate themselves and succeed in the marketplace.

**WHY MANUFACTURING MATTERS: THE ROLE OF MANUFACTURING IN THE BROADER ECONOMY**

From its influence on infrastructure development and job creation to its contribution to gross domestic product on both an overall and per-capita basis, a strong manufacturing sector creates a clear path toward economic prosperity. In 2015, manufacturing in the United States generated more jobs than any other sector, employing 12.3 million workers and supporting another 56.6 million (indirect and induced jobs). The sector also creates higher income jobs: A typical US manufacturing worker earned an average of $81,289 in 2015 compared to average earnings of $63,830 in other industries.
A framework for analyzing high performers

To truly understand the strategies of high-performing manufacturers—or any company—you have to delve deep into how these organizations are developing competitive capabilities.

1. The positioning of clusters of capabilities along two dimensions is the first element of our framework. Those two dimensions are (a) how competitive an organization is today with regard to the capability and (b) how important the organization believes that capability is to its future competitiveness, which is a surrogate for how much emphasis it is placing on enhancing its competitiveness specific to that capability in the future. Figure 2 shows the two dimensions of this first element in our framework, with the horizontal axis (x-axis) representing how competitive a company is today specific to an individual capability, and the vertical axis (y-axis) representing how important it believes that capability is to its future competitiveness. Taking high performers as a group, we plotted their ratings of each capability along the two axes (figure 4) and then looked for logical groupings or clusters of capabilities (figure 5) to gain a clear picture of these high-performing companies’ strategies.

2. The four classes of differentiating capabilities are the second element of our framework. We also asked these manufacturing executives to rate the future importance of those same capabilities. With this as our starting point, we converted their answers into a 100-point index scale from 10 to 100, while normalizing responses for company size and geography. This allowed us to compare the responses and strategies of high performers to those of all other manufacturers using a framework of three key elements:

   (a) game changers, (b) creating advantage, (c) being challenged, and (d) qualifiers. Figure 3 defines the four classes and groups the 35 individual capabilities by class, while figure 4 shows the specific class for each capability among the high-performing companies in our sample, plotted along the dimensions of current competitiveness (x-axis) and future importance (y-axis).
Game changers are capabilities where high performers are both more competitive today and place more importance on the capability for future competitiveness than their peers. This means that, relative to all other manufacturers, high performers place game changer capabilities further to the right and further toward the top along the two dimensions of competitiveness. Creating advantage capabilities are those where there is no real difference between high performers and other companies with regard to their current competitiveness, but on which high performers are placing a much higher degree of emphasis and importance for the future. Being challenged capabilities are those in which high performers hold a competitive advantage today, but on which high performers and other companies place a similar degree of importance for the future. Finally, qualifiers are capabilities where there is no statistically significant dif
Figure 3. The four classes of competitive capabilities

**Game changers**

- **Definition:** Capabilities in which high performers stand apart from the pack, and in which they likely will continue to lead.

  **High-performing capabilities**
  - Brand strength
  - Skilled workforce availability
  - Global sales and marketing
  - Global distribution and logistics
  - Penetrate to new markets
  - Balance sheet strength
  - Cybersecurity and IP protection

**Creating advantage**

- **Definition:** Capabilities in which high performers currently hold no significant current advantage but have high future importance compared to the rest of the companies.

  **High-performing capabilities**
  - Innovation culture
  - Speed of new products to market
  - Advanced data analytics
  - Risk management
  - Total delivered cost
  - Cost of materials

**Being challenged**

- **Definition:** Capabilities in which high performers currently hold a strong lead, but where they may lose ground as other manufacturers close the gap.

  **High-performing capabilities**
  - Leadership and management
  - Customer-perceived value
  - Sales experience
  - Manufacturing processes and capabilities
  - Supplier network strength
  - Lower price
  - Sustainability efforts

**Qualifiers (all manufacturers)**

- **Definition:** Capabilities in which high performers and the other companies do not significantly differ now or in the future; essentially, qualifiers represent table stakes for competing today and in the future.

  **High-performing capabilities**
  - Leadership succession
  - Delivery speed
  - Using technology to understand customers’ needs
  - R&D capabilities
  - Innovative product design
  - Use of advanced technologies
  - Business IT resources

  **Other capabilities**
  - Energy costs and management
  - Employee retention
  - M&A capabilities
  - Finance and accounting resources
  - Supplier collaboration
  - Higher value for price
  - Labor cost structure
  - Overhead costs

1. The difference between high performers and all other companies in either their current competitiveness or the capability’s future importance. Statistically speaking, high performers and all other companies treat qualifier capabilities the same way; they are essentially table stakes for competing today and in the future.

2. **Shift indicators** are the third element of our framework. Shift indicators are detected when a capability shows a statistically significant deviation from the diagonal (figure 6). Any capability plotted above the thick diagonal in figure 6 is considered to be more important to future competitiveness relative to companies’ current level of competitiveness in that capability; the
1. farther above the diagonal a capability falls, the more important it is to high performers’ future competitiveness relative to their current competitiveness in that capability. Similarly, any capability plotted below the thick diagonal is anticipated to be less important in the future, relative to companies’ current competitiveness in that capability. When plotted for the group of high performers, shift indicator capabilities indicate areas where these high performers are focusing significantly more (or less) in the future—signifying a “shift” in their strategic focus (figure 7). (For capabilities contained within the thickness of the diagonal, we are not able to truly determine their level of future importance relative to current competitiveness, and thus do not identify them as shift indicators.)
High performers’ strategic focus areas

Nine clusters of capabilities

WHEN we first look at the competitiveness map for high performers (figure 4), the capabilities may appear to be scattered at random. But upon closer inspection, patterns emerge. The 35 individual capabilities align to nine broad clusters of capabilities that help clarify high performers’ high-level focus areas (figure 5). A cluster’s placement relative to both axes reveals how high performers perceive its importance to their competitiveness, today and in the future. Taken as a whole, the clusters of capabilities provide valuable insight into high performers’ capability profile as well as their strategic focus areas.

The positioning of the clusters along the two dimensions of current competitiveness and future importance clearly reveals where high-performing manufacturers are placing their priorities. They are focused on being leaders in the areas of brand, reputation, and managing customer perceptions; talent; and leadership and succession strategy. They are also turning to new global markets and customers, improving price competitiveness, and pursuing advanced technologies and innovation for both new products and processes. A deep dive into the makeup of the other clusters reveals additional insights.

From our analysis of high performers’ capability clusters, we have identified the following key takeaways:

BRAND, REPUTATION, AND MANAGING CUSTOMER PERCEPTIONS IS HIGH-PERFORMING MANUFACTURERS’ TOP PRIORITY FOR CURRENT AND FUTURE COMPETITIVENESS

High-performing manufacturers rank brand-related capabilities high in current competitiveness and future importance. This cluster of capabilities collectively gravitates toward the upper-right quadrant of the competitiveness map; simply stated, this means that high performers consider these capabilities vital to both their current and future competitiveness.

History has shown the detrimental effects a declining brand and reputation can have on a manufacturer’s bottom line. It is no wonder that brand strength is considered a game changer capability, with high performers placing significantly more emphasis on this capability than other manufacturers both now and in the future. Among the other capabilities within this cluster, delivery speed, customer perceived value, and sales experience also rank high on both axes, with manufacturing executives indicating that these too are capabilities important to both current and future competitiveness.

Looking at the differences between high performers and other companies with respect to these capabilities (figure 4) yields additional insights. With delivery speed classified as a qualifier (that is, a capability on which high performers do not differ from other man
manufacturers), along with high performers being challenged in customer perceived value and sales experience, manufacturing executives are indicating that “the rest” are actively looking to close the gap with high performers in these capabilities.

Given their strategic importance both now and in the future, as well as the narrowing gap between high performers and other manufacturing companies, these brand, reputation, and managing customer expectations capabilities look to play a critical role in the manufacturing competitiveness battlefield ahead.

TALENT REMAINS A KEY CAPABILITY AMONG HIGH PERFORMERS, WHILE THE GAP IS CLOSING ON LEADERSHIP CAPABILITIES

Many of today’s high-performing manufacturers also consider the talent cluster of capabilities to be strategically important, indicated both by its placement on the scatterplot and the game changer designation of skilled workforce availability. In fact, these findings echo those of another study conduct-
ed by Deloitte and the US Council on Competitiveness, which found that manufacturing executives worldwide ranked talent as the most important driver of country-level manufacturing competitiveness.3

Talent will likely be a key competitive lever going forward as the skills gap issue becomes increasingly pervasive. As many as 2 million US manufacturing jobs are likely to go unfilled between 2015 and 2025 due to the unavailability of skilled workers.4 It appears that high performers already recognize the increasing need for a skilled and talented workforce in the face of an evolving manufacturing and technology landscape: High-performing companies plan to continue to differentiate their current and future performance by focusing on this game changer capability. However, concerned with the challenges posed by the skills gap and the difficulty of attracting new, top talent, both high-performing companies and all other manufacturing firms are placing relatively high emphasis on employee retention now and in the future, making it a table-stakes qualifier capability.

With the large wave of Baby Boomer retirements, and the consequent exodus of years of tribal knowledge and leadership, all manufacturers are finding leadership succession increasingly important to their future competitiveness. Strong leadership capabilities can help manufacturing companies effectively push through difficult business decisions, navigate rough waters, and establish marketplace dominance. During tumultuous times, in particular, the importance of strong leadership cannot be overstated. And while high performers currently place greater emphasis on leadership and management than other manufacturers, the gap with regard to its perceived importance for the future is closing.

HIGH PERFORMERS ARE FOCUSED ON IMPROVING THEIR PRICE COMPETITIVENESS WHILE SETTING THEIR SIGHTS ON NEW MARKETS AND NEW CUSTOMERS

Many high performers are clearly interested in pursuing new markets and new customers, as this cluster is home to three game changer capabilities. As manufacturing companies look to benefit from continued globalization, high performers are placing significant emphasis on penetrating new markets and expanding their global sales and marketing capabilities to cater to these new customers and geographies, as well as to hedge against economic downturns or suppressed demand in mature geographies. Rounding out the cluster with yet another game changer capability is global distribution and logistics, a key capability needed to penetrate new markets and spur growth among new customers.

Meanwhile, as high performers continue to penetrate new markets, they are looking to leverage price competitiveness capabilities, creating advantage by focusing on total delivered cost more sharply in the future than their competitors. And while creating higher value for price is a capability on which high-performing manufacturers place strong emphasis, our findings indicate that they will actually find it increasingly difficult to differentiate themselves on this capability. They are therefore apt to look for new ways to create value—in particular, ways involving new technology and innovation.

HIGH PERFORMERS ARE AGGRESSIVELY APPLYING NEW, ADVANCED TECHNOLOGIES TO HELP DRIVE INNOVATION WHILE PROTECTING INTELLECTUAL PROPERTY THROUGH AN ENHANCED EMPHASIS ON CYBERSECURITY

Manufacturers continue to seek to set themselves apart and thrive amid global competition by creating a pipeline of differentiated products and services that help capture higher market share and margins. High-performing manufacturers realize that without differentiation through technology or innovation, they are more likely to become cost-driven commodity businesses, making it difficult for them to succeed in the long run. Further, advanced technologies—and the products and services they can enable—hold sizable potential, and they are a core component of many companies’ overall future growth strategy.5

High performers are pursuing differentiation by emphasizing capabilities within the advanced technologies, innovation, and cybersecurity cluster that
appear difficult for other companies to duplicate. For example, cybersecurity and intellectual property protection, an innovation culture, advanced data analytics, and speed of new products to market are all game changer or creating advantage capabilities, meaning that high performers have placed or plan to place increased importance on these areas relative to their peers. Meanwhile, R&D capabilities and innovative product design, while critically important to a manufacturer, are increasingly being seen as new table stakes in the manufacturing competitiveness landscape. Advanced technologies and the use of technology to understand customer needs—both capabilities considered to be shift indicators—emerge as areas on which manufacturers are looking to significantly increase their focus in the future.

**Figure 6. Framework for analyzing competitiveness (with the diagonal)**

*Variables lying within the diagonal do not have a significant difference between current and future scores; variables above the diagonal have significantly higher future scores; and variables below the diagonal have significantly higher current scores.

Source: Deloitte Touche Tohmatsu Ltd. and US Council on Competitiveness.
Four classes of differentiating capabilities

While the nine capability clusters depicted in figure 5 define the strategies of high performers along our two dimensions of current competitiveness and future importance, the four classes of differentiating capabilities—described in figure 3 and depicted among high performers in figure 4—help draw out what differentiates high performers’ capabilities from those of other manufacturing organizations. An examination of which capabilities fall into each of these four classes of differentiation helps to answer the following questions:

1. Game changers: Which differentiating capabilities are high performers leveraging to create game-changing competitive advantage now and in the future?

High performers both currently outperform their competition and place more importance for the future on game changer capabilities such as creating value through brand strength and using that competitive advantage to penetrate new markets. High performers globalize brands through the use of additional game-changing capabilities such as global sales and marketing and global distribution and logistics capabilities. They build and enable competitive advantage through the use of capabilities related to maintaining a skilled workforce and balance sheet strength. And they have a strong understanding of the need to protect IP and mount strong cybersecurity capabilities to protect their most valuable assets and to continue to differentiate their performance now and in the future.

2. Creating advantage: How are high performers positioning themselves to create new competitive advantage in the future?

Bolstering the above game-changing capabilities, high-performing manufacturers indicate that delivering innovative new products to market faster, cultivating a strong innovation culture, and applying advanced analytics to create competitive advantage by generating deeper insights will be areas of future emphasis. Simultaneously, they plan to seek to lower total delivered cost to create a cost and/or pricing advantage over the competition. They are also focusing more strongly than their peers on risk management capabilities to improve their future competitiveness.

3. Being challenged: In what areas are other companies catching up with high performers?

High performers face challenges from other manufacturers in capabilities such as sales experience, their product and service bundles’ customer perceived value, and their ability to lower price. In addition, high performers are being challenged as “the rest” look to increase the strength of their supplier network and manufacturing processes while simultaneously stepping up their sustainability efforts. Lastly, other companies are also doubling down and catching up with high performers in critical leadership capabilities as a key way to try to close the gap.

4. Qualifiers: Are yesterday’s differentiating capabilities still enough to drive high performers’ future success, or have they become table stakes?

The gap between “the best” and “the rest” is closing: The absolute difference between high performers and other companies in their current competitiveness and future focus has significantly diminished over the past three years. For instance, it is becoming much more difficult for high performers to sustain a competitive edge in back-office areas like finance and accounting resources and business IT resources. Areas such as labor cost structure, overhead costs, and higher value for price have become table stakes as well. However, there are also areas on which most manufacturers—high performers as well as the rest—are placing greater strategic focus in the future, such as R&D capabilities, innovative product design, use of advanced technologies, and using technologies to understand customer needs. That said, the implication remains that, with an increasing number of capabilities becoming table stakes, it is getting harder to differentiate oneself as a high performer.
Identifying shift indicators

As described earlier, shift indicators are capabilities that show a statistically significant deviation from the diagonal of our scatterplot (figure 7). Among the group of high performers, shift indicators are useful for detecting sometimes subtle but important changes in the areas where high performers are placing their bets for the future—or, in some cases, instances where blind spots may be emerging.

Above the diagonal: For individual capabilities, a position significantly above the diagonal on the scatterplot indicates an increase in emphasis on that capability among high performers. As shown in figure 7, high performers are strategically shifting their focus toward capabilities such as speed of new products to market, use of advanced technologies, and using technology to understand customer needs. These capabilities, when woven together, suggest that high performers will be increasingly adopting advanced technologies and data analytics to develop and deliver innovative new products and services to market faster, while allowing them to connect more closely with their global customers in global markets.

Below the diagonal: A position significantly below the diagonal on the scatterplot in figure 7 indicates a decrease in emphasis on that capability among high performers. While our findings indicate that high performers are highly focused on developing new capabilities that can enhance their competitive advantage, like all companies, they can only concentrate on so many capabilities. This leaves a number of qualifier and being challenged capabilities in clusters below the diagonal, hinting that these capabilities may come under future competitive threat. And although manufacturing executives at high-performing companies likely consider many such capabilities to be table stakes for future competitiveness, these capabilities may still provide competitive opportunities for other manufacturers if high performers become complacent. For instance, balance sheet strength, a game changer capability for high performers today, is also a capability on which high performers plan to place significantly less emphasis in the future. Similarly risk management is a creating advantage capability for high performers, but they are placing less importance on it in the future compared to their current competitiveness. Balance sheet strength and risk management may in fact be potential blind spots—areas that high performers may not realize are sources of important strategic advantage and, therefore, on which they are not planning to capitalize as much in the future as they could or should. Granted, our findings indicate that, at this time, the rest of the pack is not focusing on these capabilities to close the gap either. Still, these blind spots may be of some concern, as lower-performing companies could easily sneak up on their higher-performing rivals over time and turn the tables in these areas.

Still, these blind spots may be of some concern, as lower-performing companies could easily sneak up on their higher-performing rivals over time and turn the tables in these areas.
Figure 7. Identifying industry shift indicators

HIGH PERFORMERS’ ADVANTAGE IS NARROWING

When comparing our 2013 and 2016 studies for shifts in capability types or positioning (and the magnitude of those shifts), we found that the difference in capability performance between high performers and other companies has significantly narrowed over the last three years. This indicates that “the rest” have intensified their efforts to close the gap, as reflected by the greater number of qualifiers and the lower number of game changers in this year’s study. This implies that to remain competitive high-performing companies will need to continue to keep their foot on the gas—they should not take their current lead for granted or rest on their laurels. Among the relevant findings:

• Many capabilities have become table stakes in 2016 compared to 2013. The absolute differences between high performers and other companies in their current competitiveness and future focus have significantly diminished from 2013 to 2016. This means that more and more companies are deploying their resources on the capabilities we studied—and that it is becoming much more difficult for high performers to maintain a competitive edge.

• The number of game changer and creating advantage capabilities decreased by nearly 50 percent from 2013 to 2016. For instance, R&D capabilities, delivery speed, supplier collaboration, and innovative product design, all of which were either game changer or creating advantage variables in the 2013 study, are now merely qualifiers. Similarly, manufacturing processes, a game changer in 2013, is a being challenged capability today.

• Brand and talent remain vitally important. Skilled workforce availability coupled with a strong brand reputation help a company produce better products and build a loyal customer base, contributing to higher profitability margins. These two capabilities remained game changers from 2013 to 2016, indicating the consistently important role that talent and brand play in creating a distinctive competitive advantage.

• New clusters of capabilities, such as advanced technologies, innovation, and cybersecurity, are becoming increasingly important for future competitiveness. Three capabilities—use of advanced technologies, use of technology to understand customer needs, and cybersecurity and IP protection—were added in the 2016 study to help clarify the role that advanced technology plays in shaping competitiveness. Cybersecurity and IP protection emerged as a game changer, as high-performing companies think that this capability helps them differentiate their performance both now and in the future. This is not surprising. With more and more manufacturing companies becoming part of a connected ecosystem through smart products, mobile apps, industrial control systems, and ever-growing connected supply networks, it becomes that much more necessary for them to protect themselves from cyberattacks; in addition, advanced manufacturing executives cite IP as their top data protection concern. High performers are also looking to increase their focus on advanced data analytics, innovation culture, and speed of new products to market to create competitive advantage in the future. Finally, advanced technologies and use of advanced technologies to understand customer needs were identified as shift indicators, illustrating the importance that both high performers and other companies assign these capabilities for the future. Indeed, the sheer amount and level of focus on advanced technologies by manufacturing executives around the world is quite high: They understand what is at stake and the pace at which the industry is transforming, and they are placing strategic bets in this area as a key battleground in the manufacturing competitiveness landscape going forward.
What does this mean for manufacturers?

The bottom line is that manufacturing executives cannot and should not assume that the capabilities that set them apart today will continue to do so in the future. The three-part framework described in this report can help executives analyze their own capabilities and guide them in implementing a relatively simple three-step strategy—assess, align, and act—that can not only better position high performers to continue to excel, but also help “the rest” improve their overall performance and competitiveness.

Assess

Evaluate your company’s capabilities, determine each capability’s position based on current competitiveness and future importance, and assess their relative positioning against that of high performers. This can help answer these important questions:

- **What is your company’s winning aspiration?** Aspirations are statements about the ideal future. The winning aspiration broadly defines the scope of the company’s activities—“where to play and how to win.” Aspirations can be refined and revised over time but should not change day to day; they exist to consistently align activities within the company.

- **Where will your company play?** Executives should clearly decide upon the company’s chosen playing field—in which markets, with which customers and consumers, in which channels, and in which product categories and services it will compete.

- **How will your company win?** How to win is the recipe for success in a company’s chosen playing field.

- **What capabilities should be considered to execute?** Executives and function/department leaders should identify the capability types and configurations the company will need to win in its chosen segments and chosen way.

- **What management systems are required?** Executives should determine if the company has the required systems, structures, and measures to enable the selected capabilities and strategic choices.

Align

To align to the company’s aspiration, executives should zoom out and develop a long-term, 10- to 20-year view of the manufacturing industry’s likely evolution. They should then determine the company’s ideal-state capability map and chart the path forward.

- **Have strategic focus.** Be explicit about aligning resources across specific strategic capabilities which create significant differentiation. Ensure the organization’s configuration, competencies, and incentives reinforce strategic goals as well as attract and motivate top talent.

- **Take a portfolio approach and set risk profile strategies accordingly.** Balance short-term needs with long-term aspirations and shape strategies, risk profiles, and investments accordingly.
Simultaneously, executives should zoom in to identify the gaps between the current and the ideal positions of their company’s capabilities. Review the 35 individual capabilities examined in this study as well as the clusters above and below the diagonal. Which capabilities does your company have, and on which does it need to place greater emphasis? Develop two to three high-impact initiatives in the next 6 to 12 months to accelerate toward the ideal state in a few focused areas. Remember:

- **Anticipate customer needs.** Tomorrow’s customers will expect products and services that are increasingly convenient, cost-effective, customized, and connected.

- **Operate outside traditional walls.** Innovative manufacturers are exploring various mechanisms to connect with the broader ecosystem to meet customer needs and desires at new levels.

- **Perseverance pays.** Firms with a fear of failure will likely remain followers, behind innovative companies with a greater risk tolerance. There is no single solution or pathway to success.

The bottom line is that manufacturing executives cannot and should not assume that the capabilities that set them apart today will continue to do so in the future.
What’s next for “the best” and “the rest”?

The story of “the best” and “the rest” will continue to unfold in the face of economic, financial, market, and technological disruptions. Not only have these disruptions caused a tectonic shift in the competitive landscape, but they have also narrowed the divide between high performers and other companies. Gone are the days when companies could rise with the tide and hide their inefficiencies. High performers today reap the rewards of their superior products and exceptional service in the form of substantial market share and better profitability. However, becoming a high performer is not easy; it requires a keen focus on acquiring needed capabilities—and these change with time. Winning is not an end unto itself but an ongoing process that a company must sustain over many periods to become a true high performer.
ENDNOTES


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Industry 4.0 and manufacturing ecosystems
Exploring the world of connected enterprises
**Introduction**

“INDUSTRIE 4.0 connects embedded system production technologies and smart production processes to pave the way to a new technological age which will radically transform industry and production value chains and business models.”

—Germany Trade and Invest

Manufacturers face changes on multiple fronts. Advanced manufacturing—in the form of additive manufacturing, advanced materials, smart, automated machines, and other technologies—is ushering in a new age of physical production. At the same time, increased connectivity and ever more sophisticated data-gathering and analytics capabilities enabled by the Internet of Things (IoT) have led to a shift toward an information-based economy. With the IoT, data, in addition to physical objects, are a source of value—and connectivity makes it possible to build smarter supply chains, manufacturing processes, and even end-to-end ecosystems.

As these waves of change continue to shape the competitive landscape, manufacturers must decide how and where to invest in new technologies, and identify which ones will drive the most benefit for their organizations. In addition to accurately assessing their current strategic positions, successful manufacturers need a clear articulation of their business objectives, identifying where to play in newly emerging technology ecosystems and (as important) what are the technologies, both physical and digital, that they will deploy in pursuit of decisions they make about how to win.

The charge is perhaps easier to execute in theory than in practice. Despite the hype around advanced digital and physical technologies, many are not well-understood. Likewise, many stakeholders are unclear as to what all this connectivity means for their companies—and for the broader manufacturing ecosystem.

One thing is certain, however: It would be folly to underestimate the crucial role the flow of information plays in the physical aspects of advanced manufacturing. In order to fully realize the opportunities both of these domains present, it is crucial to integrate the two—use the digital information from many different sources and locations to drive the physical act of manufacturing. In other words.

While Deloitte refers to smart, connected manufacturing as Industry 4.0, several other commonly known terms may point to the same phenomenon. These include:

- Industrial Internet
- Connected Enterprise
- SMART Manufacturing
- Smart Factory
- Manufacturing 4.0
- Internet of Everything
- Internet of Things for Manufacturing
words, integrate information technology (IT) and operations technology (OT) to forge a stronger manufacturing organization—a state that we and others refer to as Industry 4.0.8 Also known as SMART manufacturing or Manufacturing 4.0, Industry 4.0 is marked by a shift toward a physical-to-digital-to-physical connection.

In this report, we offer a perspective to help manufacturers navigate toward an Industry 4.0 future. We do so by examining the flow of information in intelligent production and connected supply chains—that is, systems that inform and coordinate the manufacturing, distribution, and aftermarket process—through the lens of Deloitte’s Information Value Loop (IVL). We then review the impact of the IVL on the manufacturing value chain. In the remainder of this article we will:

- Explain the term “Industry 4.0,” its history, and the expanding breadth of the concept
- Review the fundamentals of Deloitte’s IVL framework and its relation to Industry 4.0
- Identify two strategic areas—growing the business and operating the business—and six transformational plays that encompass the core opportunities for manufacturers to create with Industry 4.0 technologies
- Uncover key challenges for Industry 4.0 deployments
ROOTED in the notion that the swarm of connected, smart technologies could marry—and thus revolutionize—production, the term Industry 4.0 encompasses a promise of a new industrial revolution, the fourth such transformation in the history of manufacturing (see figure 1 for a summary of the industrial revolutions).  

The definition for Industry 4.0 was first introduced in 2011 at the Hannover Messe trade fair, and was the subject of an Industry 4.0 working group established by the German federal government. Germany Trade and Invest (GTAI) defines Industry 4.0 as:

"A paradigm shift... made possible by technological advances which constitute a reversal of conventional production process logic. Simply put, this means that industrial production machinery no longer simply “processes” the product, but that the product communicates with the machinery to tell it exactly what to do."

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**Figure 1. A history of industrial revolutions: Industry evolution with key developments**

<table>
<thead>
<tr>
<th>Late 18th century</th>
<th>Beginning of 20th century</th>
<th>1970s–2000s</th>
<th>2010 onward</th>
</tr>
</thead>
</table>
| First industrial revolution: Power generation  
  • Introduction of the power loom in 1784  
  • Mechanization of production facilities with water and steam power | Second industrial revolution: Industrialization  
  • Introduction of the assembly line in slaughterhouses in 1870  
  • Electrification drives mass production in a variety of industries | Third industrial revolution: Electronic automation  
  • Development of the first programmable logic controller (PLC) in 1969  
  • Growing application of electronics and IT to automate production processes | Fourth industrial revolution: Smart automation  
  • Increasing use of cyber-physical systems (CPS)  
  • In January 2011, Industry 4.0 was initiated as a “Future Project” by the German federal government  
  • With the introduction of IPv6 in 2012, virtually unlimited addressing space becomes available  
  • Governments, private companies, and industry associations have been focusing on Industry 4.0 and making investments since the 2010s |

Sources: Germany Trade & Invest, “INDUSTRIE 4.0—Smart manufacturing for the future,” July 1, 2014; National Academy of Science and Engineering, “Securing the future of German manufacturing industry: Recommendations for implementing the strategic initiative Industry 4.0,” April 2013; Deloitte analysis.
GTAI further adds that Industry 4.0 represents “the technological evolution from embedded systems to cyber-physical systems,” an approach that “connects embedded production technologies and smart production processes.”

In other words, Industry 4.0 is a state in which manufacturing systems and the objects they create are not simply connected, drawing physical information into the digital realm, but also communicate, analyze, and use that information to drive further intelligent action back in the physical world to execute a physical-to-digital-to-physical transition.

To illuminate its concept of Industry 4.0, GTA1 invokes the concept of Cyber-Physical Systems (CPS)—technologies that marry the digital and physical worlds, typically via sensors affixed to physical devices and networking technologies that collect the resulting data. This concept is remarkably similar to the more commonly referenced IoT.

The value of the Industry 4.0 concept can be enhanced through a clarification of the role played by technologies that facilitate the physical manipulation of objects. Deloitte accepts the GTA1 definition and believes the value of the Industry 4.0 concept can be enhanced through a clarification of the role played by technologies that facilitate the physical manipulation of objects. Manufacturing leaders must understand how both control systems in the factory and manufacturing execution systems—also known as operations technologies (OT)—and general corporate function and capability that synchronizes across functional systems—also known as information technologies (IT)—are co-evolving in ways that will bring profound opportunity and change to their business. Understanding how the various information technologies interplay with the physical world to drive innovation is a good place to start.

Connectivity, information, and action: The Information Value Loop and Industry 4.0

Inherent within manufacturing is the process of information creation, communication, and action. While its output is a physical object, manufacturing inevitably begins with information: A design is created via drawing, design software, or the scanning of a physical object, creating data. These data are then communicated to machines that execute the design, bringing it forth from the digital to the physical realm. Ideally, data from the process of creation (and subsequent use) is further captured, sparking ongoing cycles between the digital and physical realms. It is here that the overlap between the concepts of Industry 4.0 and the IoT becomes apparent.
The IoT is a crucial—perhaps the most crucial—element of Industry 4.0. The IoT concept has gained traction in recent years as the importance of connectivity—both in creating products and services and increasing satisfaction among customers and clients—has become better understood. Currently, a host of connected technologies is advancing rapidly, including high-quality sensors, more reliable and powerful networks, high-performance computing (HPC), robotics, artificial intelligence and cognitive technologies, and augmented reality. Taken together, these technologies can change manufacturing in profound ways. Our analysis of the resulting flows of information motivates a framework that captures the series and sequence of activities through which organizations create value from information: the IoT Information Value Loop (IVL) (see figure 2).

Figure 2. The Information Value Loop
The IVL is initiated through an action. Measurement of the state or behavior of things in the physical world gives rise to (creates) information that is subsequently communicated, aggregated, and analyzed (passing through the stages in the IVL) in order to inform future action. In general IoT contexts, the value of information varies depending on attributes related to its magnitude, risk, and time. Thus, it is important to be strategic in creating and/or controlling the flows of information enabled by

Figure 3. The physical-to-digital-to-physical leap of Industry 4.0

Source: Deloitte analysis.

For further information about these and other advanced, connected technologies, please visit the Deloitte University Press series:

evolving digital technologies. Here companies will always need to decide where to play and how to win.

The Industry 4.0 concept incorporates and extends the IoT at the nexus of the *act* and *create* stages of the IVL—namely, the physical-to-digital and digital-to-physical leaps that are somewhat unique to manufacturing processes (figure 3). It is the leap from digital *back* to physical—from connected, digital technologies to the creation of a physical object—that constitutes the essence of the Industry 4.0 concept. It is here that we will focus our analysis.

Industry 4.0 represents an integration of the IoT and relevant physical technologies, including analytics, additive manufacturing, robotics, HPC, artificial intelligence and cognitive technologies, advanced materials, and augmented reality, that complete the physical-to-digital-to-physical cycle.

Manufacturing leaders have the opportunity to develop improved operations strategies and to realize key business objectives based on the technologies they may choose to employ at various points in the manufacturing value chain. Some of the technologies that encapsulate the physical-to-digital-to-physical reach of Industry 4.0 are listed in table 1.

<table>
<thead>
<tr>
<th>Table 1. Industry 4.0 technologies</th>
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<table>
<thead>
<tr>
<th>Product impact</th>
<th>Potential IT/OT applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>• Sensors and controls</td>
</tr>
<tr>
<td>digital</td>
<td>• Wearables</td>
</tr>
<tr>
<td></td>
<td>• Augmented reality</td>
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<tr>
<td>Digital</td>
<td>• Signal aggregation</td>
</tr>
<tr>
<td></td>
<td>• Optimization and prediction</td>
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<tr>
<td></td>
<td>• Visualization and POU delivery</td>
</tr>
<tr>
<td></td>
<td>• Cognitive and high-performance computing</td>
</tr>
<tr>
<td>Digital</td>
<td>• Additive manufacturing</td>
</tr>
<tr>
<td>physical</td>
<td>• Advanced materials</td>
</tr>
<tr>
<td></td>
<td>• Autonomous robotics</td>
</tr>
<tr>
<td></td>
<td>• Digital design and simulation</td>
</tr>
</tbody>
</table>

Source: Deloitte analysis.
Integrating the digital and the physical to achieve business objectives

Even as we explore the ways in which information creates value, it is important to understand value creation in manufacturing from the physical perspective. Creating value in the form of products and services gave rise to the notion of a manufacturing value chain: the series and sequence of activities through which an organization transforms inputs into outputs, and ultimately sells, delivers, and continues to support those outputs for customers. Note that, in contrast to the IVL, the manufacturing value chain is generally perceived to be linear, befitting its focus on the production of physical objects. We posit that by augmenting the value chain with Industry 4.0 technologies, information generated in various stages can inform other points, making the structure—while still linear—far more dynamic and, from an information perspective, a circular feedback loop.

Throughout the manufacturing value chain—from design and development to manufacture, sale, and service—business outcomes may emerge from the integration of IT and OT. Broadly speaking, we identify two business imperatives for manufacturers: operating the business and growing the business. Within these imperatives exist four core business objectives: productivity, risk reduction, incremental revenue, and new revenue. Myriad sub-objectives can fall under these categories (see, for example, table 2) that define the tactical approaches for

<table>
<thead>
<tr>
<th><strong>Table 2. Industry 4.0 Key Business Objectives, Organized</strong></th>
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<tbody>
<tr>
<td><strong>BUSINESS OPERATIONS</strong></td>
</tr>
<tr>
<td>Productivity improvements</td>
</tr>
<tr>
<td>• Maximizing asset utilization and minimizing downtime</td>
</tr>
<tr>
<td>• Driving direct and indirect labor efficiency</td>
</tr>
<tr>
<td>• Managing supply network costs and synchronization</td>
</tr>
<tr>
<td>• Ensuring schedule and plan stability and accuracy</td>
</tr>
<tr>
<td>Risk reduction</td>
</tr>
<tr>
<td>• Ensuring raw material price and availability</td>
</tr>
<tr>
<td>• Managing warranty and recalls effectively</td>
</tr>
<tr>
<td>• Mitigating geographic risks</td>
</tr>
<tr>
<td><strong>BUSINESS GROWTH</strong></td>
</tr>
<tr>
<td>Incremental revenue</td>
</tr>
<tr>
<td>• Finding sources of growth for the core business</td>
</tr>
<tr>
<td>• Growing aftermarket revenue streams</td>
</tr>
<tr>
<td>• Deepening customer understanding and insights</td>
</tr>
<tr>
<td>• Strengthening customer integration and channels</td>
</tr>
<tr>
<td>New revenue</td>
</tr>
<tr>
<td>• Creating new products and service offerings</td>
</tr>
<tr>
<td>• Expanding internationally and in emerging markets</td>
</tr>
<tr>
<td>• Identifying attractive M&amp;A opportunities</td>
</tr>
</tbody>
</table>

Source: Deloitte analysis.
managers to deliver value. Some, as we will discuss, can be addressed more readily through Industry 4.0 technologies; others can be achieved via more traditional methods.

Depending on where a manufacturer’s focus lies, it may pursue different opportunities within the manufacturing value chain. Indeed, both operating and growing the business map to different areas across the value chain. The prioritization of operations versus growth can serve as a guide as to which areas of the value chain merit the greatest attention.

For example, the first stage of the manufacturing value chain focuses on R&D and design, areas where Industry 4.0 technologies can accelerate and improve the design cycle, reducing time to market, and linking design to smarter products. Stakeholders most impacted by Industry 4.0 at this stage will likely be design engineers. At the other end of the value chain, new or incremental revenue—and business growth—can emerge from Industry 4.0 applications in the form of new and improved products and services. Stages at the middle of the value chain—planning, factories, and support—can use Industry 4.0 technologies to transform operations in various ways. Each of these uses of connected technologies includes its own IVL, in which manufacturers may encounter bottlenecks that may impede optimal outcomes. In these cases, it is important to identify technology solutions that can address each bottleneck, a topic we will explore at length in subsequent research.

Figure 4 shows six of the transformational plays that we have identified in our work related to Industry 4.0.

Here, we will explore each of these transformations to better understand the stakeholders and processes they most impact, and to offer use cases to promote better understanding of potential business value.23
Growing the business
Applying Industry 4.0 to build revenue

On either end of the manufacturing value chain, Industry 4.0 technologies can enable business growth. In particular, in the R&D and design, sell and deliver, and support stages, various physical-to-digital, digital-only, and digital-to-physical connections can transform engineering, customer interaction, and even the products themselves.24

Products: Creating smart products and services

Products in the age of Industry 4.0 run the technological gamut. The use of IT such as sensors and wearables and OT such as advanced manufacturing in the form of additive manufacturing, advanced computer numerical control, and robotics can enable product improvements in various ways (table 3).

Indeed, manufacturers are already using advanced OT (such as additive manufacturing) and advanced IT (in the form of scanning and embedded sensors) to create new products and improve upon old ones—delivering new levels of value to customers, along with new data products.

In one such example, OT and IT are being used in the mass customization of medical implants—devices needed by many individuals, but each with its own unique geometry and circumstances. At its 3D Medical Applications Center (3D-MAC), Walter Reed National Military Medical Center manufactures prosthetics by scanning the patient’s individual anatomy, enabling it to use additive manufacturing technologies to fabricate a fully customized fit.25

Similarly, OT and IT are enabling the production of customized helmets for contact sports. Researchers at the University of California, Los Angeles (UCLA), and Architected Materials are developing technologies to improve the protection offered by football helmets. By taking a 3D scan of players’ heads, helmets can be built to individual measurements.26 Embedded sensors are also used to detect

Table 3. Potential Industry 4.0 applications for product transformation

<table>
<thead>
<tr>
<th>Product impact</th>
<th>Potential IT/OT applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Making already existing products smarter</td>
<td>Add sensors and connectivity to improve product performance or safety; enable connections to mobile applications to improve the user experience; add advanced materials to existing products to improve performance</td>
</tr>
<tr>
<td>Offering the data generated from smart technologies as a product or service</td>
<td>Offer access to data and metadata generated through existing business operations; build and sell a platform on which to manage data from connected products/enterprises; develop tailored data bundles for individual end users</td>
</tr>
<tr>
<td>Developing completely new products and services</td>
<td>Develop cost-effective mass customization; enable new and hybrid product innovations through advanced manufacturing technologies; create new service formats and business models</td>
</tr>
</tbody>
</table>

Source: Deloitte analysis.
27 Similar applications can be envisioned in business-to-business settings where the application of scanning/digital design, digital manufacturing, and field sensors will change the value proposition for industrial products. Indeed, General Electric’s power and water division is implementing digital twinning for the parts it supplies to power plants, wind farms, and electrical grids. Using sensors and controls, signal aggregation, and HPC, it is developing real-time digital simulation models of its real-life, physical parts operating within the plant. These cloud-based “digital power plant” models will enable plant operators to know the condition of parts, optimize power, determine the right time for machinery maintenance, and simulate various conditions to understand how they might impact the plant.28

The information gathered from customers can be used to price and sell products and services more intelligently. For example, Deutsche Bahn AG, a European cargo rail consortium, integrated its extensive network of railway monitoring sensors with its customer ordering and billing database and added in additional real-time data around traffic and capacities to generate intelligent pricing models customized to a client’s needs and the current conditions.29 For its part, rideshare service Uber uses data from its drivers and customers to power an algorithm that calculates surge pricing, a dynamic pricing model meant to adjust prices upward when demand is high.30

IT and OT can potentially drive product and service improvements, as well as more intelligent asset utilization. Further, this data can work both ways: Not only can information be sent to the manufacturer and its partners, but also back to the customer via smart apps that offer user-experience enhancements. In one such example, a pharmaceutical company considered integrating smart monitoring sensors into its inhaler product line to gather real-time data, with the goal of analyzing it and providing insights to both patients and their physicians.31

Table 4. Potential Industry 4.0 applications for customer transformation

<table>
<thead>
<tr>
<th>Customer impact</th>
<th>Potential IT/OT applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market and sell products and services more intelligently</td>
<td>Use data to drive customer intelligence; develop intelligent pricing strategies based on inventory and customer data; use analytics to predict customers’ need for spare parts</td>
</tr>
<tr>
<td>Improve the aftermarket experience</td>
<td>Use data to track asset condition, and part and system failures to predict customer needs and maximize uptime; perform fleet performance/operation analytics; enhance the user experience through sensor-enabled apps</td>
</tr>
<tr>
<td>Optimize performance and distribution</td>
<td>Use of data to put the right products with the right dealers at the right time to better manage inventory; remotely track usage, performance, and location of products; optimize distribution of products</td>
</tr>
</tbody>
</table>

Source: Deloitte analysis.
Engineers: Accelerating innovation and design cycles

At the start of the manufacturing value chain, products are developed and designed. Various Industry 4.0 technologies—notably OT technologies such as additive/advanced manufacturing and IT, digital tools such as CAD, and simulation—can come into play to impact the process in several key ways (table 5).

The use of digital-to-physical manufacturing technologies such as additive manufacturing in rapid prototyping can speed up the design process as well as the production of end-use products, thus reducing supply chain dependencies. Ford estimates that its use of rapid prototyping during vehicle design can save it weeks, with additively manufacturing prototypes taking hours to fabricate rather than the 4 to 6 weeks taken by typical machine tooling approaches, bringing automobiles to market months earlier.

Using advanced manufacturing technologies can also enable engineers to optimize manufacturability, as they can evaluate product design options based on the eventual assembly process.

Industry 4.0 technologies can drive improved engineering effectiveness via digital design and simulation. This can take the form of virtual product development and testing. John Deere uses augmented reality to allow customers to test and provide feedback on early design concepts, so that it can adjust and redevelop designs. The company estimates that having its engineers use virtual reality simulations to design the air-handling subsystem on its JD 7760 cotton harvester reduced the design cycle time from 27 months to 9 months, and reduced design costs by more than $100,000.

These tools can also take the form of open source innovation, allowing freelance design to improve products through open sharing of intellectual property. Local Motors, for example, crowdsources many designs among customers and enthusiasts in the community, holding design competitions and allowing clients to have a strong hand in the design of its cars. The company takes an open approach to intellectual property, and maintains that doing so fosters innovation and collaboration.

John Deere uses augmented reality to allow customers to test and provide feedback on early design concepts, so that it can adjust and redevelop designs.

### Table 5. Potential Industry 4.0 applications for engineering transformation

<table>
<thead>
<tr>
<th>Engineering impact</th>
<th>Potential IT/OT applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reduce idea-to-market time</strong></td>
<td>Use rapid prototyping and production capabilities to design new products and eliminate supply chain dependencies; configure new software solutions through cloud-enabled development tools</td>
</tr>
<tr>
<td><strong>Better link design to product intelligence</strong></td>
<td>Use data to anticipate design flaws and correct for them; design products and simulate usage based on total cost of ownership and supply implications; evaluate product design options based on manufacturability</td>
</tr>
<tr>
<td><strong>Improve the overall effectiveness of engineering</strong></td>
<td>Design and test new products through virtual simulation software; allow open source sharing of intellectual property to spur or improve designs</td>
</tr>
</tbody>
</table>

Source: Deloitte analysis.
Operating the business
Using Industry 4.0 technologies to increase productivity and reduce risk

INDUSTRY 4.0 technologies also enable improved operations. In the “plan,” “source,” and “make” stages of the value chain, various physical-to-digital and digital-to-physical connections can transform planning, support, and factory operations.

Planning: Predicting changes and responding in real time

When planning for production, manufacturers often encounter a host of uncertainties across the manufacturing value chain. IT and OT can support several transformations in this area (table 6).

Demand sensing and planning using IT (for example, sensors, signal aggregation, optimization, and prediction) enable manufacturers to gather data throughout the value chain. Data can be analyzed to uncover patterns, track movements, and, ultimately, understand what customers want, and where—so they can better plan to provide it at the right time and place.

For example, Ridgeline Pipe Manufacturing, a manufacturer of polyvinyl chloride (PVC) pipes, dealt with constantly changing customer demand and short lead times. The company needed to anticipate and plan in the face of uncertain demand, rapidly adjust to unforeseen changes, and reduce production changeover time. Using legacy systems, waste, costs, and inflexibility had risen to unacceptable levels. The company adopted a flexible production platform, in which automated production controllers managed the manufacturing equipment while providing access to information on diagnostics and performance. The system also analyzes production data to offer predictive failure analytics.

Factory: Creating a digital link between OT and IT

Perhaps no other segment better encapsulates the physical-to-digital transformation inherent in Industry 4.0 than the intelligent factory. The Industry 4.0-enabled factory utilizes physical-to-digital

<table>
<thead>
<tr>
<th>Table 6. Potential Industry 4.0 applications for planning transformation</th>
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<tbody>
<tr>
<td><strong>Planning impact</strong></td>
</tr>
<tr>
<td>Demand sensing and planning</td>
</tr>
<tr>
<td>Supply planning and supplier transformation</td>
</tr>
<tr>
<td>Outbound network optimization</td>
</tr>
</tbody>
</table>

Source: Deloitte analysis.
technologies such as augmented reality, sensors and controls, wearables, and the Internet of Things to track movement and production, monitor quality control, and manage the tooling life cycle, among other capabilities. In this way, Industry 4.0 on the factory floor can enable enhanced capability effectiveness, production asset intelligence, and activity synchronization and flow (table 7).

Industry 4.0 technologies can enable safer conditions for workers, enhancing labor productivity and effectiveness. Joy Global, a mining equipment manufacturer, added about 7,000 sensors to its remote-controlled extraction device, enabling it to mine in extremely deep mineshafts—areas often dangerous to workers who typically perform the work. Similarly, Boeing uses a positioning system to pinpoint worker location and assess the status of their safety harnesses, improving worker safety.

Beyond labor productivity and safety, IT/OT can transform product asset intelligence. Harley Davidson, for example, uses smart systems to detect defects during production processes. A smart system in its York, Pennsylvania, plant monitors equipment performance and initiates action autonomously. Upon detection of measurements beyond acceptable ranges, the machinery is automatically adjusted, preventing malfunctions.

Beyond avoiding proactive quality control, IT can impact activity synchronization and flow. With its Plant Floor Controls Network, General Motors uses sensors to measure humidity levels in its plants and direct physical action on the shop floor based on this physical-to-digital information cycle. Should levels in one area rise too high, vehicle bodies are automatically re-routed to less-affected areas, reducing the need for repainting and avoiding downtime.

Support: Automating and scaling aftermarket operations

Once a part or product has been developed, manufactured, shipped, and sold, Industry 4.0 technologies can impact support in at least three key ways (table 8).

Learning the causes behind a failure can enable manufacturers to more effectively address the root of the problem, rather than its symptoms.

Learning the causes behind a failure can enable manufacturers to more effectively address the root of the problem, rather than its symptoms. For example, Schneider Electric examined both maintenance and historical data collected over the course of one

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**Table 7. Potential Industry 4.0 applications for factory transformation**

<table>
<thead>
<tr>
<th>Factory impact</th>
<th>Potential IT/OT applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhancing labor productivity and effectiveness</td>
<td>Enhance capabilities with regard to fabrication and assembly; labor efficiency tracking; monitoring worker movements and productivity; and real-time safety monitoring of both workers and equipment</td>
</tr>
<tr>
<td>Production asset intelligence</td>
<td>Use proactive sensing and quality control for detecting defects; predictive maintenance of factory machinery; and tooling life cycle management</td>
</tr>
<tr>
<td>Activity synchronization and flow</td>
<td>Use technology for dynamic routing during the production process; virtual build simulation to maximize effectiveness of engineering changes to the production floor; accommodation of varying environmental factors that might impact machines</td>
</tr>
</tbody>
</table>

Source: Deloitte analysis.
year for a 110 MW steam model turbine which had required regular, ongoing maintenance for an escalating series of ongoing breakdowns, realizing that technicians had been addressing symptoms rather than root causes for a quality issue. Analysis enabled Schneider to address the root cause—thermal expansion problems—before they led to “symptoms”—bearing vibration—that caused equipment shutdowns. The company estimates that predictive maintenance offers millions of dollars in potential savings along with far fewer days of equipment downtime.48

In another predictive analytics example, Caterpillar is partnering with a company named Uptake, analyzing data gathered through telematics devices in its machinery to predict failures and engage in proactive repair. The companies see future opportunities to monetize this capability by offering new data products and services to customers.49

When responding to field failures, wearables and augmented reality can allow remotely located technicians to walk users through maintenance procedures. An industrial equipment manufacturer, for example, faced challenges as it expanded its operations to China, including increased operational costs and more frequent downtime of machinery. These issues were, in large part, rooted in a shortage of seasoned talent to train employees within the new manufacturing facilities. The manufacturer piloted a smart-glass, wearable technology so that remote experts could see alongside the equipment operators in the facility, and offer step-by-step instructions and training. These improvements were also accompanied by risk reductions in the overall production process due to better quality management.50

Table 8. Potential Industry 4.0 applications for support transformation

<table>
<thead>
<tr>
<th>Support impact</th>
<th>Potential IT/OT applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aiding productivity and quality of field repair</td>
<td>Enable remote, “see-what-I-see” field support; leverage digital overlay augmented reality for training; combine digital and mobile technologies for product manuals</td>
</tr>
<tr>
<td>Predicting part, product, or service failure</td>
<td>Use advanced analytics to ensure proper selection of tools for field technicians; use customer data to identify common problems and adapt designs; enact end-user smart training</td>
</tr>
<tr>
<td>Responding in a timely, accurate, and effective manner to that failure—sometimes preemptively</td>
<td>Use data to plan support-network allocation; optimize spare parts inventory mix; 3D-print spare parts and tools</td>
</tr>
</tbody>
</table>

Source: Deloitte analysis.
Looking ahead

Companies implementing or planning to implement Industry 4.0 practices can face several challenges that relate to the management and integration of IT and OT. While some have an organization-level impact, other challenges exist at the broader, ecosystem level. These challenges are heightened as connected technologies evolve at a rapid pace.

- **Talent and workforce**—In the process of trying to integrate IT and OT through the use of Industry 4.0 practices at the organization level, companies often face a shortage of talent to plan, execute, and maintain new systems. The number of engineers trained in handling unstructured data and big data tools—crucial for the type and scale of data generated by connected systems—is gradually increasing, but still falls far short of anticipated demand. The challenge extends to the shop floor as well. With vast experience in conventional manufacturing, many leaders feel uncomfortable with advanced manufacturing: They simply have less experience with the properties and behavior of materials, as well as the technologies and methodologies that use them. This can result in a tentativeness or unwillingness to adopt new approaches. We believe these leaders should adopt a proactive stance toward workforce development when considering Industry 4.0 applications. They may include partnering with outside organizations, high schools, technical colleges, and universities to develop an ongoing flow of workers versed in and attracted to advanced digital and physical manufacturing technologies.

- **Standards and interoperability**—From a broader, ecosystem-wide perspective, many of the systems underpinning Industry 4.0 applications are proprietary and can present integration challenges. A lack of interoperability poses a significant challenge for full adoption of Industry 4.0 technologies. Peer consortiums, industry associations, and government bodies are working to establish competing sets of standards, but it is currently unclear which will prevail. Managers should work with partners to stay current on evolving standards in order to maximize the value delivered by Industry 4.0 investments.

- **Data ownership and control**—As more stakeholders across the value chain become connected, questions will arise within the ecosystem regarding who owns the data generated and how to ensure appropriate privacy, control, and security. These questions grow thornier as suppliers and manufacturers become increasingly intertwined. Suppliers and vendors throughout the supply chain—right up to end-use retailers and customers—could potentially stake a claim on the data generated within their particular sphere, and perhaps even beyond. As this information can be used to drive product improvements, use of components, and efficiencies within the supply chain, it is particularly valuable. Managers should therefore pay close attention to the covenants they sign related to data ownership and access. Identifying and con-
trolling bottlenecks in the flow of data is likely to yield important opportunities for value creation and capture.\textsuperscript{57}

- **Security**—In addition to data ownership, security is often cited as a concern in implementing Industry 4.0 practices.\textsuperscript{58} Complex cryptographic algorithms might improve the security of devices, but this often comes at the cost of higher power consumption. This security-power trade-off becomes more important as deployments scale. Retrofitting old systems to new Industry 4.0 applications may also increase security risks, as the old systems were not designed to be connected in this way. In order to manage security risks, companies need to secure their systems, be vigilant to avoid new risks, and be resilient to limit the damage and restore operations.\textsuperscript{59} As a result, managers should adopt a proactive stance toward cybersecurity. When it comes to planning for Industry 4.0, the time to address security issues is up front, rather than as a follow-on task.
Conclusion

Despite the challenges, there is little doubt that penetration of Industry 4.0 concepts in companies’ manufacturing processes and supply chains will grow. Information flow, advanced technologies, and materials—in other words, the IT and OT that comprise Industry 4.0—make it possible to manufacture entirely new things in entirely new ways and revolutionize supply chains, production, and business models. It is difficult to overstate the importance of the interplay between IT and OT. Business leaders should not consider applications of one without the other, and in order to realize the full benefits of Industry 4.0, they must be truly integrated—working together to inform each other.

As the integration of information technology and operations technology evolves, manufacturers will need to assess not only where they are but where they wish to be—decisions that will dictate the types of information they will need to gather, analyze, and act upon. By integrating the information identified through the Information Value Loop, where the focus lies along the manufacturing value chain, organizations can understand which types of information will be most relevant to them as they seek to transform either their business operations, or growth, or both.

Effective use of information can in turn impact key business objectives such as business growth and business operations, and transformation can be possible across the value chain and its various stakeholders. The path to realization of Industry 4.0 involves a clear understanding of the ways in which the physical can inform the digital, and vice versa.


4. For further information about how the Internet of Things impacts choices about “where to play” and “how to win,” see Raynor and Cotteleer, The more things change.

5. For further information, see Holdowsky, Mahto, Raynor, and Cotteleer, Inside the Internet of Things (IoT).


8. Ibid.


12. Ibid.


14. Note: In Deloitte’s view, the GTAI’s original definition of Industry 4.0 is so close as to be identical to the concept of the Internet of Things that we have discussed it extensively as part of our IoT campaign. See for example Holdowsky, Mahto, Raynor, and Cotteleer, Inside the Internet of Things (IoT), and Michael E. Raynor and Mark J. Cotteleer, “Themorethingschange”, http://dupress.com/articles/value-creation-value-capture-internet-of-things/.

16. In our experience, there are those who consider the overlap between the IoT and Industry 4.0 to be so substantial that they are the same thing. As we shall explain, our view differs somewhat.


19. For a full description of the information value drivers that propel the Information Value Loop, see Raynor and Cotteleer, The more things change.


21. Deloitte University Press has published detailed analysis on a number of these technologies; see http://www.dupress.com.

22. The list of technologies that could be deployed in an Industry 4.0 world is extensive. We will explore these and many other specific technologies in future articles on Deloitte University Press.

23. Future articles in this series will investigate each of these transformations in greater depth. Our intent here is to introduce these transformations so that our readers can begin discussing the possibilities within their own organizations.

24. It is important to note that the potential uses specified in this section do not constitute an exhaustive list, but rather a sample of potential impacts that are made possible with the use of Industry 4.0 technologies. This paper constitutes the first in a series of analyses that will examine the impacts of Industry 4.0 across stakeholder groups.


27. Ibid.


29. Mariani, Quasney, and Raynor, Forging links into loops.

31. Based on client work.

32. Michalik, Joyce, Barney, and McCune, *3D opportunity for product design*.


39. Ibid.


45. Ibid.

46. Mariani, Quasney, and Raynor, “Forging links into loops.”

47. Raynor and Cotteleer, *The more things change*.


50. Based on client work.


52. Ibid.

53. Sniderman, Monahan, and Forsythe, 3D opportunity for engineers.

54. For more information about IoT-enabled supply chains, see Mariani, Quasney, and Raynor, “Forging links into loops.”

55. For further information about interoperability challenges for IoT-enabled devices, see Sniderman and Raynor, “Power struggle”.


57. Raynor and Cotteleer, The more things change.


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The rise of the digital supply network

Industry 4.0 enables the digital transformation of supply chains
Introduction

Supply chains traditionally are linear in nature, with a discrete progression of *design, plan, source, make, and deliver*. Today, however, many supply chains are transforming from a staid sequence to a dynamic, interconnected system that can more readily incorporate ecosystem partners and evolve to a more optimal state over time. This shift from linear, sequential supply chain operations to an interconnected, open system of supply operations could lay the foundation for how companies compete in the future.

We call this interconnected, open system a *digital supply network* (DSN). DSNs integrate information from many different sources and locations to drive the physical act of production and distribution. The result can be a virtual world, which mirrors and informs the physical world. By leveraging both the traditional and the new, such as sensor-based data sets (such as unstructured data), DSNs enable integrated views of the supply network and rapid use-case-appropriate latency responses to changing situations.

Many organizations already on the path to creating DSNs are shifting their focus away from managing and optimizing discrete functions, such as procurement and manufacturing. Instead, they often use DSNs to focus more holistically on how the full supply chain can better achieve business objectives, while informing corporate, business unit, and portfolio strategies. Indeed, DSNs increasingly allow supply chains to become an integral part of strategic planning and decision making. To this end, organizations can develop and leverage multiple DSNs to complement different facets of their strategy and more effectively target specific needs.

Historically, supply chain professionals managed the “four Vs” (volatility, volume, velocity, and visibility) as they attempted to optimize results across a series of objectives that include total cost, service, quality, and support for innovation. These traditional priorities are not likely to change, but going forward, supply chain decision makers should be able to achieve higher levels of performance with supply chain capabilities developed with new digital technologies. Additionally, supply chain professionals can help create new sources of revenue by providing new and faster access to markets, and supporting the production of smart products. Such opportunities would add revenue to the existing list of objectives for the supply chain.

Change is often hard, but the digitization of information and the application of advanced innovative technologies present the opportunity to drive business value throughout the supply chain. Moreover, digital disruption can change supply chains in any industry. To avoid becoming a victim of disruption, it helps to understand these shifts and adapt accordingly. In the pages that follow, we explore and analyze the next stage of growth for supply chains in DSNs by:

- Tracing the technological evolutions that enable the rise of the DSN
- Defining what the DSN is, along with its role within a wider business strategy
- Examining the trade-offs inherent in a typical supply chain, and identifying the characteristics that can mitigate those trade-offs
- Considering how to build a DSN
Technological evolution spurs the rise of Industry 4.0—and ushers in disruption

DIGITAL technologies have changed dramatically in recent years, driven largely by three key developments: lower computing costs, cheaper storage, and less costly bandwidth, in keeping with Moore’s Law (figure 1). The sharp cost decline over the last few decades has made it possible for companies to invest less and still reap the benefits of digital technologies on a wider scale.

However, the surge in digital technologies has likely not been driven by cost alone. Even as these costs have declined, computing power and technological capabilities have grown significantly. Indeed, between 1992 and 2002, computing power increased at an average of 52 percent per year, enabling organizations to gather, store, and analyze greater amounts of data than ever before. By 2020, we expect that 44 zettabytes of data will be created and copied each year, up from 1 zettabyte in 2010.

The confluence of these developments—significantly lower costs, and improved power and capabilities—has led to exponential changes that enable leaders to combine information technology (IT) and operations technology (OT). Companies are now empowered to create value in new and different ways. Improved processing capabilities now augment human thinking to analyze more data more quickly, and then act upon it. Such changes have ushered in the new era of Industry 4.0.

Figure 1. Declining costs in bandwidth, storage, and computing

Source: Deloitte analysis.
Industry 4.0, or the fourth industrial revolution, is characterized by new technologies that blur the lines between physical and digital worlds—driving real-time access to new and existing data sources. Paired with powerful analytics tools, such as visualization, scenario analysis, and predictive learning algorithms, this access to data is fundamentally changing how companies operate. Companies can now gather vast data sets from physical assets and facilities in real time, perform advanced analytics to generate new insights, and execute more effective decisions.

These decisions can then be actualized by the capabilities of advanced physical technologies, such as robotics, drones, additive manufacturing, and autonomous vehicles. At its core, this digital revolution is likely changing the way products are designed, created, and delivered to customers—and it has tremendous implications for the supply chain.

Between 1992 and 2002, computing power increased at an average of 52 percent per year.
Impacts of technology disruption
From a supply chain to a DSN

The function of any supply chain centers on the movement of materials, finished goods, capital, and other assets from place to place, as well as the production of finished goods. At their core, however, supply chains consist of many transactions: the exchange of time, money, information, or physical materials for some other unit of value. Dramatic technological and digital developments, such as greater computing power and lower overall costs, have impacted the traditional supply chain in several key ways, including a reduction in transaction costs and increase in innovation related to the production process itself.

Reducing transaction costs
The increase in power and efficiency of technologies has manifested itself in greatly reduced transaction costs for business operations both internally and externally. No longer does it have to be prohibitively expensive or time intensive to gain insight into each minute step of operations, or to deeply understand customer or supplier demand patterns. The influx of inexpensively acquired and easily manipulated information seems to demand that supply chains begin to incorporate and utilize increased intelligence. While the linear flow of designing, creating, and moving physical goods remains unchanged, the underlying data now flow through and around the nodes of the supply chain, dynamically and in real time (or at whatever pace may be required). The new interconnections between processes and subprocesses have transformed supply chains into efficient and predictive networks. When the cost of transactions falls, the ability to transact with more and different partners increases. This creates an opportunity to shift to a world of more networked supply chains, as companies can simply connect with more different partners when and where necessary in order to deliver substantially increased value.

Innovation in production
Simultaneously, how production is enabled in the physical world also seems to be changing as a result of dramatic improvements in both the process by which matter can be manipulated and the embedded computing power that actuates those processes in pursuit of production. Improvements in the flexibility and capability of capital equipment should lead to less of it being required to commence production. When less capital is required, the minimum efficient scale comes down as well, and production is allowed to scatter, locating closer to demand. Furthermore, smaller and more nimble players can enter the playing field more easily. These shifts in physical capabilities should be addressed both strategically and operationally.

The shift from linear supply chain to dynamic network
Ultimately, these changes can lead to a virtual collapse in the supply chain. This does not signify catastrophe but rather an opportunity that marks the shift from traditional, linear supply chain nodes to a set of dynamic networks. Furthermore, this could allow dramatically increased differentiation for the organization that is able to harness and leverage them.

The increase in digital connectivity and technological capabilities should reduce the latency between
new information and material action. In traditional supply chains, information travels linearly, with each step dependent on the one before it. This chain of events is linked in a very structured way: develop, plan, source, make, deliver, support (figure 2). Inefficiencies in one step can result in a cascade of similar inefficiencies in subsequent stages. Stakeholders often have little, if any, visibility into other processes, which limits their ability to react or adjust their activities. To operators, this is understood to be the expensive “bullwhip” effect, in which inventory fluctuations due to changes in customer demand grow larger, and thus less predictable, further up the supply chain.

As each supply node becomes more capable and connected, however, the supply chain collapses into a dynamic, integrated supply network. DSNs overcome the delayed action-reaction process of the linear supply chain by employing real-time data to better inform decisions, provide greater transparency, and enable enhanced collaboration across the entire supply network. Figure 2 represents the shift from the traditional supply chain to a single DSN. It is important to note, however, that organizations will likely have more than one DSN.

Supply chain management has typically broken supply chain activities into first planning and then executional parts of the supply chain: procurement, manufacturing, and distribution. This is often described as plan-source-make-deliver or some variant thereof, as shown in the left side of figure 2. Although historically helpful, this language represents a separation that no longer exists in a DSN world, nor does it acknowledge new capabilities that can be built using digital technologies. Our new approach means that the language of supply chain management—and the new collapsed supply network—must evolve to reflect these new capabilities.

The DSN nodes in Figure 2 depict this new terminology. The interconnected lattice of the new DSN model is clearly visible, with digital at the core. There is potential for interactions from each node to every other point of the network, allowing for greater connectivity among areas that previously did not exist. In this model, communications, for example, is multidirectional, creating connectivity in what traditionally has been disconnected by links in the supply chain. For example, drone video monitoring of remote work sites enables site optimization analytics and rapid issue detection, while on-site 3D printers rapidly make replacements to reduce downtime. While there are multiple underlying Internet of Things technologies that would enable this process and others like it, the key is identifying how
to communicate, aggregate, analyze, and act upon available information to achieve improvements.

The transition from linear to network often requires the organization to embrace a new way of linking physical and digital assets. Traditionally, linear supply chains rely on periodic relayed forecasts and plans, which become increasingly outdated—and thus inaccurate—with each stage. By connecting all the stages to one another via advanced technologies, DSNs can minimize the latency, risk, and waste found in linear supply chains. As DSN usage progresses and companies leverage their full supply networks, the traditional barriers of time and space should shrink. Companies would then be poised to achieve new levels of performance, improve operational efficiency and effectiveness, and create new revenue opportunities.

As noted above, organizations will likely have more than one DSN. Concurrent DSNs may leverage parts of the others—for example, they may share distribution facilities—but other pieces of the DSN would be separate, as in the case of manufacturing a different product or subassembly. Where there are multiple DSNs, however, organizations have the opportunity to match DSNs to commercial strategy and update them for the needs of the specific part of the business they support. It is this capability that allows DSNs to be more nimble, flexible, and customizable, in turn to better serve the strategic needs of the organization.

Thinking strategically about DSNs: What makes them different?

What separates DSNs from traditional, linear supply chains is the fact that DSNs are dynamic, integrated networks characterized by a continuous flow of information that facilitate automation, add value, improve workflow and analytics, and generate insights. With the ability to ascertain information in real time, many of the latency challenges inherent in linear supply chains can be avoided.

For example, Tesco, a multinational grocery retailer, tries to maximize revenue by reducing the chance of product stock-outs. Tesco feeds weather data into its predictive analytics tool to forecast demand of weather-dependent products (such as coleslaw and ice cream), and adjusts inventory and supplier orders in advance on a store-by-store basis.
to minimize missed revenue. Such analysis saved the company approximately $140 million, mainly through the reduction of wasted stock. Although historically the local grocer may have had the foresight to adjust orders when warmer weather was forecast, traditional supply chain latency may not have allowed a fast-enough reaction time to prevent a stock-out. A DSN sidesteps that latency by making changes based on data, communicating changes throughout the supply network in real time.

Figure 3 describes the main characteristics of the DSN: always-on agility, connected community, intelligent optimization, end-to-end transparency, and holistic decision making. Each of these characteristics plays a role in enabling more informed decisions and can help organizations address the central question in their strategic thinking: how to win.

Since the DSN is always on, sensors and other location-based tools can continuously transmit data to provide integrated views of multiple facets of the network with little to no latency. At the same time, each of the attributes in figure 3 enables the DSN to address many more issues within the supply chain beyond simply overcoming latency challenges. Indeed, the five main characteristics of the DSN describe much more than faster data transmission. They illustrate how companies can develop a far more complete picture of the total supply network—which can foster more informed strategic decisions.

The connected community allows multiple stakeholders—suppliers, partners, customers, products, and assets, among others—to communicate and share data and information directly, rather than through a gatekeeper. Being connected in this way allows for greater data synchronicity, ensuring that stakeholders are all working with the same data when making decisions, and allowing machines to make operating decisions.

Intelligent optimization describes the ability for machines and humans to work together, sharing data that can be analyzed to optimize decision making.

Likewise, end-to-end transparency can provide instant visibility across multiple aspects of the supply chain all at once, providing insights into critical areas. Rather than simply viewing discrete, siloed batches of information from multiple sources and attempting to piece them together manually or via other systems, DSNs enable companies to track material flow, synchronize schedules, balance supply and demand, and peer holistically into financials. In a sense, this amounts to a full map of the supply network, in which companies can see how all components interact and relate to each other.

This, in turn, can enable holistic decision making, wherein transparency of information across all areas of the supply network—and across all functions—can enable better supply and demand balancing as well as decision making. Strategic planning can enable organizations to clearly understand the trade-offs any decision may entail.

This type of holistic thinking can enable broader strategic transformations: Instead of planning incremental improvements within the supply chain, organizations can consider how the supply network can be used to fuel growth across the business. For example, Nissan improved the manufacturing capabilities of its automobiles using product life cycle management (PLM) software to enable collaboration among production teams across the world. Its virtual production process tests design feasibility in real time, incorporating input from PLM and designers in various facilities. In 20 percent less time, this process helped Nissan create a final design that ultimately was named the 2014 UK Car of the Year.

Instead of planning incremental improvements within the supply chain, organizations can consider how the supply network can be used to fuel growth across the business.
Making DSNs an integral part of business strategy

As organizations seek to determine and achieve their business strategies, they must make a variety of choices. With any strategic choice, however, come trade-offs: the choices or capabilities that are often surrendered to pursue the preferred option.\(^{16}\) One strategic choice may be to focus on agility and speed to market, with the understanding that this choice can close off other avenues such as lower cost. Still others may focus their strategic efforts on higher quality while recognizing that service level may be a necessary trade-off.\(^{17}\) Manufacturers often question whether they can pursue multiple goals or develop strong capabilities in multiple areas, as focusing on one area can often mean sacrificing capabilities in another.\(^{18}\) In this traditional scenario, trying to do too much can result in not being able to do anything exceptionally well.

This can make the strategic decision-making process particularly tense, as making inopportune choices can impact the outcome. Focusing on simple questions—where to play and how to win—can help identify major considerations and stakeholders, streamline the process, and prioritize where companies should be devoting their efforts. By answering these and other strategic questions, organizations can better understand their needs and make choices more specifically geared toward their goals and aspirations. With the advent of the DSN, however, these questions can evolve to enable more transformative decisions.

Figure 4 depicts the strategic decision-making process with traditional considerations (the strategic choice cascade) mapped against the new, more transformational questions enabled by the rise of DSNs.

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**Figure 4. Strategic choice cascade, with supply chain focus**

- **What are our goals and aspirations?**
  - Purpose
  - Financial objectives
  - Non-financial objectives

- **Where will we play?**
  - Customers
  - Products
  - Geography
  - Channels

- **How will we configure?**
  - Value proposition to customers
  - Sources of defensible advantage
  - Profit model(s)
  - Partnerships
  - Constituent engagement

- **How will we win?**
  - Distinctive capabilities
  - Enabling organizational system

- **How many supply chains do you need?**
  - Where will you segment by customer, product, geography, or channel?

- **Where will you compete on …**
  - Speed?
  - Agility?
  - Service?
  - Cost?
  - Quality?
  - Innovation?

- **Digital supply networks**
  - What initiatives will you deploy to configure your DSNs?
  - Value proposition to customers
  - Sources of defensible advantage
  - Profit model(s)
  - Partnerships
  - Constituent engagement

- **What priority initiatives?**
  - Value proposition to customers
  - Sources of defensible advantage
  - Profit model(s)
  - Partnerships
  - Constituent engagement

Source: Deloitte analysis.

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DSN capabilities can impact strategy by enabling organizations to achieve multiple priorities, thereby lessening or eliminating trade-offs while still maintaining competitiveness. Since organizations can deploy multiple DSNs, once they have answered the key questions detailed in figure 4, DSNs can be implemented to address each area of strategic priority identified. Depending on the specific DSN, transformations can address a variety of considerations.

It helps to examine the specific attributes of the DSN that can make this possible, and understand the importance of involving DSN planning in all stages of the strategic development process.

From trade-offs to customization: How to think about the DSN’s strategic role

Given the interconnected nature of the DSN, its systems can theoretically see and sense what is happening at any other node in the network at any given time. In this way, a DSN can serve as an integral part of business strategy, enabling the business to negotiate and in some cases even avoid trade-offs.

As companies make choices around the customers they want to serve and the products they wish to offer, they can also customize supply networks to address customer goals. These include getting products sooner or at the lowest possible cost. Some customers may want the ability to change their minds and shift product mix in real time, or only receive the “newest and best” goods while excluding outdated products from shipments. Thus companies can take segments of the supply network and align them to what is most important to current needs.

The integrated DSN may also allow organizations to compete on a variety of differentiating factors, such as speed or service, and apply them across all the traditional nodes of the supply chain as needed. As different stages of the supply chain communicate with each other via connected, Industry 4.0–driven technologies, priorities identified during the strategic decision-making process can be addressed on multiple fronts. In effect, this gives DSNs (and supply chains) new strategic decision-making abilities unlike any they have had before.

Given the interconnected nature of the DSN, its systems can theoretically see and sense what is happening at any other node in the network at any given time.

For example, GE Aviation changed its business model from merely manufacturing and selling engines to selling services measured by flight hours. Traditionally, aircraft engines were geographically isolated, with assets moving around the globe at all times. The performance management of the engine was also limited to the required periodic inspections, aside from some outputs in the cockpit. GE Aviation closed time and geography gaps by adding sensors to its aircraft engines that collected and transmitted data. GE is now using predictive analytics to lower maintenance costs and reduce engine downtime, offering economic value to the customer and a potential new revenue stream to GE.19

Transitioning to a DSN: Shifting strategic choices

Transitioning a traditional, linear supply chain into an always-on, holistic DSN can allow companies to shift their strategies, competing across different nodes of the supply chain simultaneously rather than simply focusing on one area. Once organizations have determined how they want to win, however, they should consider how to effectively configure their supply networks to successfully execute their plan. One of the benefits—and challenges—of the DSN is its agility, and the multitude of options companies can pursue to build one. Thus, as companies determine the strategy they wish to pursue, they should identify the type of supply network needed to achieve it. They can then determine the capabilities their supply network will require.
To configure and realize a DSN-driven strategy, companies can execute multiple different supply chain transformations. Figure 5 depicts a sample of nine strategic transformations companies can make by leveraging DSNs, along with a list of sample tactics that can enable each transformation.

![Figure 5: Strategic transformations via the DSN](image)

<table>
<thead>
<tr>
<th>Supply chain transformations</th>
<th>Sample tactics</th>
</tr>
</thead>
</table>
| **Design process optimization**               | • Sensor/data-driven design enhancements  
• Open innovation/crowdsourcing  
• Rapid prototyping  
• Virtual design simulation |
| **Product optimization**                      | • Data as a product or service  
• Make-to-use with 3D printing  
• Ultra-delayed differentiation |
| **Planning & inventory efficiency**           | • Analytics-driven demand sensing  
• Dynamic inventory fulfillment  
• POS-driven auto-replenishment  
• Real-time inventory optimization  
• Sensor-driven forecasting |
| **Risk prevention & mitigation**              | • Proactive quality sensing  
• Track-and-trace solutions  
• Proactive risk sensing |
| **Supplier collaboration**                    | • Analytics-driven sourcing  
• Asset sharing  
• Blockchain-enabled transparency  
• Cloud/control tower optimization  
• Supplier ecosystem |
| **Operations efficiency**                    | • Augmented reality-enhanced operations  
• Automated production  
• Predictive maintenance  
• Sensor-enabled labor monitoring |
| **Logistics optimization**                    | • Augmented reality-enhanced logistics  
• Automated logistics  
• Direct-to-user delivery  
• Driverless trucks  
• Dynamic/predictive routing |
| **Sales optimization**                        | • Inventory-driven dynamic pricing  
• Sensor-driven replenishment pushes  
• Targeted marketing |
| **Aftermarket sales & services**              | • Augmented reality-enabled customer support  
• End-to-end transparency to customers  
• Make-to-use with 3D printing  
• Predictive aftermarket maintenance |

Source: Deloitte analysis.
However, it is important to reiterate that many large organizations can pursue multiple supply networks, depending on their needs and the needs of their customers and stakeholders. In these cases, organizations might require multiple transformations for each, depending on what they wish to change and why. For instance, a supply network that focuses on low cost as its main differentiator might want to be more agile, and mitigate some of the trade-offs associated with planning and inventory inefficiencies or inadequate design process optimization.

EasyJet, for example, employs augmented reality smart glasses to enable two-way communication between its network of remote maintenance technicians and the central engineering team. Virtual step-by-step walkthroughs in real time enable technicians to effectively perform complex maintenance tasks and reduce downtime. EasyJet also uses drones to perform efficient and immediate visual safety inspections of the exteriors of its plane bodies, reducing the time the plane is out of service, how much hangar space is required, and the amount of inspection labor. Alternatively, a supply network focused on service might want to use DSN transformation tactics to mitigate some of the trade-offs around operations efficiency and supplier collaboration. In one such example, Spine Wave utilizes Medical Tracking Solutions’ iTraycer to create a device-focused inventory management system. Sensors are placed on each piece of spinal implant equipment, enabling Spine Wave to remotely track each piece within a spinal surgery kit. Spine Wave can then immediately replenish inventory, and automate invoices at the point of use. In contrast, most hospitals today must return the surgical kit to the company, which identifies which parts must be replenished and triggers invoicing.
Implementing a DSN
The physical-to-digital-to-physical loop

For business leaders accustomed to traditional linear data and communications, the shift to real-time access to data and intelligence fundamentally transforms the way they conduct business. Once organizations make the decision to adopt a DSN, they should consider how to develop, connect, and use the various Industry 4.0–driven technologies that power it. Before developing a DSN, it can be useful to consider the process of information creation, analysis, and action as a loop. The integration of digital information from many different sources and locations drives the physical act of manufacturing and distribution, in an ongoing cycle.

Real-time access to data and intelligence is fundamentally driven by the continuous and cyclical flow of information and actions between the physical and digital worlds. This flow occurs through an iterative series of three steps, collectively known as the physical-to-digital-to-physical loop:

- Physical to digital—Capture information from the physical world and create a digital record from physical data
- Analyze and visualize—Machines talk to each other to share information, allowing for advanced analytics and visualizations of real-time data from multiple sources
- Generate movement—Apply algorithms and automation to translate decisions and actions from the digital world into movements in the physical world

Figure 6. Physical-to-digital-to-physical loop and related technologies

Source: Center for Integrated Research
**Digital to digital**—Share information and uncover meaningful insights using advanced analytics, scenario analysis, and artificial intelligence.

**Digital to physical**—Apply algorithms to translate digital-world decisions to effective data, to spur action and change in the physical world.

Figure 6 depicts not only the physical-to-digital-to-physical loop but also the various digital and physical technologies that drive and enable it.

**Making the DSN real: Building and powering the digital stack**

As manufacturing organizations evolve, information clusters will likely move from separate silos to free-flowing, integrated information supported by interconnected technology solutions. In traditional, linear supply chains, data tend to be siloed into separate information clusters. Customer engagement data, sales and service customer operations data, core operations and manufacturing data, and supply chain and partnership data are all kept separately from each other where none can inform the other. This can often lead to missed opportunities as organizations cannot see where these areas intersect or align.

An integrated DSN hub can enable a digital organization and support for the free flow of information across information clusters. This hub, or digital stack, provides a single location to access near-real-time DSN data from multiple sources—products, customers, suppliers, and aftermarket support—encapsulating multiple perspectives. The digital stack includes multiple layers that synchronize and integrate this data to support and enable informed decision making (figure 7).
DIGITAL supply networks represent the evolution of supply chains, a result of the changing technology landscape, and increasing connectivity between the digital and the physical worlds. New access to information, computational abilities, and innovative technologies have collapsed and connected the formerly linear and siloed supply chain. Now real-time information and insights can be shared across the entire supply network to drive actionable decisions.

These changes are happening quickly. But with change comes opportunity: the ability of DSNs to play an integral role in strategic decision making, fewer trade-offs, customizing multiple supply networks to the specific needs of customers and clients. To start building a functional DSN, organizations can take several steps:

**Think big**

Often the first step in transforming a supply chain into a DSN is understanding what drives the need to differentiate. With a firm grasp on how and why one wants to differentiate, organizations can examine real supply chain applications that suit their business objectives.

Now real-time information and insights can be shared across the entire supply network to drive actionable decisions.

**Immerse yourself in innovation.** Explore the art of the possible to push the organization to understand the application of various technologies and their potential impacts on the business.

**Build your ecosystem.** Assess the organization’s digital maturity to understand what might be feasible, and what steps should be taken to build the technological capabilities necessary for a functional DSN.

**Start small**

The journey of a thousand miles begins with a single step. Consider ways to make the transition to DSNs a manageable and realistic one.

**Scale at the edges.** At times, it makes sense to start with smaller stakes, where strategies can be tested and refined with relatively fewer consequences. Selecting projects at the “edges” of the organization can provide greater latitude for building DSN capabilities, and can also help individuals feel less afraid to fail, which ultimately leads to greater innovation.

**Start with one or two transformations.** Prioritize areas that can unlock several waves of potential value, and build on those successes to continue to establish DSNs where they make strategic sense. At the same time, it can be essential to act with growth in mind: Focus on areas that might unlock several waves of potential value, creating a ripple effect that leads to exponential growth.
Act fast

Don’t wait for “perfect.” Exponential growth techniques are rapidly evolving, requiring constant iterations. Establishing a competitive advantage requires the willingness to join the fray, but you should do so quickly.

• **Prove it works.** Small successes can serve as proof points, leading to a greater willingness to take a chance on more substantive investments. By starting small and moving quickly, organizations can generate success stories that prove the value and importance of the DSN.

• **Market your successes.** Success generates success. Sharing examples of successful DSNs can evangelize skeptics within the organization. It can also demonstrate to customers that the organization is at the forefront of technology and is focused on their needs.

Advancing to an “always-on” DSN is not about a single technology implementation; it is more about developing an agile supply culture and promoting a more strategic approach to meeting customers’ needs. Investments in DSN technology and tactics can become key differentiators in not only supporting but also advancing business strategy.
ENDNOTES


3. Moore’s Law refers to the principle developed by Gordon Moore of Intel in 1965, which observed that processing capabilities would double roughly every two years.


7. For further information about Industry 4.0, see Sniderman, Mahto, and Cotteleer, *Industry 4.0 and manufacturing ecosystems*.


17. Ibid.


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Advanced Technologies Initiative
Manufacturing & Innovation

Executive Summary
Introduction

Nations have long striven to advance to the next technology frontier and raise their economic well-being. In today’s highly dynamic environment, advanced technologies have become even more essential in improving economic competitiveness and national prosperity. The manufacturing industry, propelled by advanced technologies and innovation, plays a key role in enhancing economic prosperity through increased productivity, higher GDP output, high value exports and the creation of higher-income jobs. A new globally competitive environment has emerged in which America’s technology and innovation leadership faces fresh and persistent vulnerabilities from increasingly competitive nations. Though the United States remains a global technology leader, retaining its innovation leadership has become a paramount, long-term concern. Thus, we are at an inflection point. To better qualify these challenges and highlight opportunities for future competitive advantage, a closer look was needed to determine how to reinvigorate America’s vibrant, future focused, and technologically innovative industrial base.

Thus Deloitte and the Council on Competitiveness (Council), as part of their multi-year Manufacturing Competitiveness Initiative, embarked on the Advanced Technologies Initiative to better understand the US innovation ecosystem, identify the most promising technologies impacting the manufacturing industry, as well as understand current and future trends in US and global scientific research and development (R&D). To this end, over the course of the last year Deloitte and the Council interviewed nearly three dozen chief technology officers (CTOs), chief research officers (CROs), chief executive officers (CEOs), and company presidents from the manufacturing sector, as well as nearly a dozen directors of US national laboratories and research facilities.

In the following executive summary, we highlight key findings from the full Advanced Technologies Initiative study. These insights examine the role of manufacturing in determining national prosperity, the most promising advanced manufacturing technologies, the US national innovation ecosystem, global research and development trends, opportunities and challenges faced by US businesses and concludes with an industry innovation playbook. Deloitte and the Council see this report as a foundation for ongoing dialogue with key stakeholders, such as industry, government, labor, academia, and national labs. The insights and recommendations developed here can further foster and enable an ecosystem in which research institutions and industry work together for mutual benefit and the betterment of society.
The linkages between national prosperity and advanced technologies, manufacturing and the innovation ecosystem

- The US manufacturing industry, increasingly propelled by advanced technologies, comprises a large portion of the economy, and drives economic prosperity through higher levels of productivity, GDP output, high value exports and higher income jobs than other industries.

- 21st century advanced manufacturing competitiveness has fully converged the digital and physical worlds where advanced hardware combined with advanced software, sensors, and massive amounts of data and analytics results in smarter products, processes, and more closely connected customers, suppliers, and manufacturers.

- Across dozens of interviews and hundreds of survey responses, senior executives consistently stressed as their highest priority the importance of digital technology, including the use of advanced sensors, the ‘Internet-of-Things’ as well as ‘Predictive Analytics,’ in driving their future competitiveness. In addition, ‘Advanced Material Science’ was also a key priority.

- Many nations, including the United States, have invested heavily in establishing national innovation ecosystems which connect people, resources, policies and organizations to collectively translate new ideas into commercialized products and services.

- Executives indicated the United States retains a leadership position in research, technology and innovation having created a strong foundation over the past century including: an educational system that fosters creative thinking, superior talent, world leading universities, excellent research infrastructure, solid venture capitalist presence, and strong support for regional innovation clusters (e.g., Silicon Valley).

Global R&D trends and America’s relative position

- Although the United States currently enjoys a leadership position, the gap in terms of R&D competitiveness is narrowing rapidly as countries, such as China, have been aggressive in attracting and nurturing STEM (Science, Technology, Engineering, and Math) talent, building domestic R&D capabilities, and offering attractive R&D incentives to foreign companies. In fact, though the United States is still the leader in R&D spend, some experts are projecting China may overtake it in R&D spend before the end of this decade.

- Nations have different research strategies and approaches. Both the United States and China have spread their R&D expenses across various industries including: computers & electronics, pharmaceuticals, and industrial machinery. However, other countries take a more focused approach – i.e., both Japan and Germany center their R&D efforts on the automotive and computers & electronics sectors, while more than half of South Korea’s manufacturing R&D expenditure is in computer & electronics alone.

- Businesses account for the lion’s share of R&D spending, an accelerating trend across leading nations. In addition, US companies dominate the global R&D spending landscape with 41 of the top 100 global companies (in terms of R&D spend).

- While US government spending on R&D has grown in real terms this past decade, it has declined as a percentage of the total federal budget, putting the basic and applied R&D leadership position of government-sponsored research institutes at risk.

Opportunities for US industry

- A host of promising long-term global trends will help provide opportunities for US companies to spur growth and innovation, including: an expanding middle class and rapid urbanization across Asia, increased global demand for commercial aircraft, the rapid technological advances in the auto industry (e.g., autonomous vehicles), increased output in the US chemical sector supported by low-cost domestic natural gas, and improving economic conditions resulting in increased industrial machinery demand.

Challenges for US industry

- Challenges faced by US companies include: a significant talent shortage and widening skills gap, alignment to foreign market conditions and business environments, coping with the risk of weak Intellectual Property (IP) protection around the world, and the high cost and complexity of compliance in an uncertain US regulatory environment.

Industry Innovation Playbook

- In order for companies to grow and succeed in the highly competitive global innovation space, there are a number of key insights to guide solid business strategy development, including: thinking like a venture capitalist to adopt a risk tolerant portfolio approach, operating outside of traditional walls to take advantage of collaboration opportunities across the innovation ecosystem, and understanding there is no singular solution where the path to success is forged in synergistic solutions and perseverance.
The Advanced Technologies Initiative:
List of executive interviewees

• Le Tang, Ph.D.—Vice President & Head of US Corporate Research Center, ABB
• Darlene Solomon, Ph.D.—Senior Vice President & Chief Technology Officer, Agilent Technologies
• Christine Tovee—Chief Technology Officer, Airbus North America
• Peter B. Littlewood, Ph.D.—Laboratory Director, Argonne National Lab
• Barbara Burger, Ph.D.—President, Chevron Technology Ventures
• Carmelo Lo Faro, Ph.D.—Vice President & Chief Technology Officer, Cytec Industries
• Klaus G. Hoehn, Ph.D.—Vice President, Advanced Technology & Engineering, Deere & Company
• Dean Bartles, Ph.D.—Executive Director, Digital Manufacturing and Design Innovation Institute
• A.N. Sreeram, Ph.D.—Corporate Vice President & Chief Technology Officer, The Dow Chemical Company
• Stephen G. Crawford—Senior Vice President & Chief Technology Officer, Eastman Chemical Company
• Ram Ramakrishnan—Executive Vice President & Chief Technology Officer, Eaton Corporation
• Ken Washington, Ph.D.—Vice President, Research & Advanced Engineering, Ford Motor Company
• Mark M. Little, Ph.D.—Former Senior Vice President, Director of Global Research & Chief Technology Officer, General Electric Company
• Gregory Powers, Ph.D.—Vice President of Technology, Halliburton Company
• I.P. Park, Ph.D.—Executive Vice President & Chief Technology Officer, Harman International
• Alex Dickinson, Ph.D.—Senior Vice President, Strategic Initiatives, Illumina, Inc.
• Tilak Agerwala, Ph.D.—Research Emeritus & Former Vice President, Data Centric Systems, International Business Machines Corporation (IBM)
• Jan Ziskasen—Chief Technology Officer, Kraft Foods Group, Inc.
• Paul J. de Lia—Corporate Vice President of Science and Technology & Chief Technology Officer, L-3 Communications Corporation
• Horst Simon, Ph.D.—Deputy Laboratory Director, Lawrence Berkeley National Lab (LBNL—Berkeley Lab’)
• Bill Goldstein, Ph.D.—Laboratory Director, Lawrence Livermore National Lab (LLNL)
• John B. Rogers, Jr.—CEO and Co-Founder, Local Motors
• Ray O. Johnson, Ph.D.—Former Senior Vice President & Chief Technology Officer, Lockheed Martin Corporation
• Ajay P. Malshe, Ph.D.—Founder, Executive Vice President and Chief Technology Officer, NanoMech, Inc.
• Dan Arvizu, Ph.D.—Former Laboratory Director & Chief Executive, National Renewable Energy Lab (NREL)
• Thomas E. Mason, Ph.D.—Laboratory Director, Oak Ridge National Laboratory (ORNL)
• Steven Ashby, Ph.D.—Laboratory Director, Pacific Northwest National Laboratory (PNNL)
• Mehmood Khan, Ph.D.—Vice Chairman & Chief Scientific Officer, Global Research & Development, PepsiCo, Inc.
• Diego Olego, Ph.D.—Senior Vice President & Chief Strategy and Innovation Officer, Philips Healthcare
• Kurt G. Olson, Ph.D.—R&D Fellow, PPG Industries
• Paul Hommert, Ph.D.—Former Laboratory Director, Sandia National Laboratories
• Cyril Perducat—Executive Vice President, Digital Services and IoT, Schneider Electric S.E.
• Patrick J. Byrne—President, Tektronix, Inc.
• Douglas H. Smith—Product Line Vice President, Tapered Roller Bearings, The Timken Company
• David L. Britten—Senior Vice President & Chief Technology Officer, United States Steel Corporation
• J. Michael McQuade, Ph.D.—Senior Vice President, Science and Technology, United Technologies Corporation
• Martin Thall—Executive Vice President & President, Electronics, Visteon Corporation
• Timothy D. Leuliette—Former President & CEO, Visteon Corporation
The linkages between national prosperity and advanced technologies, manufacturing and the innovation ecosystem

In today's highly dynamic environment, innovation through advanced technologies has become essential in improving economic competitiveness and national prosperity. As a result, many nations, including the United States, have invested heavily in establishing national innovation ecosystems which connect people, resources, policies and organizations to collectively translate new ideas into commercialized products and services. Given the number of significant trends emerging in the technology and innovation space, it is imperative to analyze America's relative position within the global innovation environment to accurately assess the myriad challenges that threaten its competitive standing.

A valuable “knock-off” effect is created through advanced technologies in the manufacturing ecosystem

The US manufacturing industry, increasingly propelled by advanced technologies, comprises a large portion of the economy. In order for companies to grow and succeed against aggressive global competition, manufacturers indicate advanced technologies are critical to company-level competitiveness by increasing differentiation through creating premium products, processes, and services that capture higher margins. The use of advanced technologies to produce complex products also enhances export competitiveness, leading to greater economic prosperity. Advanced manufacturing has the effect of strengthening the overall economy by creating higher-income jobs. This creates a knock-off effect where these industries are responsible for a greater proportion of jobs in the entire value chain, leading to a higher standards of living for the nation overall. To unlock this potential, nations need to continuously invest in R&D to develop strong manufacturing know-how as advanced manufacturing capabilities depend on a nation's support of cutting-edge R&D activities.

Ultimately, innovation and economic growth have a compounding and symbiotic effect. Indeed, a strong, innovative, and technology-savvy manufacturing base encouraged by an integrated support structure attracts more businesses which, in turn, creates more demand for high-paying jobs, thereby attracting more top-tier talent. These foundational elements build upon each other and become incrementally more valuable as the innovation ecosystem grows. This phenomenon presents both industry and government with a win-win situation that should encourage them to collaborate to build a strong and vibrant national innovation ecosystem.

Advanced industries drive national prosperity and generate more jobs, output and earnings

- Represent 17 percent of US economy (~$2.7 trillion)
- Account for 60 percent of US exports (~$600 billion)
- 70 percent of US Advanced Industries are Advanced Manufacturing Companies
- Perform 90 percent of private-sector R&D (~$250 billion)
- Represent 80 percent of the nation’s engineer’s (~5 million)
- Generate approximately 85 percent of all US patents (~360,000)
- Technology-intensive Manufacturing has a knock-off effect of 16
- Advanced industry workers earn nearly twice as much as those in other industries
- Produce almost twice as much GDP output per worker ($117K vs. $218K per worker)

Advanced technologies will unlock new opportunities...

...and underpin global manufacturing competitiveness, as 21st century manufacturers have fully converged the digital and physical worlds where advanced hardware combined with advanced software, sensors, and massive amounts of data and analytics results in smarter products, processes, and more closely connected customers, suppliers, and manufacturers.

‘Predictive Analytics,’ ‘Internet-of-Things’ and ‘Advanced Materials’ are considered the most promising in the United States. Across dozens of interviews as well as hundreds of survey responses, 5 US senior executives consistently stressed as their highest priority the importance of digital technology, including the use of ‘Predictive Analytics.’ They were also looking to place significant focus on innovative, smart and connected products. While interviewees were highly engaged in discussing the question of which technologies are the most attractive and/or promising, as most of the interviewed executives discussed and debated nearly every technology we asked them about, there was a strong collective focus on and interest in advanced manufacturing technologies such as ‘Predictive Computing and Analytical Modeling,’ ‘Connected Technology/Sensors (i.e., the Internet-of-Things or the ‘IoT’); as well as ‘Advanced Materials’ such as Advanced Ceramics and Composites.’ Collectively, the interviewees felt many of these advanced technologies were promising—especially when used together in a synergistic manner—and such technologies would be vital to their companies’ future.

China is prioritizing ‘Predictive Analytics’ to close gap with the United States and create competitive advantage through ‘High Performance Computing (HPC)’. In China, the highest ranked forward-looking strategy for advanced manufacturing technologies centers on ‘Predictive Analytics’ which aligns with the top priority in the United States. Companies in China are also looking to extend their manufacturing competency with a focus on developing ‘Smart Factories (IoT)’ to close the gap with global leaders including the United States. However, in contrast to strategies being followed in both the United States and Europe, China is also prioritizing the focus on ‘High Performance Computing (HPC)’ going forward, creating a potential “blind spot” for American and European companies looking to maintain their competitive position on the global stage.

Integrated European priorities are very much aligned with “Industry 4.0”. In European markets, the top strategic focus for advanced technology manufacturing companies is around creating an integrated and connected closed loop design and build process, with ‘Smart Factories (IoT)’ as their top focus. A second priority for companies in Europe centers on developing ‘Smart Products’ followed by increased efforts on the ‘Digital Design and Simulation Technologies.’ Considered as a group, these top three priorities represent a very integrated, strategic approach to advanced technologies going forward.

<table>
<thead>
<tr>
<th>Advanced Manufacturing Technologies</th>
<th>United States</th>
<th>China</th>
<th>Europe</th>
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<tbody>
<tr>
<td>Predictive Analytics</td>
<td>1</td>
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<td>Smart, Connected Products (IoT)</td>
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<td>Advanced Materials</td>
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<td>Smart Factories (IoT)</td>
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<td>Digital Design, Simulation, and Integration</td>
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<td>High Performance Computing</td>
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<td>Advanced Robotics</td>
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<td>Additive Manufacturing (3D Printing)</td>
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<td>Open-Source Design / Direct Customer Input</td>
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<tr>
<td>Augmented Reality (to improve quality, training, expert knowledge)</td>
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<td>6</td>
<td>8</td>
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<tr>
<td>Augmented Reality (to increase customer service &amp; experience)</td>
<td>11</td>
<td>9</td>
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Note: The 2016 Global Manufacturing Competitiveness Index (GMC), conducted by Deloitte and Council on Competitiveness, studied perspectives from over 500 global executives around key drivers of manufacturing competitiveness, including advanced manufacturing technologies.

The US national innovation ecosystem

**US innovation ecosystem plays a leading role in determining the nation’s competitiveness**

According to study results, the United States retains a leadership position in research, technology and innovation having created a strong foundation over the last century. Executives indicated advanced industries are closely linked to the entire innovation ecosystem – which consists of universities, research institutions, other supporting industries, financing mechanisms, and the government – and the competitiveness of a nation ultimately depends upon the success of its national innovation ecosystem. The ability for private and public sectors to work together and engage in creating an environment in the United States that promotes competitive R&D work and advanced manufacturing is vital.

“The United States remains the epicenter of ‘breakthrough innovations’ thanks to the ready availability of excellent research infrastructure, highly skilled talent, and lower hurdles to innovation—all part of a smoothly functioning innovation ecosystem.”

**Executive interviewee**

The current US innovation ecosystem possesses the critical attributes that positions it at the forefront of cutting-edge science, technology and innovation, including: an educational system that fosters creative thinking, world’s leading universities, superior talent, excellent research infrastructure, low hurdles to innovation, and strong support for regional innovation clusters. In addition, the United States’ entrepreneurial spirit and substantial funding from venture capital firms are huge competitive advantages and key differentiators for the country. This positions the United States well to actualize the substantial promise of advanced technologies and further strengthen its advanced industries.

**The current US innovation ecosystem – a byproduct of historical legacies and new market dynamics**

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b. Other Federal and State Agencies mainly include National Institutes of Health (NIH), United States Department of Agriculture (USDA), Department of Defense (DoD), Department of Homeland Security (DHS), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), Office of Science and Technology Policy, and state governments.
c. National Labs include 17 federally funded R&D centers (FFRDCs) under DOE as well as a variety of other federally funded research labs.
d. Lab managing entities include: Battelle Memorial Institute, MRIGlobal, University of Chicago, Bechtel National, Inc., University of California, The Babcock & Wilcox Company, URS Corporation, University of Tennessee, University of California, and Lockheed Martin Corporation.
e. NNMI, DoD Labs, MIT Lincoln Lab, and other labs.
Leveraging key strengths of our US innovation ecosystem

Executives indicated the United States should leverage key strength areas, such as:

World’s leading academic institutions and research facilities focused on innovation: The United States has top-tier universities which provide high value talent, while dedicated research institutions and national labs attract highly qualified researchers and scientists from around the world, positioning it well to actualize the substantial promise of advanced technologies by supporting its innovation ecosystem with requisite resources.

Top notch technologically advanced firms: From blue chips to successful start-ups, the United States is home to an enviable number of technologically advanced, innovative companies.

Strong Venture Capital (VC) investments feed national innovation pipeline: Executives interviewed highlighted the unique entrepreneurial spirit of US technology companies and the substantial funding made available by venture capital firms as significant competitive advantages and key differentiators for the country. The average equity value of VC deals in the US between 2010 and 2014 topped $42 billion and the United States has been more efficient than some other nations at converting early-stage investments into late-stage ventures.

Proximity to regional innovation clusters: Regional innovation clusters not only act as magnets for top students, researchers, scientists and VC funds, but also enable fruitful partnerships between research and educational institutions and corporations, that can lead to revolutionary research outcomes in key focus areas. Examples include the IT cluster (Silicon Valley) in San Francisco, the biotechnology cluster in Boston, and the automotive cluster in Detroit.

Global leadership in research, technology, and innovation: Study results indicate the United States is still the biggest global spender on R&D ($356 billion), eclipsing R&D expenditures by other nations around the world. This is particularly true in foundational areas like basic and applied research. Companies looking to have leading edge in specific technologies should look at partners within the broader ecosystem, like the National Labs, to broaden their research agenda, identify new potential applications and advance their innovation portfolio and ecosystem.

Advanced Technology deep dives: e.g., Internet-of-Things (IoT) The study also includes an entire section with additional insights for some of the most promising advanced technologies identified, including market size, potential current and future applications, as well as national labs that are heavily involved in these areas.

### Internet-of-Things

**Global Market Size, Growth** and **Description**

Internet-of-Things (IoT) refers to amalgamation of advanced software, cost-effective sensors, and network connectivity that allow objects to interact digitally.

The IoT concept involves connecting machines, facilities, fleets, networks, and even people to sensors and controls; feeding sensor data into advanced analytics applications and predictive algorithms; automating and improving the maintenance and operation of machines and entire systems; and even enhancing human health.

Note: Market size of IoT is exceedingly large since IoT encompasses many of the emerging technologies that have applications across industries.

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<td>$1,928 billion</td>
<td>19.6% (2.9 x)</td>
<td>$5,649 billion</td>
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**Current Applications Include**

- Services related to safety of the vehicle and passengers, navigation, location-based services, and infotainment.
- RFID technology - made possible through IoT — to predict retailer’s inventory requirements in real-time.
- Developing a behavioral model that can predict disease outbreaks.
- Enabling smart city infrastructure, smart manufacturing, building and home automation, and smart farming (that ensures better crop yield, greater control of soil conditions, better irrigation management and real-time weather monitoring).

**Promising Future Application Examples**

- Use in remote vehicle monitoring, control and diagnosis; enhanced human-machine interactions; enhanced and automated safety systems; smart parking and traffic management; vehicle-to-vehicle (V2V), vehicle-to-device (V2D) and vehicle-to-infrastructure (V2I) communications; autonomous or self-driving vehicles.
- Use in precision manufacturing; improved logistics/supply management.
- Remote Machine and Machine to Machine (M2M) communications will enable new levels of smart manufacturing automation across industries and value chains.

**DID YOU KNOW?**

It is projected that 4.9 billion connected devices (enabled by IoT) will be in use by 2015 and will likely increase to 25 billion by 2025.

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1. Argonne National Lab
2. Pacific Northwest National Lab
3. Sandia National Labs

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12. Current Applications Include

13. Promising Future Application Examples

14. DID YOU KNOW?
Global R&D trends

**The United States is leading but the gap is closing:** Though the United States retains a leadership position in research, technology and innovation having created a strong foundation over the last century, the gap in terms of R&D competitiveness between the United States and other nations, such as China, is narrowing rapidly. Many experts interviewed for the study attribute this phenomenon primarily to the growing competitiveness of emerging nations. These nations have been aggressive in attracting and nurturing STEM (Science, Technology, Engineering, and Math) talent, building domestic R&D capabilities, and offering attractive R&D incentives to foreign companies. In fact, though the United States is still the leader in R&D spend globally, some experts are projecting China may overtake it in R&D spend before the end of this decade.

**China is on the rise:** Success of the US innovation ecosystem has been in part due to the government's unflinching focus on financing foundational basic and applied research, and supporting businesses involved in R&D through various incentives. In contrast, China's R&D budget tilts heavily toward spending on commercialization, with only a small portion allocated to basic and applied research. While this fast follower approach might not pose a significant threat to foundational innovation currently, should China switch gears and ramp up investments in foundational basic and applied research, it could pose a competitive threat to US leadership in the long run.

**Nations have different research strategies:** Emerging advanced technologies expected to transform the entire global technology landscape, will likewise significantly impact and alter the manufacturing sector. However, these advanced technologies may affect different manufacturing sectors and countries to varying degrees depending upon each particular nation's strategy. Both the United States and China have spread their R&D expenses across various industries including: computers & electronics, pharmaceuticals, and industrial machinery. However, other countries take a more focused approach where both Japan and Germany center their R&D efforts on the automotive and computers & electronics sectors, while more than half of South Korea's manufacturing R&D expenditure is in the computer & electronics industry alone.

**R&D spending wars:** Businesses account for the lion's share of R&D spending, an accelerating trend across leading nations. In addition, US companies dominate the global R&D spending landscape with 41 of the top 100 global companies (in terms of R&D spend).

**Flat federal funding poses risks:** Executives noted while US government spending on R&D has grown in real terms this last decade, it has declined as a percentage of the total federal budget, putting the basic and applied R&D leadership position of government-sponsored research institutes at risk.

**Proximity matters:** Having said that, US industries currently enjoy a competitive advantage over other nations as a significant amount of basic and applied research occurs within US borders, allowing the innovation ecosystem to take advantage of the geographic proximity to national research assets. US businesses can help maintain this edge, and preempt competition, by bolstering mechanisms to translate these local research outputs into superior products and services before their global competition. This calls for efficient, effective and collaborative mechanisms between industry, research labs, and other players in the ecosystem.

**Innovation Ecosystems - The sum is greater than the parts:** The United States also remains the center for “disruptive innovation” thanks to its research infrastructure and low barriers for entrepreneurs and start-ups. Disruptive innovation is fueled by active investments through a variety of mechanisms including: traditional venture capital (VC) firms and angel investors, separate venture funding arms established by industrial companies, crowdsourcing and open platform sharing, and crowdfunding for new ideas. The Silicon Valley innovation ecosystem exemplifies how the proximity to industry, start-ups, VCs, labs, and universities can enhance an industry sector’s competitiveness. In fact, executives interviewed for the study said regional innovation clusters not only act as magnets for top students, researchers, scientists and VC funds, but also enable fruitful partnerships between research and educational institutions and corporations, that can lead to revolutionary research outcomes in key focus areas.
Clearly, a strong focus on innovation is essential to the health of not only individual companies, but also the overall US economy. In order for advanced manufacturing companies to capitalize on emerging opportunities while mitigating potential risk, there are a number of key insights to guide solid business strategies and include in their “Innovation Playbook” going forward.

Putting ideas to work – The Industry Innovation Playbook

Think like a venture capitalist
In today’s highly dynamic and interconnected world, highly innovative companies are adopting calculated risk-taking strategies and leveraging best practices from more agile start-ups.

Take a portfolio approach
Companies not only need to invest in short-term innovations for immediate benefits with existing products but should also place emphasis on long-term R&D investments that result in transformational gains.

Operate outside of traditional walls
Innovative companies are exploring various mechanisms of collaboration outside of their walls and with the broader innovation ecosystem (e.g. VC arm, joint ventures with cross-industry companies/organizations, university and/or national lab innovation partnerships, crowd sourced solutions).

There is no singular solution
Many advanced technologies hold great promise but the most significant transformational shifts occur when multiple technologies are combined synergistically to achieve innovative solutions. There is no singular solution where the path to success is forged in synergistic solutions and perseverance.

Have strategic focus
Successful companies are explicit about aligning their activities and resources across different innovation ambition levels and ensure the approach, organization configuration, competencies, and incentives consistently reinforce their strategic goals.

Be risk tolerant
Truly transformative innovations, like basic research breakthroughs, are saddled with high risks of failure. But, if successful, transformative innovations can create new business opportunities which result in significant market share gains and profits.

Perseverance pays
Firms which fear failure or which fear to bounce back when met with failure will remain as followers to innovative firms which have a greater appetite to risk, innovate consistently and have gained experience from their failures.

Be explicit about innovation ambitions
Then organize and execute accordingly.

Look beyond product innovation
To transform other elements of your business system.

Diagnose your capabilities
And build up your innovation management system along with your ecosystems partnerships.

Source: Deloitte Monitor Innovation Matrix.
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Endnotes


2. Ibid.


6. Ibid.

7. Ibid.


17. Ibid.

3D opportunity for business capabilities

Additive manufacturing transforms the organization
Additive manufacturing (AM) has existed for decades, largely used for prototyping or building demonstration models. More recently, driven in part by the advent of the Industry 4.0, a wider understanding of AM’s value potential in product manufacturing, supply chain configuration, and new business models has emerged. Advancements in technology, a wider selection of materials, and growing operational competencies have made AM a more viable option for companies to consider—one that offers transformative potential.
Additive manufacturing
More than an experiment

BUT deploying AM in an organization typically requires more than the capital for purchasing and installing an industrial-grade AM printer. Successfully implementing and scaling AM technology to an industrial level—or even to determine whether it is economically justifiable—often requires organizations to consider factors beyond the AM machinery. Key among these are talent development and workforce management, quality assurance, material science, and data management. Whether an organization has initially tested or implemented AM and is looking to scale it, or it is only beginning to consider an implementation, identifying and developing these additional enabling elements can be critical to success.

In this paper, we discuss the enabling elements that organizations should consider as they seek to build their AM capabilities. Using the Deloitte AM framework as a guide, we examine each of the enabling elements that organizations may need to develop as they pursue the AM paths most relevant to their operational, financial, and strategic goals. Through a series of executive interviews, we also recount real-life examples of organizations that have built those elements in pursuit of their AM goals, presenting lessons for those who may want to do so themselves.

THE ADDITIVE MANUFACTURING FRAMEWORK

AM’s roots go back nearly three decades. Its importance is derived from its ability to break existing performance trade-offs in two fundamental ways. First, AM can reduce the capital required to achieve economies of scale. Second, it increases flexibility and reduces the capital required to achieve scope.

Capital versus scale: Considerations of minimum efficient scale can shape supply chains. AM has the potential to reduce the capital required to reach minimum efficient scale for production, thus lowering the manufacturing barriers to entry for a given location.

Capital versus scope: Economies of scope influence how and what products can be made. The flexibility of AM facilitates an increase in the variety of products a unit of capital can produce, which can reduce the costs associated with production changeovers and customization and, thus, the overall amount of required capital.

Changing the capital versus scale relationship has the potential to impact how supply chains are configured, and changing the capital versus scope relationship has the potential to impact product designs. These impacts present companies with choices on how to deploy AM across their businesses.

Companies pursuing AM capabilities can choose different paths (figure 1):
Path I: Companies do not seek radical alterations in either supply chains or products, but they may explore AM technologies to improve value delivery for current products within existing supply chains.

Path II: Companies take advantage of scale economics offered by AM as a potential enabler of supply chain transformation for the products they offer.

Path III: Companies take advantage of the scope economics offered by AM technologies to achieve new levels of performance or innovation in the products they offer.

Path IV: Companies alter both supply chains and products in pursuit of new business models.
ORGANIZATIONS adopting AM often start with path I (stasis), focusing on rapid prototyping and then moving on to tooling. This enables them to exploit some of the more easily attainable benefits of AM—faster design cycles, accelerated innovation, rapid development of tooling, and other manufacturing aids—while minimizing operational risks. Indeed, Deloitte has explored the benefits of stasis-driven AM applications at length in its 3D Opportunity series (see the sidebar “Learn more about 3D Opportunity”).

Stasis-quadrant AM applications fit largely into established processes and do not directly touch production. Thus limited need exists to modify or develop new manufacturing or supply chain procedures in path I, or to connect to larger information and management systems. Similarly, there are few impacts to the organizational structure outside of the engineering function. Perhaps, most critically, less complex quality assurance (QA) requirements are required than for other paths, given the relatively simple QA requirements for prototypes and internal tooling. Indeed, QA requirements can serve as a barrier to broader AM adoption, with the need for greater and more complex QA deterring organizations from employing AM beyond stasis.

“Most of my experience has been with manufacturing, whereas AM evolved from prototyping. Prototyping is different than manufacturing—it’s like the inverse. Prototyping might make 10 of the same part; chances are you can get by with a less rigorous build layout, and no post-processing may be required, with little specification or requirements. In manufacturing, you are going to make 1,000 parts, and if you have a 10 percent error in your build, you are scrapping 100 parts. It’s not easy to translate that mind-set. I think that is why it is such an exciting time in the AM industry. Arconic has a long history in manufacturing, and it’s my job to make sure we learn our lessons for this new technology in a shorter period of time.”

— John Barnes, Arconic

Stasis activities and applications are available to almost any organization that is able to afford the appropriate AM machines, material, and software. However, it can be difficult, if not impossible, to unlock the value in subsequent AM paths without further developing AM enabling elements. The value derived from pursuing these additional paths can justify the investment required. Figure 2 depicts the areas of potential value along each path of AM transformation.
Applications from which value can be derived in the paths beyond stasis can be summarized in the following way:

**Path II**: Two key sources of value in this path are distributed manufacturing (the ability to manufacture in multiple, geographically dispersed sites closer to the point of use) and digital inventory (the ability to print on demand, as needed, using digital design files, thus reducing or eliminating requirements for physical inventory).

**Path III**: Value is derived from using AM to improve product functionality through design optimization (essentially, making products with geometric and mechanical features that are not possible through conventional manufacturing) or to enable cost-effective product customization.

**Path IV**: Here, new value is created and delivered in new ways by leveraging both AM-driven product and supply chain innovations. This results in new business models driven by capabilities established in both paths II and III.

Before pursuing a new path within AM, it is important for organizations to review their operational and strategic priorities, and examine how these will be impacted by the pursuit of different types of AM value. Executives interviewed suggest several approaches to successfully exploring these other sources of value. In one approach, organizations start AM adoption with less complex AM solutions, adding and refining competencies and then progressing to more complex solutions. Other executives, however, advocate exploring all four quadrants simultaneously. We explore both of these approaches below.
Starting small to build for the future

Examining the relationship between types of AM value and an organization’s financial, operating, and strategic objectives can help determine which AM enabling elements to prioritize for development. This exercise of choosing a starting point for AM investment partially defines the organization’s future options for successfully capturing AM value. For example, Greg Kilchenstein, a senior Department of Defense Acquisition, Technology, and Logistics (DoD AT&L) official, explained why the armed services are currently focused on understanding and adopting AM on a smaller scale, for discrete objectives:

“My perspective is that focusing our attention on 3D printing technology is great, but there is an urgent opportunity to leverage additive capabilities here and now to accomplish what we want to do in the near future. If we can figure out how to use this technology to better sustain our $500 billion in weapons systems, that can lead the way to real value. Let’s cut our teeth on things providing benefit in the near term, and continue to build the levers to set the stage and work toward the ‘apples at the top of the tree,’ like 3D-printing metal flight-critical parts.”

— Greg Kilchenstein, AT&L

This is an example of an organization that is focused on unlocking initial supply chain value by addressing a specific operational issue, sustainment, and using that experience to build more sophisticated AM supply chain capabilities. AT&L’s experience in AM-enabled sustainment can serve as a foundation for capturing larger and more complex forms of AM value, such as printing system-critical parts closer to the point of use (a path II application).

Unlocking value in all quadrants

A broader approach to moving beyond stasis is to build out all of the AM enabling elements required for following other paths. The advantages of this comprehensive approach include more integrated enablers, a clearly defined transformation imperative, coordination, and greater efficiency in enabler implementation. While a larger investment is initially required, this approach enables the organization to realize value across a breadth of initiatives much more rapidly. At the same time, however, the learning curve can be steeper, and the need for large-scale adoption can be challenging to coordinate and implement.

John Barnes, an executive at Arconic, a global technology, engineering, and advanced manufacturing leader, explains the array of applications for which the company uses AM:

“Arconic looks at AM comprehensively owing to our breadth of manufacturing capability. For example, in direct printing, we have announced our agreement with a large aircraft manufacturer for manufacturing 3D-printed titanium fuselage and engine pylon parts. We also have a group that makes all manner of latches, who are looking at replacing more complex parts with additive manufacturing for weight and cost savings. In hybrid, our forging group is working to combine traditional and additive manufacturing to reduce material input and create value for our customers. We have been using AM in an indirect manner via our casting group to reduce the time to market for investment castings. But we also use it ourselves to improve our internal processes, make shop aids for safety, and even repair components and return them to service. At Arconic, we are hitting all of those areas, and we see huge opportunity for aerospace.”

— John Barnes, Arconic
REGARDLESS of the approach organizations take, as they seek to develop the processes, people, and technology that help capture the value in other quadrants beyond stasis, how should they prioritize their investments? Operating AM beyond stasis typically requires developing a mix of enabling elements (figure 3).

- **Business case**: To present AM as a viable business alternative and capture its full value, orga-

**Figure 3. Six core building blocks to unlock AM value**

- **Organizational roles and structure**: Clear roles, decision rights, and policies
- **Talent/workforce**: Competencies, skills, talent infrastructure, and workforce planning
- **Process**: Integrated set of process and activities designed to achieve an effective AM output
- **Quality assurance**: Validating the quality and consistency of AM production
- **Digital thread**: Additional technologies (i.e., IT) and tools required for mature 3D printing capability
- **Business case**: Understanding the cost and value dynamics of AM

Source: Deloitte analysis.
Organizations should understand cost and value dynamics across the entire process. The business case should consider economics beyond unit cost and consider the total cost and revenue impact of deploying AM.13

- **Talent/workforce**: The more sophisticated the application of AM, the greater the requirement for new competencies, skills, talent infrastructure, and workforce planning.14

- **Digital thread**: Sophisticated, successful, and large-scale AM value capture typically requires the linking of multiple data sources, models, and sensors. Further, improvements in complementary technologies, such as inspections processes, advanced sensors, and physics-based modeling, are often crucial for ensuring that processes continue to advance and generate reliable, traceable data. This IT system of electronic linking is often referred to as the *digital thread*.15

- **Quality assurance**: Validating the quality and consistency of AM production is currently often the greatest challenge in using AM to produce more sophisticated, higher-value parts. While this is less of a challenge for parts requiring less conformance and functionality, it is still a necessary part of any AM production solution.16

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**LEARN MORE ABOUT 3D OPPORTUNITY**

Deloitte has explored the implications of each of these enabling elements for an AM capability at length in its *3D Opportunity* series:

**Business case**
- [3D opportunity for production: Additive manufacturing makes its (business) case](#)
- [3D opportunity for life cycle assessments: Additive manufacturing branches out](#)

**Talent/workforce**
- [3D opportunity for the talent gap: Additive manufacturing and the workforce of the future](#)

**Digital thread**
- [3D opportunity and the digital thread: Additive manufacturing ties it all together](#)
- [3D opportunity for scan, design, and analyze: The first phase of the digital thread](#)

**Quality assurance**
- [3D opportunity for quality assurance and parts qualification: Additive manufacturing clears the bar](#)

**Process, organizational roles, and structure**
- [3D opportunity for engineers: Using behavioral science to help build a new mindset](#)

For additional insight, see the [3D Opportunity collection](#).
• **Process:** Deploying AM can affect the entire workflow of an organization. Modifying existing processes and activities helps ensure that AM is deployed to its full potential.

• **Organizational roles and structure:** Clear roles, decision rights, and policies typically need to be established for AM, potentially requiring a shift of responsibilities within the organization.

The level of investment in these enabling elements, and the relative emphasis required for each, may change depending on the type of value opportunity being pursued, as well as the quality and functionality requirements of the part being made. An organization locally printing mobile phone cases, for example, will likely require relatively unsophisticated and inexpensive versions of the six enabling elements. In contrast, an organization remotely producing system-critical parts could require highly sophisticated versions of the six enabling elements to achieve the necessary levels of precision and quality.

Depending on the path being pursued, different enabling elements will need to be prioritized (figure 4).

**Figure 4. Focus priorities for AM enabling elements by path**

Below, we examine the requirements for each value opportunity.

**Path II: Supply chain**

Path II has two distinct value opportunities: digitizing inventory and distributed point-of-use manufacturing. Both value opportunities require the ability to consistently transform digital design files into the production of physical parts where and when required.

*Digitizing inventory* essentially brings the design data (such as in the form of 3D drawings) and all relevant manufacturing information in digital form into the supply chain as the “object” to be distributed. The predominant function of the supply chain is to move and exploit this information. This enables organizations to carry their inventory in digital form and produce physical inventory only when required, radically reducing working capital requirements and potentially eliminating long-tail inventory.17

*Distributed point-of-use manufacturing* has a similar set of required enabling elements. Manufactur-
ing in multiple sites or closer to the point of use and customer provides several avenues for value. Distributed production on demand represents one scenario in which a decentralized network of AM printers replaces some or all of the centralized production facilities that use conventional equipment. By reducing inventories, lead times, and the dependence on large facilities, footprints, and forecasting, this path can produce significant supply chain value.\textsuperscript{18}

Successfully executing supply chain strategies typically requires the development of multiple elements in the following ways:

**BUSINESS CASE**

The ability to articulate the business case will likely require a strong understanding of both supply chain methodologies and AM cost levers. For example, reducing production lead time by eliminating costs associated with transporting the finished object may outweigh the logistical burden of purchasing and placing AM machines and materials. For some users, however, the business case is less about cost and more about the responsiveness that point-of-use manufacturing can provide:

“There are two reasons we are excited about AM: Enhancing warfighting capabilities and increasing readiness. We have been using the technology for over 20 years for indirect applications like tooling, molds, fixtures, and jigs to help make our legacy production processes more cost-effective and efficient. We are currently transitioning into producing end-use items, which has the potential to significantly disrupt conventional logistics: being able to print at point of need, on demand. We have also embedded introductory AM technology with our sailors and marines as an educational tool and innovation enabler, and there are a number of examples now of warfighters producing items that solve readiness issues.”

— Benjamin Bouffard, US Department of Navy\textsuperscript{19}

**TALENT/WORKFORCE**

Training and workforce development considerations are significant: Engineers require a better understanding of digital design processes to ensure files are prepared for successful AM production; and machine operators need extensive training in operation, maintenance, and monitoring of AM machines, as well as data management and analysis.\textsuperscript{20} Additionally, significant training may be required for technicians at the location where manufacturing may take place, as well as for business decision makers who may need to consider the types of machines in which to invest and where to do so.

**DIGITAL THREAD**

To digitize inventory and realize remote production values, it is often crucial to have a full digital thread with the scope and functionality to digitally link together all of the required data sets, models, and sensors. Because AM changes the predominant function of a supply chain from moving physical goods to moving information (digital designs) to where it can be best exploited to create economic value, the digital thread acts as an essential information backbone. The DoD, for example, places particular significance on the development of a digital thread as it seeks to evolve its AM supply chain:

“There are two reasons we are excited about AM: Enhancing warfighting capabilities and increasing readiness. We have been using the technology for over 20 years for indirect applications like tooling, molds, fixtures, and jigs to help make our legacy production processes more cost-effective and efficient. We are currently transitioning into producing end-use items, which has the potential to significantly disrupt conventional logistics: being able to print at point of need, on demand. We have also embedded introductory AM technology with our sailors and marines as an educational tool and innovation enabler, and there are a number of examples now of warfighters producing items that solve readiness issues.”

— Benjamin Bouffard, US Department of Navy\textsuperscript{21}
QUALITY ASSURANCE

As previously stated, the level of quality and functionality required for a specific product defines how sophisticated the QA abilities should be. Getting this right is critically important; otherwise the parts produced may cause unnecessary and potentially unacceptable risks. Digital inventory should materialize parts with the right geometric and functional properties. Similarly, distributed manufacturing should produce parts with the right geometric and functional properties, and it may even require a higher level of investment in QA than digital inventory. This element can lead to significant opportunity with respect to both aftermarket services and scaling production to an industrial level:

“Aftermarket services are being explored. But what will those services look like? We are in the initial stages of those discussions now. We were able to fly a flight-critical component, but now what if we wanted industry to make it? We need a robust technical data package and qualification plans; in other cases, there could be intellectual property considerations. . . . We are working extensively in these areas, but there is more work to do. Of note, this is not DoN specific, and the broader DoD is also working in many of these areas.”

― Benjamin Bouffard, US Department of Navy

PROCESS

Along path II, transforming process takes on particular significance—possibly requiring the conversion of some or all of the supply chain systems to emphasize digital information management over physical inventory, and enabling agile reconfiguration to optimize supply chain economics.

ORGANIZATIONAL ROLES AND STRUCTURE

Given the distributed nature of this path, the structure of the organization, and thus the roles within it, may need to change significantly. In order to successfully accommodate distributed manufacturing, the entire value stream would need to be reconfigurable to adjust and adapt to any new product or part that must be produced. Further, due to the different production method—AM machines instead of traditional manufacturing machinery and apparatus—the facility footprint will likely look quite different. Likewise, inventory levels could also change, as they would be based on digital-to-physical conversions of materials and different material types and formats: filaments or powders, for example, rather than billet.

Taken together, all of these changes would impact planning across multiple functions, from operations to finance. It will likely require greater collaboration between these groups, as the condensed design-and-production process for AM production would flatten the organization.

“When leadership starts to get together on a regular basis and drive unity of effort to achieve AM roadmaps, that is where you see the lightbulb go off in the service partners, for them to see the opportunity for commonality. There is a lot more commonality than there is uniqueness among service partners. There is opportunity to address all the challenges commonly. I think that’s the next logical step from developing a roadmap to the ‘now what?’ What you should see in the roadmap are all the functional disciplines represented.”

― Greg Kilchenstein, AT&L

Path III: Product design

Path III value opportunities, including design for functionality and mass customization, are the result of AM’s ability to break traditional manufacturing’s requirements of scope. One of AM’s strongest benefits is that it provides greater degrees of design freedom: Not only does AM create more design options, but they are economically viable to produce.

Designing for functionality is largely understood as creating new components or end items using novel, AM-enabled design principles, with an emphasis on improved performance and capability over traditionally manufactured designs. Organizations that incorporate AM have the potential to enhance their products through increased geometric complexity, decreased system complexity, increased novelty,
and enhanced performance. Put simply, AM allows users to build products optimized for performance rather than for manufacturability (as required by more traditional manufacturing techniques). Mass customization is one of the oft-touted applications of AM. Via AM, mass customization of components and end items to individual requirements may become cost-effective. The technology is well suited to product customization because it can support a wide variety of complex geometries without the manufacturer needing to incur the additional set-up costs typically associated with tailoring a product. For example, using conventional manufacturing techniques, customization can require multiple unique machine set-ups, unique molds and other tooling, and product-specific post-processing. AM can produce custom outputs without physically changing the production equipment to avoid many of these requirements.

When pursuing opportunities along this path, organizations should consider the following enabling elements:

BUSINESS CASE

AM’s ability to overcome many of the design limitations and scale production requirements of conventional manufacturing, while still keeping production costs relatively low, may help tip the business case in AM’s favor. Organizations agree:

“It’s important to make sure you hit the value proposition from the dollars and cents side. To convince someone to produce an object additively, it needs to make sense cost-wise: It must either improve lead times or reduce overall system costs. At the end of the day, the challenge to AM adoption is putting together a convincing value proposition: either helping people to look at things holistically as a system cost, or figuring out how to quantify the benefits if, say, you are combining multiple parts together. That’s when a technology gets adopted—when people see the ROI or bottom-line cost savings.”

— Jeff Schultz, Oerlikon

TALENT/WORKFORCE

Shifting design processes from conventional manufacturing constraints to AM often requires a shift in engineering mind-set. Engineers may need to learn to design in new ways, reconsider traditional design rules, and open their minds to previously impossible shapes and design paradigms. They may also have to learn to use new design software, tools, and processes. Moreover, design software is considered by many industry insiders to be lagging with respect to the development of AM capabilities; as it develops, it will likely require more training of designers.

“In going out and discussing with customers about buying our materials or using our service, I’ve seen that a lot of customers have the same fears and challenges. As much as companies may say they are engaged in using additive manufacturing, they really haven't committed to a great degree. This gets back to getting engineers to think differently. The exciting opportunity is that once you get design engineers to understand the benefits of AM, they really come up with neat ideas and applications. It’s about knowledge dissemination, re-educating design engineers. I think we, as a high-end metal AM group, tend to think about the impact of consumer printers and toys, and how it will lead to the next generation of design engineers who learn a different design paradigm than we were educated under.”

— Jeff Schultz, Oerlikon

DIGITAL THREAD

A more limited scope of the digital thread, the “front end,” is typically required for product design: from scanning, designing, and analyzing the part to having a printable data set ready for production. The remainder of the digital thread can leverage additional value chain (or supply chain) partners along with the actual AM production.
QUALITY ASSURANCE

QA is exceptionally important when engaging in AM product design, particularly when dealing with designs that are complex, have feature-specific, tailored mechanical properties, or may be built using new materials or old materials with uncertain properties. Product design creates the design of the product as well as the process “recipe” upon which all AM QA is based.36

PROCESS

Beyond prioritizing QA, however, it may be essential to make smart choices about process design, with a relative emphasis on the front end. In addition, because of the importance of quality, organizations are very likely going to need to worry about process all the way through object validation. On the other hand, other processes can be deprioritized to some extent as the organization focuses on the front end of process design; for example, it might be able to deemphasize supply chain processes such as distribution, which could instead be handled through normal channels.

ORGANIZATIONAL ROLES AND STRUCTURE

Organizational roles and structures may change with relation to product design processes, as the process of design, test, and redesign may condense and accelerate and the need for successive reviews by engineers with discrete specialties may grow less necessary. This will likely result in condensed workflows and roles.37 Additionally, opportunities for third-party and customer involvement in design may change the organizational structure to some extent, to accommodate external contributions and feedback. It may become important, for example, to organize teams to determine and analyze ways to implement suggestions originating outside the organization. Internal processes such as ideation, conceptual design, and beta design are opening up to customer participation as the digitization of these activities allows increasing levels of external access.

“We know that we have an innovative workforce within the department. We found that, although there is no real requirement to use AM equipment, when it is provided as a tool, our workforce (engineers, marines, sailors, etc.) all come up with some great solutions to problems. We have found that we need a digitally literate workforce and have worked to provide the tools necessary to develop this digital manufacturing education. We can envision a day when warfighters can iterate on prototypes in the field and then reach back for engineering support.”

— Benjamin Bouffard, US Department of Navy39

Path IV: New business models

The most ambitious source of AM value, the final path involves operating in a fundamentally new way. This is achieved by changing both product design and supply chain configuration to take advantage of the AM value synergies between the two. Essentially a “clean sheet” approach, new business models are likely to require extensive changes to an organization’s technology, processes, and skills, as well as careful management of the systems dynamics between them, with significant development needed across all six enabling elements. In short, path IV enabling elements are essentially the sum of those needed for paths II and III.

New business models represent an opportunity to create value in unexpected ways. For example, the DoD has invested time and research in 3D-printing unmanned aerial vehicles, or drones, which would both save costs through product design and manufacturing as well as enable distributed manufacturing in the field to help execute critical missions.40 Successfully implementing this AM capability requires a comprehensive approach to the value stream: upstream in the product design phase and downstream with the users—sailors, soldiers, and airmen—who would be expected to produce and use this technology in the field.
Moving from machine to business model

As shown above, the real key to unlocking value from additive manufacturing is found in five key findings:

- **Go beyond stasis** and plot your path to one of the other “quadrants.” Knowing the value path the organization is targeting can help prioritize which elements warrant relatively higher investment. Producing a brand-new, innovatively designed part (path III) will likely require a relatively higher investment and change in talent and the workforce, process and workflow, and, potentially, the digital thread, while printing spare parts on a deep sea oil rig (path II) entails higher investments in training and QA.

- ** Understand where the six enabling elements required** to further take advantage of AM fit into the organization’s strategy. Examining each of the six enabling elements and honestly assessing how the organization rates in each can help companies identify gaps in existing elements and prioritize investments.

- **New business models have unique requirements**, and complexity can vary by organization. By and large, however, those seeking

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**Figure 5. AM’s place in the broader suite of organizational technologies and capabilities**

Source: Deloitte analysis.
• to explore path IV applications may have to develop all six enabling elements. But development may not look the same for every company. Mature companies seeking to advance an existing AM capability into a truly new business model may have to consider the impacts on the full range of enabling elements. New entrants with new business models, however, benefit from a much more focused set of priorities and investment as they are not forced to deal with and accommodate legacy systems or processes.

• Don’t consider AM in isolation. AM is but one technology in a suite of many that an organization may have on hand (figure 5), and not all may choose to invest in it. Growing a true AM capability can present opportunities for growth and innovation in other parts of the business. For example, retraining design engineers to understand AM design may generate a culture clash with other parts of the engineering workforce that use other technologies but ultimately expand horizons in terms of design. Additionally, directing resources and priorities toward building an AM capability may impact legacy work streams and efforts elsewhere but aid in moving processes forward. These are just a few examples of why AM should not be assessed without considering the larger enterprise perspective.

• Bring AM out of the shop floor and into the office to complete the alignment of the enabling elements and value proposition. It is all too easy for innovative technologies to remain in the hands of specialists and enthusiasts, but AM’s potential suggests that it should be understood and planned for at the business value level. The elements considered crucial for enabling AM, from QA to talent and workforce, span business functions and typically require investment and planning. The emphasis and required scope of the enabling elements depend on the type of value and path being pursued as well as the quality requirements and complexity of the parts being made. The form these enabling elements will take and the degree to which investments might be necessary can be further defined by measuring their impact against the organization’s operating, financial, and strategic objectives.

As organizations seek to develop and scale AM, the challenge remains to not over- or underinvest in enabling elements but to accurately define the necessary and sufficient enabling elements to achieve an organization’s goals. Capturing the value AM can offer typically involves carefully targeted investment and effort.


4. For further information, see our AM series at https://dupress.deloitte.com/dup-us-en/focus/3d-opportunity.html.

5. For a full discussion of these dynamics, see Cotteleer and Joyce, “3D opportunity: Additive manufacturing paths to performance, innovation, and growth.”


8. John Barnes (executive, Arconic), phone and personal interviews with authors, September 14, 2016.


10. Greg Kilchenstein (Enterprise Maintenance Policy and Programs, Office of Under Secretary of Defense, DoD AT&L), phone and personal interviews with authors, September 1, 2016.

11. The term *sustainment*, in the context of military weapons systems, is related to those life cycle costs after the initial acquisition of say a fighter plane. Sustainment includes the spare parts, maintenance activities, and related capabilities required to keep that weapon system in service.

12. Barnes interview.


18. Ibid.


20. Vazquez, Passaretti, and Valenzuela, 3D opportunity for the talent gap.


22. Ibid.

23. Sniderman, Monahan, and Forsythe, “3D opportunity for engineers.”

24. Kilchenstein interview.

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29. Ibid.

30. Crane, Crestani, and Cotteleer, 3D opportunity for end-use products.

31. Sniderman, Monahan, and Forsythe, “3D opportunity for engineers.”

32. Jeff Schultz (head of AM service expansion, Oerlikon), phone and personal interviews with the authors, September 8, 2016.

33. Sniderman, Monahan, and Forsythe, “3D opportunity for engineers.”

34. Ibid.

35. Schultz interview.

36. Wing, Gorham, and Sniderman, 3D opportunity for quality assurance.

37. Vazquez, Passaretti, and Valenzuela, 3D opportunity for the talent gap.

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Blockchain: Trust economy
Taking control of digital identity
from TECH TRENDS 2017: THE KINETIC ENTERPRISE
Blockchain is outgrowing its adolescent cryptocurrency identity, with distributed consensus ledgers becoming smart contracts facilitators. Beyond creating efficiencies by removing the legal and financial intermediary in a contractual agreement, blockchain is assuming the role of trusted gatekeeper and purveyor of transparency. In the emerging “trust economy” in which a company’s assets or an individual’s online identity and reputation are becoming both increasingly valuable and vulnerable, this latest use case may be blockchain’s most potentially valuable to date.

Blockchain, the shared-ledger technology that only a few years ago seemed indelibly linked in the public imagination to cryptocurrencies such as Bitcoin, is assuming a new role: gatekeeper in the emerging “trust economy.”

First, a bit of background. Last year’s Tech Trends report examined how maintaining the procedural, organizational, and technological infrastructure required to create institutionalized trust throughout an increasingly digitized global economy is becoming expensive, time-consuming, and in many cases inefficient.

Moreover, new gauges of trustworthiness are disrupting existing trust protocols such as banking systems, credit rating agencies, and legal instruments that make transactions between parties possible. Ride-sharing apps depend on customers publicly ranking drivers’ performance; an individual opens her home to a paying lodger based on the recommendations of other homeowners who have already hosted this same lodger. These gauges represent the codification of reputation and trustworthiness. We are growing accustomed to the notion that positive comments appearing under an individual’s name means we can trust that person.1

In a break from the past, the trust economy developing around person-to-person (P2P) transactions does not turn on credit ratings, guaranteed cashier’s checks, or other traditional trust mechanisms. Rather, it relies on each transacting party’s reputation and digital identity—the elements of which may soon be stored and managed in a blockchain. For individuals, these elements may include financial or professional histories, tax information, medical information, or consumer preferences, among many others. Likewise, companies could maintain reputational identities that establish their trustworthiness as a business partner or vendor. In the trust economy, an individual’s or entity’s “identity” confirms membership in a nation or community, ownership of assets, entitlement to benefits or services, and, more fundamentally, that the individual or entity actually exists.

Beyond establishing trust, blockchain makes it possible to share information selectively with others to exchange assets safely and efficiently and—perhaps most promisingly—to proffer digital contracts. This transforms reputation into a manageable attribute that can be baked into each individual’s or organization’s interactions with others.

In the next 18 to 24 months, entities across the globe will likely begin exploring blockchain opportunities that involve some aspects of digital reputation. We’re already seeing companies that operate at the vanguard of the trust economy acknowledge blockchain’s potential. When asked during a recent interview about possible blockchain deployment by P2P lodging site Airbnb, company co-founder and CTO Nathan Blecharczyk replied, “I think that, within the context of Airbnb, your reputation is everything, and I can see it being even more so in the future, whereby you might need a certain reputation in order to have access to certain types of homes. But then the question is whether there’s a way to export that and allow access elsewhere to help other sharing economy models really flourish. We’re looking for all different kinds of signals to
tell us whether someone is reputable, and I could certainly see some of these more novel types of signals being plugged into our engine.”

The blockchain/trust economy trend represents a remarkable power shift from large, centralized trust agents to the individual. And while its broader implications may not be fully understood for years to come, it is hardly a death knell for banks, credit agencies, and other transactional intermediaries. It may mean, however, that with blockchain as the gatekeeper of identity and trust, business and government will have to create new ways to engage the individual—and to add value and utility in the rapidly evolving trust economy.

**In blockchain we trust**

Given blockchain’s starring role in the Bitcoin hype cycle, there may be some lingering confusion about what this technology is and the value it can potentially bring to business. Simply put, blockchain is a distributed ledger that provides a way for information to be recorded and shared by a community. In this community, each member maintains his own copy of the information, and all members must validate any updates collectively. The information could represent transactions, contracts, assets, identities, or practically anything else that can be described in digital form. Entries are permanent, transparent, and searchable, which makes it possible for community members to view

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**Figure 1. Three levels of blockchain**

1. **Storing digital records**
   Blockchain allows unprecedented control of information through secure, auditable, and immutable records of not only transactions but digital representations of physical assets.

2. **Exchanging digital assets**
   Users can issue new assets and transfer ownership in real time without banks, stock exchanges, or payment processors.

3. **Executing smart contracts**
   Self-governing contracts simplify and automate lengthy and inefficient business processes.

   **Ground rules** Terms and conditions are recorded in the contract’s code.

   **Implementation** The shared network automatically executes the contract and monitors compliance.

   **Verification** Outcomes are validated instantaneously without a third party.
transaction histories. Each update is a new “block” added to the end of the “chain.” A protocol manages how new edits or entries are initiated, validated, recorded, and distributed. Crucially, privacy can also be selectively enforced, allowing varying degrees of anonymity or protection of sensitive information beyond those who have explicitly been given access. With blockchain, cryptology replaces third-party intermediaries as the keeper of trust, with all blockchain participants running complex algorithms to certify the integrity of the whole.

As the need for portable, manageable digital identities grows, individuals and organizations can use blockchain to:

**Store digital records:** To understand blockchain in the context of the trust economy, think of it as the tech-charged equivalent of the public ledgers that would be used in towns to record everything of importance: the buying and selling of goods; the transfer of property deeds; births, marriages, and deaths; loans; election results; legal rulings; and anything else of note. Instead of a bearded master wielding a long-stemmed stylus to record miniscule but legible entries in an oversized ledger, blockchain uses advanced cryptography and distributed programming to achieve similar results: a secure, transparent, immutable repository of truth—one designed to be highly resistant to outages, manipulation, and unnecessary complexity.

In the trust economy, the individual—not a third party—will determine what digital information is recorded in a blockchain, and how that information will be used. With an eye toward curating a single, versatile digital representation of themselves that can be managed and shared across organizational boundaries, users may record:

- Digitized renderings of traditional identity documents such as driver’s licenses, passports, birth certificates, Social Security/Medicare cards, voter registration, and voting records
- Ownership documents and transactional records for property, vehicles, and other assets of any form
- Financial documents including investments, insurance policies, bank accounts, credit histories, tax filings, and income statements
- Access management codes that provide any identity-restricted location, from website single sign-on to physical buildings, smart vehicles, and ticketed locations such as event venues or airplanes
- A comprehensive view of medical history that includes medical and pharmaceutical records, physician notes, fitness regimens, and medical device usage data

As a repository of valuable data, blockchain can provide individual users with unprecedented control over their digital identities. It can potentially offer businesses an effective way to break down information silos and lower data management costs. For example, in a recent blog post, Bruce Broussard, president and CEO of health insurance provider Humana, shared his vision of a future in which hospitals, clinics, and insurance companies streamline administrative processes, increase security, and achieve significant cost savings by storing and managing electronic health records on a blockchain.3

**Exchange digital assets without friction:** Using blockchain, parties can exchange ownership of digital assets in real time and, notably, without banks, stock exchanges, or payment processors—all applications requiring trusted digital reputations. Many of blockchain’s earliest use cases for business involved facilitating cross-border payments and intracompany transfers. Applying that same basic transactional model to P2P transactions, blockchain could potentially become a vehicle for certifying and clearing asset exchanges almost instantaneously. What once took T + 3 days to clear now takes T + 3 milliseconds.

Though broad acceptance of P2P asset exchanges via blockchain may still be a few years away, the exploratory steps some companies are currently taking offer insight into where blockchain deployment may be headed. For example, Microsoft and Bank of America Merrill Lynch are jointly developing a cloud-based “blockchain-as-a-service”
offering that will execute and streamline asset exchanges between companies and their customers.4

Execute smart contracts: Smart contracts represent a next step in the progression of blockchain from a financial transaction protocol to an all-purpose utility. They are not contracts in the legal sense, but modular, repeatable scripts that extend blockchains’ utility from simply keeping a record of financial transaction entries to implementing the terms of multiparty agreements automatically. The fact that they are not legally binding makes trust even more important.

Here’s how they work: Using consensus protocols, a computer network develops a sequence of actions from a smart contract’s code. This sequence of actions is a method by which parties can agree upon contract terms that will be executed automatically, with reduced risk of error or manipulation. Before blockchain, this type of smart contract was impossible because parties to an agreement of this sort would maintain separate databases. With a shared database running a blockchain protocol, the smart contracts auto-execute, and all parties validate the outcome instantaneously—and without the involvement of a third-party intermediary.

Though smart contracts may not be appropriate for some legal agreements, they can be a worthwhile option in situations where networks of parties engage frequently, or in agreements where counterparties are performing manual or duplicative tasks for each transaction. For example, they could be deployed for the automated purchase or sale of financial instruments, parametric insurance contracts, and certain automatic market-making activities, as well as for digital payments and IOUs. In each case, the blockchain acts as a shared database to provide a secure, single source of truth, and smart contracts automate approvals, calculations, and other transacting activities that are prone to lag and error.5

Chain of tools

In the greater context of the trust economy, blockchain is not a cure-all for the challenges of establishing and maintaining trust. As a technology, it is still maturing; standards and best practices do not yet exist. The very features that protect blockchain against theft and fraud could also drive overhead if not correctly implemented—a potential obstacle on the path toward individual deployment of the technology. Finally, legal recognition of contracts and digitally transferred assets is currently limited. The good news is that organizations can take steps now to mitigate if not fully address these challenges.

Some pundits are likening the emergence of blockchain technology to the early days of the World Wide Web, and for good reason. In 1991, the foundations for distributed, open communication were being laid—network infrastructure, protocols, and a variety of enabling technologies from javascript to search engines to browsers. There were also new enterprise software suites that made it possible to take advantage of digital marketing, commerce, and linked supply networks, among countless other opportunities. Hyper-investment chased perceived opportunity, even as specific scenarios describing how the technology would change the world had not yet been defined.

Blockchain may lead to even greater disruption by becoming the new protocol for digital assets, exchanges, contracts, and, perhaps most importantly, identity and trust. With efforts to create a new stack for all facets of blockchain attracting investment, the time is now for enterprises to explore the underlying technology, and to envision how blockchain may be used for more than just the easy use cases of cost savings and efficiency within their own boundaries. Take a hard look at your core business, surrounding ecosystems, and even the long-established mechanics of the way your industry operates, and then direct your experimentation toward a truly innovative path.
Smart play with smart contracts

Delaware, home to more than 60 percent of Fortune 500 firms, is teaming up with Symbiont, a distributed ledger and smart securities vendor, to launch a blockchain-based smart contracts system. Smart contracts are protocols that allow blockchain technology to record, manage, and update encrypted information in a distributed ledger automatically, without intermediaries. The system will enable participants to digitize incorporation procedures such as registering companies, tracking shares, and handling shareholder communications. For companies incorporated in Delaware, this could make registration and follow-up steps in the process faster, less expensive, and more transparent.

At the heart of Symbiont’s solution is an immutable, append-only database, which provides a single, global accounting ledger for system participants. Transaction history is appended and replicated across all network nodes, with access permissions restricted down to the specific organization or even user level. Each company registering with the state of Delaware signs in with a private key that verifies its identity to other participants. Autonomous recordkeeping will trigger notifications when actions are required, such as new filing requirements when thresholds are met or when documents approach expiration.

Project teams are taking a two-pronged approach to deployment. First, they will rebuild the public archives using a distributed ledger for storage and “smart records” to automate the control and encryption of public and private records. This critical step will make it possible for digital documents to be shared in multiple locations and, importantly, be recovered in the event of system failure. Next, they will place incorporation and other legal documents on a smart contract-enabled blockchain and establish operational procedures for using and maintaining them.

This deployment is part of a larger effort called the Delaware Blockchain Initiative, which will lay the legal and technological groundwork needed to support blockchain-based systems going forward. The governor’s office is currently collaborating with the legislature to build the legal framework required to support blockchain-based incorporation processes and digitally originated securities. “We see companies allocate significant financial resources to correct and validate stock authorization and issuance errors that could have been correctly and seamlessly handled from the outset,” says Delaware Governor Jack Markell. “Distributed ledger [transactions] hold the promise of immediate clearance, immediate settlement, and bring with them dramatic increases in efficiency and speed in sophisticated commercial transactions.”
SWIFT: From middleman to enabler

Blockchain has the potential to rewire the financial industry and beyond, generating cost savings and new revenue opportunities. Payment rails have been the subject of various blockchain-driven initiatives. Payment transaction firm SWIFT has been testing use cases to demonstrate how its 11,000-plus member financial institutions can optimize the technology’s transparency while maintaining the industry’s privacy requirements in the emerging trust economy.

The organization’s new R&D arm, SWIFT Innovation Labs, was launched with an eye on eventually providing distributor ledger technology (DLT)-based services that leverage its standards expertise, strong governance, and security track record. DLT, it says, would provide trust in a disseminated system, efficiency in broadcasting information, complete traceability of transactions, simplified reconciliation, and high resiliency.13

SWIFT’s team of 10 experts in standards, securities, architecture, and application development built a bond lifecycle application that tracks and manages bonds from issuance to coupon payments to maturity at an ecosystem level rather than by individual company. SWIFT applied its own ISO 20022 methodology to DLT to gauge interoperability with legacy systems in cases where all stakeholders were not on the distributed ledger.13

The bond life cycle proof-of-concept was built using an Eris/Tendermint consensus engine to enable smart contracts written in Solidity, a language for the Ethereum blockchain. Monax’s Eris platform was chosen because it is open-source; it enables a permissioned blockchain that can only be viewed and accessed by the parties involved in the transaction; it supports smart contracts; and its consensus algorithm has better performance than Bitcoin’s blockchain.15

SWIFT’s lab team set up five blockchain nodes (in its California office, at an account servicer in Virginia, and at investment banks in Brazil, Germany, and Australia)16 on a simulated network that implemented the ISO 20022 standard, which covers transaction data for banks, securities depositories, and high-value payments. The standard’s layered architecture consists of coded business concepts independent of any automation, which according to SWIFT “seems a good place to look for content that can be shared and re-used” via a distributed ledger.17

“SWIFT has been targeted in the press as a legacy incumbent that will be doomed by DLT,” says Damien Vanderveken, head of R&D at SWIFT Innovation Labs. “But we believe SWIFT can leverage its unique set of capabilities to deliver a distinctive DLT platform offer for the [financial] community.”18 This could translate into cheaper, faster, and more accessible remittance and corporate disbursement services around the globe.
Just as distributed architecture and open standards play spotlight roles in the inevitable architecture trend, they loom large in blockchain and the emerging trust economy. Blockchain is an open infrastructure technology that enables users operating outside of an organizational or network boundary to execute transactions directly with each other. Blockchain’s fundamental value proposition is anchored in this universal availability.

It is also anchored in integrity. When someone adds a block, or executes a blockchain-based smart contract, those additions are immutable. The potential value of the numerous blockchain applications currently being explored—including regulatory compliance, identity management, government interactions with citizens, and medical records management—resides, to a large degree, in the security benefits each offers users. These benefits include, among others:

- The immutable, distributed ledger creates trust in bookkeeping maintained by computers. There is no need for intermediaries to confirm transactions.
- Transactions are recorded with the time, date, participant names, and other information. Each node in the network owns the same copy of the blockchain, thus enhancing security.
- Transactions are authenticated by a network of computer “miners” who complete complex mathematical problems. When miners arrive at the same solution, the transaction is confirmed and recorded on the “block.”

The distribution of miners means that the system cannot be hacked by a single source. If anyone tries to tamper with one ledger, the nodes will disagree on the integrity of that ledger and will refuse to incorporate the transaction into the blockchain.

Though blockchain may feature certain security advantages over more traditional transactional systems that require intermediaries, potential risks and protocol weaknesses that could undermine the integrity of blockchain transactions do exist. For example, it has recently come to light that vulnerabilities may exist in the programming code that some financial services companies are using as they integrate distributed ledger technologies into their operations.19

Given that there is no standard in place for blockchain security, other potential cyber issues could emerge. For this reason, users currently rely—arguably too much—on crowdsourced policing.

Blockchain is a relatively new technology, and therefore discussion of its potential weaknesses is somewhat academic. Somewhere down the road, an underlying vulnerability in blockchain may emerge—one that would put your systems and data at risk.

Though you should not let fear of scenarios like this prevent your company from exploring blockchain opportunities, as with other leading-edge technologies, it pays to educate yourself and, going forward, let standards of acceptable risk guide your decisions and investments.
Where do you start?

The hype surrounding blockchain is reaching a fever pitch. While this technology’s long-term impact may indeed be formidable, its immediate adoption path will most likely be defined by focused experimentation and a collection of moderately interesting incremental advances. As with any transformative technology, expertise will have to be earned, experience will be invaluable, and the more ambitious deployment scenarios will likely emerge over time. The good news? It’s still early in the game, and numerous opportunities await.

Here are some suggestions for getting started on your blockchain journey:

• **Come all ye faithful:** The financial services industry is currently at the vanguard of blockchain experimentation, and the eventual impact of its pioneering efforts will likely be far-reaching. Yet blockchain’s disruptive potential extends far beyond financial services: Every sector in every geography should be developing a blockchain strategy, complete with immediate tactical opportunities for efficiency gains and cost savings within the organization. Strategies should include more ambitious scenarios for pushing trust zones to customers, business partners, and other third parties. Finally, sectors should envision ways blockchain could eventually be deployed to challenge core business models and industry dynamics. While it often pays to think big, with blockchain you should probably start small given that the technology’s maturity—like that of the regulations governing blockchain’s use—is still relatively low.

• **Wayfinding:** Start-ups and established players are aggressively pushing product into every level of the blockchain stack. Part of your adoption journey should be understanding the fundamental mechanics of blockchain, what pieces are absolutely necessary for your initial exploration, and the maturity of the offerings needed for the specific scope being considered.

• **The nays have it:** Ask your blockchain gurus to define scenarios and applications that are *not* a good fit for blockchain. This is not reverse psychology: It’s simply asking advocates to keep a balanced perspective, and thoughtfully casting a light on this emerging technology’s current limitations and implications. Sure, expect challenges and prescribed roadblocks to yield to future advances in the field. But until then, challenge your most enthusiastic blockchain apostles to remain objective about the technology’s potential upside and downside.

• **You gotta have friends:** Blockchain offers little value to individual users. To maximize its potential—particularly for applications and use cases involving digital identity—explore opportunities to develop a consortium or utility for blockchain use.

• **Stay on target:** Far-reaching potential can lead to distracting rhetoric and perpetual prognostication. As you explore blockchain, focus your brainstorming and your efforts on actionable, bounded scenarios with realistic scope that can lead to concrete results and—hopefully—better value. Wild-eyed aspirations are not necessarily bad. But they are best served by grounded progress that leads to hands-on proof and an earned understanding of what is needed to realize the stuff of dreams.

**Bottom line**

In a historic break from the past, the foundational concept of trust is being tailored to meet the demands of the digital age, with blockchain cast in the role of gatekeeper of reputation and identity. While the broader implications of this trend may not be fully understood for years to come, business and government are beginning to explore opportunities to selectively share composite digital identities with others not only to help establish trust but to exchange assets safely and efficiently, and—perhaps most promisingly—to proffer digital contracts.
ENDNOTES


7. Ream, Chu, and Schatsky, Upgrading blockchains.


13. Ibid.


15. Ibid.


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About The Manufacturing Institute

The Manufacturing Institute is the 501(c)(3) affiliate of the National Association of Manufacturers. As a non-partisan organization, the institute is committed to delivering leading-edge information and services to the nation’s manufacturers. It is the authority on the attraction, qualification, and development of world-class manufacturing talent. For more information, visit www.themanufacturinginstitute.org.
Cyber risk in advanced manufacturing
Manufacturers drive extensive innovation in products, manufacturing process, and industrial ecosystem relationships in order to compete in a changing global marketplace.

Technologies utilized to drive the business are likely to include complex global networks, a myriad of back office business applications, generations of different industrial control systems (ICS) controlling high-risk manufacturing processes, and a variety of technologies directly embedded into current and emerging products. Further, manufacturers continue to drive extensive innovation in products, manufacturing process, and industrial ecosystem relationships in order to compete in a changing global marketplace. As a result, the manufacturing industry is likely to see an acceleration in the pace of change in technology due to emerging trends, such as:

- Large scale investments in intellectual property (IP) and exponential technologies
- Exploration of industry 4.0 digital manufacturing opportunities and increased interconnectivity of the industrial ecosystem
- Rapid adoption of sensor technology, smart products, and Internet of Things (IoT) strategies and analytics to drive increased customer service and business efficiency

This existing technology footprint, along with its accelerating pace of change in business and manufacturing technology, is expected to have a dramatic impact on the breadth and complexity of the cyber risks manufacturers will need to address over the next decade.

Our exploration of these trends, and the recent enterprise risk study by Deloitte and The Manufacturers Alliance for Productivity and Innovation (MAPI) have highlighted the need for a broader and deeper understanding of:

- The current state of cyber risks facing manufacturers
- Emerging risks likely to materialize as a result of rapid technology change
- An assessment of leading strategies manufacturers are employing to address these types of cyber risks

To that end, Deloitte and MAPI launched the Cyber Risk in Advanced Manufacturing study to assess these trends. We conducted more than 35 live executive and industry organization interviews, and in collaboration with Forbes Insights, we collected 225 responses to an online survey exploring cyber risk in advanced manufacturing trends.

The results of this study may help manufacturers engage their senior leadership teams and boards in a deeper conversation on how to make their businesses secure, vigilant, and resilient. Applying lessons learned from this study can help them:

- **Be Secure** – Take a measured, risk-based approach to what is secured and how to secure it. This includes managing cyber risks as a team and increase preparedness by building cyber risk management strategies into the enterprise and emerging technologies as they are deployed.
- **Be Vigilant** – Monitor systems, applications, people, and the outside environment to detect incidents more effectively. This includes developing situational awareness and threat intelligence to understand harmful behavior and top risks to the organization and actively monitoring the dynamic threat landscape.
- **Be Resilient** – Be prepared for incidents and decrease their business impact by improving organizational preparedness to address cyber incidents before they escalate. This also includes capturing lessons learned, improving security controls, and returning to business as usual as quickly as possible.
Key cyber risk themes

As a result of this extensive study, our own research, and an innovation lab that explored survey results and leading practices with manufacturing executives, we coalesced around the following key themes.
We believe these themes are critical to manufacturers’ abilities to capture the value associated with this new frontier of technology while appropriately addressing the dynamic cyber risks, in order to protect and enhance value over the longer term. Key insights from the study include:

1. **Executive and board level engagement**

- Given its focus on innovation and an increasing reliance on connected products, those interviewed consistently shared their belief that manufacturing is an industry that is highly vulnerable to cyber risk. In spite of new investments in IoT technologies and broad concerns with such risk, the manufacturing industry as a whole is still fragmented in its approach to managing cyber-related risks, and in having the organizational ownership to do so effectively. From a broad perspective, manufacturing is seen as lagging other sectors such as financial services and retail in the maturity of enterprise cyber risk programs.

- Due to the growing severity and sophistication of cyberattacks, only 52 percent of surveyed executives are either very confident or extremely confident their organization’s assets are protected from external threats, meaning nearly half of manufacturing companies are only somewhat confident or less.

- In some cases, there are challenges with top leadership for funding, as cyber risk has not always been a top-of-mind topic. However, according to our survey, senior executive and board support has increased considerably in the past couple of years as seen with the increased frequency of C-suite and board briefings, more often occurring annually, with up to quarterly updates. When it comes to a board update, the following framework can help boards evaluate questions to ask to determine whether the scope of the update they are receiving is complete:
Figure 1. Cyber risk programs: a framework for leading practice board reporting

<table>
<thead>
<tr>
<th>Governance and Leadership Engagement</th>
<th>Talent and Organizational Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearly 50% of executives lack confidence they are protected</td>
<td>48% lack adequate funding</td>
</tr>
<tr>
<td>36% cited IP protection as top concern</td>
<td>75% lack skilled resources</td>
</tr>
<tr>
<td>50% isolate or segment ICS networks</td>
<td>IT/OT gap drives behavior</td>
</tr>
<tr>
<td>31% have not conducted an ICS assessment</td>
<td></td>
</tr>
<tr>
<td>50% perform ICS vulnerability testing less often than once a month</td>
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<tr>
<td>27% do not include ICS in incident response plans</td>
<td></td>
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<tr>
<td>27% do not include connected products to incident response plans</td>
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</tbody>
</table>

**Traditional board reporting**

**Be secure**
- Take a top down, risk based approach to implementing security strategies for the most critical networks, systems, and data

**Enterprise Network & Business Systems**
- 36% cited IP protection as top concern

**Industrial Control Systems**
- 50% isolate or segment ICS networks
- 31% have not conducted an ICS assessment
- 50% perform ICS vulnerability testing less often than once a month

**Connected Products**
- 35-45% use sensors, smart products, and mobile apps
- 55% encrypt the data

**Be vigilant**
- Implement routine monitoring mechanisms for high risk networks, systems, and data that will alert the company to abnormal activity and enable prompt action

A top executive concern is increasing sophistication/proliferation of threats
- 50% perform ICS vulnerability testing less often than once a month
- 77% had performed end to end product assessment

**Be resilient**
- Plan ahead before a breach occurs so the entire organization is prepared to respond in order to quickly neutralize threats, prevent further spread, and recover from business impacts

- 39% experienced a breach in the last 12 months
- 38% had losses $1 - 10m+
- 37% do not include connected products to incident response plans

- 27% do not include ICS in incident response plans
- Only 12% currently employ tactics such as wargaming exercises
Overall, one-third of manufacturers indicate their cybersecurity budgets have either remained flat or decreased over the past three years despite the growing concern posed by cyber risk. That said, two-thirds of executives said their cybersecurity budget represents between three and 10 percent of the company’s annual IT spend.

The top three near-term cyber initiatives cited by manufacturing executives are: (1) enterprise cyber risk assessments, (2) data loss prevention programs, and (3) increased employee training and awareness. Initiatives such as wargaming simulations are much further down the list with only 12 percent of manufacturing executives indicating it was at the top of their agenda for the balance of the year.

Figure 2: Top 10 cyber threats facing manufacturers (percent of respondents)

- Theft of intellectual property: 34%
- Phishing, pharming and other related variants: 32%
- Increasing sophistication and proliferation of threats: 28%
- Security breaches involving third party: 28%
- Social engineering: 27%
- Employee errors and omissions: 26%
- External financial fraud involving information systems: 25%
- Employee abuse of IT systems and information: 25%
- Mobile devices (e.g., smartphones, tablets): 24%
- Attacks exploiting mobile network vulnerabilities: 23%

Source: Cyber risk in advanced manufacturing, Deloitte and MAPI.
2. Talent and human capital

- Manufacturing executives indicate that four of the top ten cyberthreats facing their organizations are directly attributable to internal employees. These threats include: phishing/pharming, direct abuse of IT systems, errors/omissions, and use of mobile devices. Smaller companies (<$500M in revenue) are more exposed to direct employee threats while midsize companies ($500M-$5B in revenue) are more concerned with IP theft, and large companies (>$5B in revenue) report their largest cyber risk concern focuses on phishing and pharming threats, which most often target financial gain or IP.

- The lack of skilled talent in the cybersecurity function represents a significant challenge for manufacturers, especially for midsize companies ($500M-$5B in revenue). The difficulty in attracting and retaining cybersecurity talent makes it hard for companies to maintain an adequate defense against cyber adversaries intent on penetrating enterprise networks.

- Chief Information Security Officer (CISO) reporting structures vary significantly within manufacturing organizations as 30 percent of executives indicate their company’s CISO reports directly to the Chief Executive Officer (CEO) while a further 31 percent report to the Chief Information Officer (CIO), leaving nearly 40 percent of CISOs reporting to someone else in the organization. Further, ownership of key areas of cyber risk such as ICS and connected products may be unclear or fall outside the responsibilities of the CISO / CIO to manufacturing operations, research and development (R&D), or other departments, which may not be as high a priority or mature in identifying and addressing cyberthreats.

- Ownership of enterprise cyber risk is often fragmented across an organization to include leaders in Operations (ICS), R&D (IP; smart products), or other departments or business units resulting in varying levels of maturity and approaches in handling cyber risk. This may leave CISOs with a limited visibility of the enterprise cyber risk landscape and limited ability to influence policies, risk management strategies, and remediation activities for these important parts of the business.
3. Intellectual property

• Over one-third (35 percent) of executives believe IP theft was the primary motive for the cyberattacks experienced by their company in the past 12 months—second only to financial theft (45 percent of survey respondents). Many companies interviewed had not yet fully implemented data protection and data loss prevention programs to mitigate this risk.

• Theft of IP is the most frequently cited cyberthreat (34 percent of surveyed executives) facing manufacturers, followed closely by phishing and pharming attacks (32 percent). IP theft also ranks closely with consumer data as the top sensitive data concern for manufacturing companies.

• In 42 percent of surveyed advanced manufacturing companies, the responsibility for IP protection falls to someone other than the CISO (20 percent) or the CIO (33 percent). In fact, 20 percent of executives indicate IP protection falls under the head of R&D while a further 22 percent of executives said this responsibility falls to the head of manufacturing.
4. Industrial control systems

- Almost one-third of manufacturers have not performed any cyber risk assessments specifically focused on the ICS operating on their shop floors, resulting in a potentially significant risk to their operations. Further, nearly two-thirds of companies that have performed an ICS cyber risk assessment used internal resources, potentially introducing organizational bias into the assessment process.

- Half of all advanced manufacturing companies address shop floor related security vulnerabilities through network segmentation. Further, 43 percent of manufacturing executives said they isolate their facilities from outside networks (air-gapping). Although air-gapping is a common approach to ICS security, when companies actually take the next step to test that strategy, they often find it is a fallacy. This can lead to at least two significant concerns:
  1. Since many manufactures have not tested or monitored this control or conducted a thorough inventory of connected assets, live network access points, especially easy to install wireless access points, can remain hidden from view.
  2. In an ever more increasingly connected business environment, simply cutting off access to the outside world can severely limit a company from accessing key advanced technology cost-savings and efficiency benefits.

- Half of the manufacturing executives surveyed indicate their companies perform targeted vulnerability or penetration tests on their ICS less often than once a month. Further, only one in five manufacturers indicate implementing a Secure Information and Event Management (SIEM) system or Security Operations Center (SOC) is a top near-term priority.

- Over one-quarter of companies’ incident response programs have not included operational technology (OT) in those plans.

- One in four companies do not develop, implement or document ICS-specific policies and procedures so that stakeholders have a comprehensive understanding of the company’s stance on ICS security.
5. Connected products

• Close to 50 percent of manufacturers have mobile apps associated with their connected product. In addition, 76 percent of companies choose Wi-Fi to enable data flows between their connected products, easily eclipsing the use of Bluetooth (48 percent).

• Over half of manufacturing executives (52 percent) said the connected products their companies produce are able to store and/or transmit confidential data including social security and banking information. The most common method of securing this information as it flows through connected products is data encryption, cited by 55 percent of executives.

• A significant number of manufacturing companies use internal resources rather than external, third parties for product-related security assessments. This is particularly true for both applications (57 percent) and network assessments (49 percent). This can be seen as a potential missed opportunity for manufacturers to take advantage of unbiased, fresh thinking that comes from working with external partners.

• In cases of product-related cyber breaches, nearly 40 percent of manufacturers do not incorporate those products within the company’s broader incident response plan, signaling a need for a more holistic approach to cyber risk when it comes to connected products.
6. Industrial ecosystem

• In terms of the broader value-chain, today’s ever-changing business environment sees increasing digital expectations from clients and customers, and new cybersecurity requirements being put on suppliers. Many manufacturers are just beginning to assess cyber risks related to key third parties in their innovation network, subcontractors, supply chain, and other critical business partners.

• There is also a growing desire among manufacturers to share knowledge and leading practices around cyberthreats as many companies operating in this space see the same kinds of challenges on a daily basis.

• A significant percentage (86 percent) of executives surveyed for this study indicate the preferred method of managing the adequacy of third-party cyber practices is through identification of any material risks as part of the normal assessment process. Further, 84 percent of respondents indicated they address third-party cyber risk through the contracting process, while 81 percent said they prefer to sign confidentiality and/or non-disclosure agreements.

The following content explores each of the six themes in greater detail, offering insights derived from both the online survey and interviews with cybersecurity leaders at manufacturing companies.
In order for manufacturing companies to capture the business value associated with emerging exponential technologies, address the dynamic cyber risk landscape, and increase preparedness should a cyber breach occur, they must remain secure, vigilant, and resilient:

1. **Set the tone.** Set the right tone at the top for cyber in the organization. The CISO cannot be an army of one. He or she needs to be appropriately supported by the leadership team and management to accomplish key cyber risk objectives for the company.

2. **Assess risk broadly.** Perform a cyber risk assessment that includes the enterprise, ICS and connected products. If the company has already done one in the last six months, review the scope to confirm it was inclusive of advanced manufacturing cyber risks such as IP protection, ICS, connected products and third-party risks related to industrial ecosystem relationships. Make sure this risk assessment addresses the secure, vigilant, and resilient principles mentioned above.

3. **Socialize the risk profile.** Share the results of the enterprise cyber risk assessment, and recommended strategy and roadmap with executive leadership and the board. Engage in dialogue as a team relative to the business impact of key cyber risks, and discuss how to prioritize resource allocation across the secure, vigilant, and resilient areas to address those risks commensurate with the organization’s risk tolerance, risk posture and capability for relevant business impact.

4. **Build security.** Evaluate top business investments in emerging manufacturing technologies, IoT, and connected products and confirm whether those projects are harmonized with the cyber risk program. Determine whether cyber talent is resident on those project teams to help them build in cyber risk management and sound strategies on the front end.

5. **Remember data is an asset.** It is important to change the mindset in manufacturing from a transactional mindset to the fact certain data alone may be an asset. This will necessitate a tighter connection between business value associated with data and the strategies used to protect it. In addition, it is important to assess not only where valuable data resides in the rest of the organization, but also how its risk profile changes as it moves throughout the organization, from business systems, to the shop floor, through the supply chain, and to third parties and back.

6. **Assess third-party risk.** Inventory mission critical industrial ecosystem relationships and evaluate strategies to address the third-party cyber risks that may coincide with these relationships.

7. **Be vigilant with monitoring.** Be vigilant in evaluating, developing, and implementing the company’s cyberthreat monitoring capabilities to determine whether and how quickly a breach in key areas of the company would be detected. Remember to extend cyberthreat detection capabilities to the shop floor and connected products.

8. **Always be prepared.** Increase organizational resiliency by focusing on incident and breach preparedness through table top or wargaming simulations. Engage IT as well as key business leaders in this exercise.

9. **Clarify organizational responsibilities.** Be crystal clear with the executive leadership team on the organizational ownership responsibilities for key components of the cyber risk program, and make sure there is a clear leader on the team with responsibilities to bring it all together.

10. **Drive increased awareness.** Last but certainly not least, get employees on board. Ensure they are appropriately aware of their responsibilities to help mitigate cyber risks related to phishing or social engineering, protecting IP and sensitive data, and appropriate escalation paths to report unusual activity or other areas of concern.

The detail in this study provides a new opportunity to engage in a deeper dialogue around core aspects of a company’s cyber risk program, identify continuous improvement opportunities, and establish a road map for companies to become secure, vigilant, and resilient.
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Machine intelligence
Technology mimics human cognition to create value
from TECH TRENDS 2017: THE KINETIC ENTERPRISE
DATA’S emergence as a critical business asset has been a persistent theme in every Tech Trends report, from the foundational capabilities needed to manage its exploding volumes and complexity to the increasingly sophisticated analytics tools techniques available to unearth business insights from data troves. By harnessing analytics to illuminate patterns, insights, and opportunities hidden within ever-growing data stores, companies have been able to develop new approaches to customer engagement; to amplify employee skills and intelligence; to cultivate new products, services, and offerings; and to explore new business models. Today, more and more CIOs are aggressively laying the foundations needed for their organizations to become more insight-driven.

Artificial intelligence (AI)—technologies capable of performing tasks normally requiring human intelligence—is becoming an important component of these analytics efforts. Yet AI is only one part of a larger, more compelling set of developments in the realm of cognitive computing. The bigger story is machine intelligence (MI), an umbrella term for a collection of advances representing a new cognitive era. We are talking here about a number of cognitive tools that have evolved rapidly in recent years: machine learning, deep learning, advanced cognitive analytics, robotics process automation, and bots, to name a few.

We are already seeing early use cases for machine intelligence emerge in various sectors. For example, a leading hospital that runs one of the largest medical research programs in the United States is “training” its machine intelligence systems to analyze the 10 billion phenotypic and genetic images stored in the organization’s database. In financial services, a cognitive sales agent uses machine intelligence to initiate contact with a promising sales lead and then qualify, follow up with, and sustain the lead. This cognitive assistant can parse natural language to understand customers’ conversational questions, handling up to 27,000 conversations simultaneously and in dozens of spoken languages.

In the coming months, expect to read about similar use cases as more companies tap into the power of machine. Spending on various aspects of MI is already increasing and is projected to reach nearly $31.3 billion in 2019. It is also becoming a priority for CIOs. Deloitte’s 2016 Global CIO Survey asked 1,200 IT executives to identify the emerging technologies in which they plan to invest significantly in the next two years. Sixty-four percent included cognitive technologies.

Data, now more than ever

What we think of today as cognitive computing actually debuted in the 1950s as a visionary effort to make technology simulate human intelligence. Though somewhat primitive AI technologies were commercially available by the 1980s, it wasn’t until the 2000s that AI—and the cognitive computing capabilities that comprise the emerging machine intelligence trend—took off.

A confluence of three powerful forces is driving the machine intelligence trend:

**Exponential data growth:** The digital universe—comprising the data we create and copy annually—is doubling in size every 12 months. Indeed, it is
expected to reach 44 zettabytes in size by 2020. We also know that data will grow more rapidly as new signals from the Internet of Things, dark analytics, and other sources proliferate. From a business perspective, this explosive growth translates into a greater variety of potentially valuable data sources than ever before. Beyond the potential to unlock new insights using traditional analytics techniques, these volumes of structured and unstructured data, as well as vast troves of unstructured data residing in the deep web, are critical to the advancement of machine intelligence. The more data these systems consume, the “smarter” they become by discovering relationships, patterns, and potential implications.

Effectively managing rapidly growing data volumes requires advanced approaches to master data, storage, retention, access, context, and stewardship. From signals generated by connected devices to the line-level detail behind historical transactional data from systems across all businesses and functions, handling data assets becomes a crucial building block of machine intelligence ambitions.

**Faster distributed systems:** As data volumes have grown larger and analysis more sophisticated, the distributed networks that make data accessible to individual users have become exponentially more powerful. Today, we can quickly process, search, and manipulate data in volumes that would have been impossible only a few years ago. The current generation of microprocessors delivers 4 million times the performance of the first single-chip microprocessor introduced in 1971. This power makes possible advanced system designs such as those supporting multi-core and parallel processing. Likewise, it enables advanced data storage techniques that support rapid retrieval and analysis of archived data. As we see with MapReduce, in-memory computing, and hardware optimized for MI techniques like Google’s Tensor Processing Units, technology is advancing to optimize our ability to manage exponential data more effectively.

Beyond increases in sheer power and speed, distributed networks have grown in reach as well. They now interface seamlessly with infrastructure, platforms, and applications residing in the cloud and can digest and analyze ever-growing data volumes residing there. They also provide the power needed to analyze and actuate streamed data from “edge” capabilities such as the Internet of Things, sensors, and embedded intelligence devices.

**Smarter algorithms:** In recent years, increasingly powerful MI algorithms have advanced steadily toward achieving cognitive computing’s original goal of simulating human thought processes.

The following algorithmic capabilities will likely see broader adoption in the public and private sectors as machine intelligence use cases emerge over the next 18 to 24 months:

- **Optimization, planning, and scheduling:** Among the more mature cognitive algorithms, optimization automates complex decisions and trade-offs about limited resources. Similarly, planning and scheduling algorithms devise a sequence of actions to meet processing goals and observe constraints.

- **Machine learning:** Computer systems are developing the ability to improve their performance by exposure to data without the need to follow explicitly programmed instructions. At its core, machine learning is the process of automatically discovering patterns in data. Once identified, a pattern can be used to make predictions.

- **Deep learning:** Developers are working on machine learning algorithms involving artificial neural networks that are inspired by the structure and function of the brain. Interconnected modules run mathematical models that are continuously tuned based on results from processing a large number of inputs. Deep learning can be supervised (requiring human intervention to train the evolution of the underlying models) or unsupervised (autonomously refining models based on self-evaluation).

- **Probabilistic inference:** New AI capabilities use graph analytics and Bayesian networks to identify the conditional dependencies of random variables.

- **Semantic computing:** This cognitive category includes computer vision (the ability to analyze images), voice recognition (the ability to analyze
Figure 1. Machine intelligence’s impact: Sample acquisitions and investments, 2014–2016
A Deloitte analysis reveals that Fortune 500 companies and venture capital firms have recognized the potential of machine intelligence and are strategically investing to build new capabilities.

Sources: Publicly available information on all Fortune 50 companies and on technology companies in the Fortune 500; Erin Griffith, “Here are the 51 technology and telecommunications companies of the Fortune 500,” Fortune, June 7, 2016, http://for.tn/22o9uUO; All investment information provided by cited companies, December 2016.
and interpret human speech), and various text analytics capabilities, among others, to understand naturally expressed intention and the semantics of computational content. It then uses this information to support data categorization, mapping, and retrieval.

- **Natural language engines:** A natural language engine understands written text the way humans do, but it can manipulate that text in sophisticated ways, such as automatically identifying all of the people and places mentioned in a document; identifying the main topic of a document; or extracting and tabulating the terms and conditions in a stack of human-readable contracts. Two common categories are natural language processing for techniques focused on consuming human language and natural language generation for techniques focused on creating natural language outputs.

- **Robotic process automation (RPA):** Software robots, or “bots,” can perform routine business processes by mimicking the ways in which people interact with software applications. Enterprises are beginning to employ RPA in tandem with cognitive technologies such as speech recognition, natural language processing, and machine learning to automate perceptual and judgment-based tasks once reserved for humans.

### How machine intelligence can create value

For CIOs, pivoting toward machine intelligence will require a new way of thinking about data analysis—not just as a means for creating a static report but as a way of leveraging a much larger, more varied data corpus to automate tasks and gain efficiencies.

Within machine intelligence, there is a spectrum of opportunities CIOs can consider:

- **Cognitive insights:** Machine intelligence can provide deep, actionable visibility into not only what has already happened but what is happening now and what is likely to happen next. This can help business leaders develop prescribed actions to help workers augment their performances. For example, in call centers around the globe, service representatives use multifunction customer support programs to answer product questions, take orders, investigate billing problems, and address other customer concerns. In many such systems, workers must currently jump back and forth between screens to access the information they need to answer specific queries.

- **Cognitive engagement:** At the next level on the machine intelligence value tree lie cognitive agents, systems that employ cognitive technology to engage with people. At present, the primary examples of this technology serve consumers rather than businesses. They respond to voice commands to lower the thermostat or turn the television channel. Yet there are business tasks and processes that could benefit from this kind of cognitive engagement, and a new field of applications is beginning to emerge. They will likely be able to provide access to complex information, perform digital tasks such as admitting patients to the hospital, or recommend products and services. They may offer even greater business potential in the area of customer service, where cognitive agents could potentially replace some human agents by handling billing or account interactions, fielding tech support questions, and answering HR-related questions from employees.

- **Cognitive automation:** In the third—and potentially most disruptive—machine intelligence opportunity, machine learning, RPA, and other cognitive tools develop deep domain-specific expertise (for example, by industry, function, or region) and then automate related tasks. We’re already seeing devices designed with baked-in machine intelligence automate jobs that have, traditionally, been performed by highly trained human workers. For example, one health care start-up is applying deep learning technology to analyze radiology images. In testing, its system has been up to 50 percent better than expert human radiologists at judging malignant tumors.

In the education field, machine intelligence capabilities embedded in online learning programs mimic the benefits of one-on-one tutoring by tracking the “mental steps” of the learner during problem-solving tasks to diagnose misconceptions. It then provides the learner with timely guidance, feedback, and explanations.
“Co-bots,” not robots

Facing cost pressures driven by prolonged low interest rates, increased competition, and evolving customer and market dynamics, global insurance provider American International Group Inc. (AIG) launched a strategic restructuring to simplify its organization and boost operational efficiency. Part of this effort involved dealing with mounting technical debt and a distributed IT department struggling to maintain operational stability.

According to Mike Brady, AIG’s global chief technology officer, by restructuring IT into a single organization reporting to the CEO, AIG laid the foundation for creating a new enterprise technology paradigm. The first step in this transformational effort involved building foundational capabilities, for which the team laid out a three-part approach:

**Stabilize:** Overall network performance needed improvement, since users experienced high-severity outages almost daily and the virtual network went down once a week.

**Optimize:** The strategy focused on self-service provisioning, automation, and cost-efficiency.

**Accelerate:** To move forward quickly, the team implemented a DevOps strategy to create a continuous integration/continuous deployment tool chain and process flow to deploy software in real time.

AIG turned to machine learning to help with these directives. The company developed an advanced collaborative robot program that utilizes built-in algorithmic capabilities, machine learning, and robotic process automation. These virtual workers have been dubbed “co-bots”—a nod to the company’s desire for everyone on staff to treat the virtual workforce as an extension and assistant to employees.

In October 2015, AIG deployed “ARIES,” the company’s first machine learning virtual engineer, to resolve network incidents around the globe. During a 90-day pilot program, ARIES was trained in a “curate and supervise” mode in which the machine operated alongside, and learned from, its human counterparts. In this approach, ARIES learned through observation and experimentation how to assess outage sources and identify probable causes and responses. The co-bot was ready for full deployment on day 91. It’s not that these machines are dramatically faster—in fact, AIG has found that humans take an average of eight to 10 minutes to resolve a typical issue, while co-bots take an average of eight minutes. The benefit lies in its scale: Co-bots can work around the clock without breaks or sleep, and they can resolve incidents so rapidly that queues and backlogs never develop.

Within six months of ARIES’s deployment, automation identified and fixed more than 60 percent of outages. Within a year, ARIES’s machine intelligence, coupled with the expansion of sensors...
monitoring the health of AIG’s environment, was making it possible to programmatically resolve an increasing number of alerts before they become business-impacting events. The virtual engineer can automatically identify unhealthy devices, perform diagnostic tests to determine the cause, and log in to implement restorative repairs or escalate to a technician with “advice.” Additionally, the co-bot correlates network issues, so if data patterns show one device caused 50 incidents in a month, for example, the IT team knows it needs to be replaced. Those efforts have reduced the number of severity 1 and 2 problems by 50 percent during the last year. They have also increased technician job satisfaction. Instead of having to perform mundane and repetitive tasks, technicians can now focus on more challenging, interesting tasks—and benefit from the co-bots’ advice as they begin their diagnosis.

Four additional co-bots, each operating with a manager responsible for governance, workloads, training and learning, and even performance management, have been deployed with consistent successful adoptions.

Following the success of the co-bot program in IT, AIG is exploring opportunities to use machine learning in business operations. “We want business to use machine learning instead of requesting more resources,” Brady says. “We need to leverage big data and machine learning as new resources instead of thinking of them as new costs.” Internal trials are getting under way to determine if co-bots can review injury claims and immediately authorize payment checks so customers need not delay treatment. Other opportunities will likely emerge in the areas of cognitive-enhanced self-service, augmented agent-assisted channels, and perhaps even using cognitive agents as their own customer-facing channels.

“The co-bot approach takes work,” Brady adds. “If it’s really complex, you don’t want inconsistencies in how the team does it. That’s where design thinking comes in. Since we started doing this a little over a year ago, we have resolved 145,000 incidents. It’s working so incredibly well; it just makes sense to move it over to business process and, eventually, to cognitive customer interaction.”
In the context of cybersecurity, machine intelligence (MI) offers both rewards and risks. On the rewards front, harnessing robotic process automation’s speed and efficiency to automate certain aspects of risk management could make it possible to identify, ring-fence, and detonate (or, alternatively, scrub) potential threats more effectively and efficiently. Leveraging machine intelligence to support cyber systems could potentially help scale data analysis and processing and automate the means of acting in a deliberate manner on the risks these tools identify.

MI’s efficacy in this area can be further enhanced by predictive risk and cyber models that extend its data mining net further into largely unexplored areas such as the deep web, and address nontraditional threats it may encounter.

Companies can also harness MI to drive channel activity, strategy, and product design. For example, using capabilities such as deep learning, sales teams can construct fairly detailed customer profiles based on information readily available on social media sites, in public records, and in other online sources. This information can help sales representatives identify promising leads as well as the specific products and services individual customers may want.

But there is a potential downside to MI’s customer-profiling power: These same applications can create cyber vulnerabilities. MI might make inferences that introduce new risks, particularly if those inferences are flawed. By creating correlations, MI could also generate derived data that presents privacy concerns. Ultimately, companies should vet derived data based on inferences and correlations.

Indeed, as automation’s full potential as a driver of efficiency and cost savings becomes clear, many are discussing broader ethical and moral issues. What impact will automating functions currently carried out by humans have on society, on the economy, and on the way individual organizations approach opportunity? How will your company manage the brand and reputation risk that could go hand-in-hand with aggressive automation initiatives? Likewise, will your organization be able to thrive long-term in what some are already describing as “the post-work economy”?

Finally, risk discussions should address the “black box” reality of many MI techniques. At this juncture, it may not be possible to clearly explain how or why some decisions and recommendations were made. While there is an ongoing push for algorithmic transparency that could eventually drive development of new means for auditing and understanding assumptions, observing patterns, and explaining how conclusions are justified, those means do not currently exist. Until they do, try to determine where a lack of visibility could be an issue (legal, reputational, or institutional) and adjust your plans accordingly.

As we sail into these uncharted waters, CIOs, CEOs, and other leaders should carefully balance the drive for shareholder value with a host of potential risks to reputation, security, finance, and others that will likely emerge in the years to come.
Where do you start?

Few organizations have been able to declare victory in and around data. Even when data was largely structured and limited to information housed within the company’s four walls, managing and analyzing could prove challenging. Today, sophisticated algorithms and analysis techniques enable us to solve complex scenarios; we can move from passively describing what happened to actively automating business responses. Yet even with rapidly advancing capabilities, some organizations still struggle with data.

The good news is that machine intelligence offers new approaches and technologies that may help us finally overcome some longstanding data challenges:

- **Curate data:** MI techniques can be applied in a largely automated fashion to data taxonomies and ontologies to define, rationalize, and maintain master data. MI can analyze every piece of data, its relationships, and create a derived approximation of data’s quality. Likewise, it can potentially provide a means for remedying content or context issues that arise.

- **Bounded and purposeful:** Focus on gaining insight into business issues that, if resolved, could deliver meaningful value. Let the scope of the problem statement inform the required data inputs, appropriate MI techniques, and surrounding architectural and data management needs. By resolving a few of these issues, you may acquire greater license to apply MI to more complex questions.

- **Sherpas welcome:** MI is enjoying its own age of enlightenment, with academia, start-ups, and established vendors bolstering capabilities and adding new techniques. Consider partnering with vendors willing to co-invest in your efforts. Likewise, collaborate with academics and thought leaders who can provide unbounded access to valuable expertise.

- **Industrialized analytics:** Data has become a critical strategic corporate asset. Yet too few organizations have invested in a deliberate, holistic commitment to cultivate, curate, and harness this asset across the enterprise. Industrializing analytics means driving consistent and repeatable approaches, platforms, tools, and talent for all dimensions of data across the enterprise—including machine intelligence. Tactically, this will likely lead to services for data ingestion, integration, archiving, access, entitlement, encryption, and management.

**Bottom line**

Artificial intelligence may capture more headlines, but the bigger story is machine intelligence, a term describing a collection of advances in cognitive computing that can help organization move from the legacy world of retrospective data analysis to one in which systems make inferences and predictions. The ability to take these insights, put them into action, and then use them to automate tasks and responses represents the beginning of a new cognitive era.


7. Schatsky, Muraskin, and Gurumurthy, Demystifying artificial intelligence.


12. Interview with Mike Brady, global chief technology officer, American International Group Inc., November 22, 2016.
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Help wanted
American manufacturing competitiveness and the looming skills gap

DELOITTE REVIEW 16
THE future of manufacturing has been a topic of debate over the past decade. By the time the new millennium rolled around, many considered manufacturing a relic of the 20th century and not meaningful for developed nations in a 21st-century knowledge, information, and services economy. Making things had given way to other forms of adding value in a developed economy, and many developed nations, including the United States, watched, and often encouraged, their manufacturing sectors being displaced, outsourced, and diminished in favor of low-cost products and cleaner, supposedly smarter, and more sustainable service sectors such as financial services and health care. But the Great Recession that began in 2007–2008 caused a rethinking in established economies in North America, Western Europe, and Japan. It seemed manufacturing did indeed matter. Enormous effort and taxpayer money were spent to “save” the automobile industry and associated jobs in the United States, Canada, Germany, and Japan. Manufacturing jobs that had long been offshored were now coveted by both developed and emerging nations for their generally higher wages, strong multiplier effect on other jobs in the economy, positive impact on the prosperity of the middle class, and their critical linkage to a nation’s innovation ecosystem. Americans in particular were clamoring for more manufacturing jobs. In an annual survey of the US general public by Deloitte Consulting LLP and the Manufacturing Institute, conducted from 2009 through 2014, US citizens selected manufacturing first each and every year when asked to rank industries in which they would most prefer to create a thousand new jobs.¹

What is driving this manufacturing renaissance? Joint research by Harvard and MIT revealed that the competitive strength of a nation’s manufacturing sector is the most reliable predictor of a nation’s economic prosperity over the long term.² In fact, their index of manufacturing complexity, or the robustness of a nation’s manufacturing sector, proved to be a more accurate predictor of a country’s economic prosperity than any other traditional measure. Further, they found that the more advanced a nation’s manufacturing sector (meaning the more complex and the higher the value of the products a nation can produce and trade) and its manufacturing processes and know-how, the more prosperous the nation and its citizens become. Finally, they found that virtually every nation in the world has been advancing its manufacturing capabilities over the past 50–60 years, and the most successful have had the greatest gains in traditional measures of economic prosperity such as GDP per capita (for example, China, Vietnam, and Thailand).

But what drives a nation’s or a company’s ability to engage in advanced manufacturing? Research we conducted in conjunction with the World Economic Forum, and separately with the US Council on Competitiveness, exploring the factors contributing most to manufacturing competitiveness identified a highly productive workforce, strong intellectual property protection policies, favorable financial
and monetary policies, broad infrastructure, strong R&D capabilities, and established supply chains as important contributors to 21st-century advanced manufacturing competitiveness. But the most important factor identified was a nation’s ability to foster talent-driven innovation—that is, its ability to ensure a sufficient supply of talented workers, which enables companies to advance innovation agendas and produce more innovative, higher-value goods and services capable of winning in global markets. From researchers, scientists, and engineers to shop floor workers, the most critical ingredient identified by the thousands of executives worldwide participating in our research was the quality and availability of talent.

While many of the strengths and capabilities that propelled the United States during the 20th century remain, the growing skills gap threatens America’s competitiveness today and in the long term. An estimated 600,000 manufacturing jobs went unfilled in the United States in 2011, even as the nation was emerging from the economic downturn; manufacturers could not find enough workers literate in the science, technology, engineering, and math (STEM) disciplines necessary to effectively function in advanced manufacturing environments. This number could grow to over 2 million over the next decade, as 2.7 million workers retire and modest economic expansion creates the need for an additional 700,000 workers. A total of over 3.4 million manufacturing jobs will be available, and manufacturers will be able to fill fewer than half of these job openings due to the skills shortage. Unless it begins to close the growing skills gap and stem the loss of manufacturing knowledge resulting from retirements and fewer qualified candidates, the United States’ ability to continue to innovate and advance its 21st-century manufacturing capabilities may be in jeopardy.

Race among nations

Manufacturing is crucial to the US economy: For every dollar spent in manufacturing, $1.32 is added to America’s economy; 9 percent of the workforce is directly employed in manufacturing; and American manufacturing supports more than 12 million workers directly and 17.4 million jobs in total. At the same time, the United States isn’t the only nation that recognizes the economic importance and value of manufacturing. Developed and emerging nations are focused on improving their manufacturing competitiveness, attracting companies, and creating jobs, and as a result, they are challenging America’s position as a globally competitive manufacturing nation. Over the past few decades, emerging countries have taken advantage of their low labor costs and coupled them with incentives and enabling polices to support the growth of their manufacturing base and middle-class jobs. Over the last 20 years, manufacturing, which used to be concentrated in a few developed countries in North America, Europe, and Japan, has gradually moved to emerging, more
cost-competitive markets, leading to an eightfold increase in exports from emerging economies in the last two decades. However, moving factories to low-cost destinations has had an unintended impact on American manufacturing and the workforce. Between 1990 and 2010, thousands of US factories closed, millions of manufacturing jobs were lost, and younger generations started looking elsewhere for better career opportunities. The combination of retirement and jobs displaced to the east over decades has resulted in a significant loss of embedded knowledge. As a result, there is a generational gap in technical skills in the United States as well as many European countries. Meanwhile, economies in Asia have experienced cost increases in labor, supply chain and logistics, and all forms of energy, with price differentials in electricity and natural gas increasing over the years. This has led manufacturers in developed nations, such as the United States, to consider “reshoring” facilities.

These factors represent an inflection point for American manufacturing. Since 2009, manufacturing has outperformed the overall economy. The economic rebound, declining energy costs due to the recent shale gas boom, and decreasing levels of offshoring in response to fading labor rate arbitrage advantages have all contributed to manufacturing growth in America. But the US labor force participation rate is declining. Baby Boomers continue to retire in droves. And the US pipeline of young talent is weak compared to many other manufacturing nations, both developed and emerging. Over the next decade, nearly 3.5 million manufacturing jobs will be available in the United States.

While this should bode well for the United States’ long-term economic forecast, our research suggests manufacturers may be hard-pressed to fill all of those jobs. The issue that has concerned many for decades has finally reached a boiling point. The United States either must find and develop people to address the talent shortage or risk facing another wave of offshoring to places where talent is in greatest supply.

Deloitte Consulting LLP and the Manufacturing Institute polled a nationally representative sample of manufacturing companies about the state of talent in the US manufacturing industry. Eighty-four percent of manufacturing executives agree there is a talent shortage in US manufacturing, and they estimate that 6 out of 10 open skilled production positions are unfilled due to the shortage.

The talent shortage is already affecting US domestic firms as well as larger multinationals. Manufacturing output data from 2004 to 2013 reveal that US manufacturing lost a minimum of $17 billion annually due to unfilled positions. That figure exploded to over $45 billion in 2012 and 2013. Manufacturing executives believe the talent shortage will continue to impact their success. For example, nearly 80 percent of executives surveyed believe the talent shortage will affect their ability to meet growing customer demand, as well as develop new products and implement new technologies.

America’s manufacturing sector will likely require an estimated 3.4 million workers over the next decade (2015–2025) when accounting for the retirement of Baby Boomers and the forecast economic expansion. Of these, nearly 2 million jobs are expected to remain unfilled due to shortage of workers with the skills necessary to operate in a 21st-century advanced manufacturing environment (figure 1).

The magnitude of the skills shortage has not gone unnoticed, and the US government is taking steps to address the issue. New programs motivate businesses and educational institutions to create programs that develop America’s workforce by imparting relevant skills. For example, $450 million in job-driven training grants is being distributed in 2014 across nearly 270 US community colleges. However, these programs are not quick fixes, nor are they likely to be enough to tip the scale on their own. By the time the graduates of these new programs enter the workforce, the window of opportunity will have shrunk.

This skills gap may be manufacturing’s Achilles’ heel which—with nearly 3.5 million jobs at stake over the next decade, could swell to become the Achilles’ heel of the entire US economy. It is no longer simply a short-term issue of filling current hard-to-fill open positions, or one that can reasonably be expected to be solved in time by government policymakers. A holistic look at the issue, as well as an examination
Understanding of the key variables contributing to the gap, will be crucial. The situation suggests the need for a new kind of workforce strategy that focuses on addressing prospective workers’ perceptions of manufacturing, optimizing the deployment of the existing workforce, augmenting recruitment practices, and, ultimately, building the talent pipeline.

The inflection point

The velocity of technological advances and innovation is also driving the need for new workers, as well as a highly skilled talent profile. Creating the demand for higher skills are streamlined production lines, coupled with increasingly automated processes and reliance upon advanced technologies that utilize fully connected computer-controlled processes, advanced robotics, and new manufacturing techniques such as 3D printing. As a result, manufacturers may face a shortage of qualified candidates emerging from the K-12 education system (particularly candidates with adequate STEM skills) as well as skill challenges within their existing workforce.

Manufacturers need to ramp up recruiting and talent development efforts and turn a watchful eye to finding “hyper-skilled” workers who have the requisite skills to keep up with today’s dynamic manufacturing environments, and who also possess traits that indicate adaptability, such as creativity, problem-solving skills, and critical thinking skills, to meet future needs. Otherwise, technological change and innovation will likely outpace the limited supply of skilled workers with the talent profile needed to meet today’s (and tomorrow’s) advanced manufacturing requirements.

We are at an inflection point. Developing multifaceted workforce programs that address the full spectrum of the skills gap can mean the difference between keeping and creating jobs in the United States and increasing reliance on offshore resources. Confronting the skills gap head-on requires a unified approach that includes business leaders,
policy-makers, academicians, scientists, and labor leaders.

Are the issues really that complex?

A closer look at the drivers of the US skills gap suggests that the issues are complex in themselves, and even more complex in aggregate.

- **Baby Boomers are retiring.** There have been discussions about the impending "tsunami of retirements" for many years. Trends suggest that this wave of retirements is about to be unleashed. According to a recent Gallup study, the average retirement age of US workers is 64. While the average retirement age may increase slightly as the sluggish US recovery continues and nest egg worries mount, more than 2.7 million workers are likely to retire between 2015 and 2025.

- **The pipeline of talent isn’t deep enough or developing quickly enough.** Increasingly, K-12 students demonstrate a lack of proficiency in math and science. Remedying this issue is neither easy nor quick. The United States is lagging behind many other nations, particularly in math, science, and reading, as reflected in PISA test results. On average, over the next decade, between 3.2 million and 3.5 million students will graduate from US high schools annually. Few of these students will be qualified for careers in an advanced manufacturing environment and, based on test scores, few will have the necessary STEM skills for on-the-job training.

- **Today’s workers are deficient in requisite skills.** Executives indicate that current employees are deficient in technology, basic technical, and problem-solving skills. Seventy percent of executives report that their current workers do not have adequate technology and computer skills; over two-thirds indicate that they lack adequate problem solving skills; and 60 percent indicate that they lack sufficient math skills. Most troublingly, over two-thirds indicate that they lack basic technical training (figure 2).

- **Business is expanding following the recession.** Prior to 2009, the US manufacturing sector underperformed compared to the overall economy. The sector lost more than 2 million jobs between 2008 and 2010. However, since the recession ended, US manufacturing has grown. The share of GDP attributed to US manufacturing increased from 11.9 percent in 2009 to 12.4 percent in 2013. Looking to the future, data suggest that between 2015 and 2020, approximately 400,000 additional jobs will likely be created from natural growth or business expansion. By 2025, this number will likely grow to a cumulative 700,000 new jobs.

- **A new type of worker will be required because the skill set required is changing.** As the industry has changed, the nature of

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**Figure 2. Percentage of executives that indicate current employees are not proficient in key skills**

<table>
<thead>
<tr>
<th>Skill</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology/computer skills</td>
<td>70%</td>
</tr>
<tr>
<td>Basic technical training</td>
<td>67%</td>
</tr>
<tr>
<td>Problem-solving skills</td>
<td>69%</td>
</tr>
<tr>
<td>Math skills</td>
<td>60%</td>
</tr>
</tbody>
</table>

Source: Deloitte and Manufacturing Institute’s 2014 Skills Gap Study.
the work has also changed. Manufacturers not only need to fill volumes of open positions—they need to fill those positions with skilled workers who can contribute effectively in a highly sophisticated and technical manufacturing environment. The pace of change that the industry is experiencing, combined with global competitive pressures, means that manufacturers will continue to expect more from their employees. Essentially, manufacturers need skilled workers who have the ability to master new, advanced technologies, work in highly collaborative team environments, use critical thinking and problem-solving skills, adapt to ever-changing environments, and embrace an attitude of never-ending learning.

Adding to the skills shortfall are three factors that also need to be addressed in the development of America’s strategy to help close the skills gap. First, US wages are growing at a slower rate than wages in other developed and emerging countries, potentially contributing to a lack of applicants. Second, labor force participation in the United States is decreasing. Simply put, people are leaving the workforce and not returning. And third, average American citizens do not view manufacturing as a viable career choice for themselves, nor are parents encouraging their children to explore manufacturing careers.

### Talent shortage most severe among skilled production and highly skilled workers

To identify the occupations that are likely to face the greatest talent shortage, we asked executives to identify the business areas they think are most affected now and will be most affected by 2020. The results indicate that skilled production workers, engineers, researchers, and scientists are in short supply today. More worrisome, however, is that the gap is likely to worsen by 2020 (figure 3).

One of the categories forecast to be hardest hit may be skilled production workers (machinists, welders, cutters, and solderers), who accounted for 51 percent of manufacturing employment in 2012. Today, this category is experiencing the highest demand for skilled workers among all the categories in the study.

![Figure 3. Workforce categories in which the skills gap is most severe, today and anticipated in 2020](image-url)
Moreover, two-thirds of the executives participating in the study expressed concern that the impact of the shortage in this category could be felt through 2020.

To put this in perspective, the number of welders has already fallen from 570,000 in 1988 to fewer than 360,000 in 2012. Today, the average age of a welder in the United States is 55, and he or she is likely to retire within 10 years. Accounting for these retirements and the current talent pipeline, the American Welding Society estimates that, by 2020, there will be a shortage of 290,000 welding professionals. And this is just one segment within skilled production occupations. The shortfall is even more daunting when one examines the many types of trades within this cohort that are all facing the same issue.

The talent outlook for engineers, researchers, and scientists is also troublesome. Not only do one-third of the surveyed executives cite a severe shortage of engineers today, but nearly half expect this shortage to remain severe until 2020. Compounding this issue is the time our respondents indicate it takes to fill these jobs. They report that it can take an average of 94 days to fill engineering, research, and scientist positions.

Not just a numbers game—Finding, attracting, and retaining the right skills is at the heart of the matter

One of the key contributors to the skills shortage is the continued decline of interest among people with the right skills in pursuing manufacturing careers. The image of the manufacturing industry as “dirty, dumb, dangerous, and disappearing” has persisted despite vast innovations within manufacturing facilities that today are pristine environments housing highly advanced production machines and processes. These facilities are typically characterized by work cells composed of numerous computer-controlled, but operator-managed, machines and robots where one worker ensures that software, hardware, tooling, and materials all work together and to detailed specifications. Unfortunately, many young people do not recognize this evolution. As a result, manufacturing has an image problem that further exacerbates the skills gap.

This lack of awareness has contributed to a lack of interest from students. Lack of engagement from industry may have also led to insufficient manufacturing-related learning curricula. A rapid rate of innovation suggests that manufacturers face a growing and long-term need for a new type of worker who is STEM-literate, creative, and capable of problem solving. For those who are interested in working in manufacturing—and are aware of the opportunities—these dynamics can offer significant opportunity for long-term, financially and personally rewarding careers.

A new approach to recruiting, managing, and developing talent

RECRUITING TALENT

Fifty-eight percent of executives reported they are either “currently revamping” (31 percent) or “considering changes to” (27 percent) their talent sourcing and recruiting strategies. Manufacturing executives should likewise consider new approaches to recruiting the right people.

Recruit from new sources: Manufacturers can recruit from relatively untapped sources of talent, including veterans and the long-term unemployed. Companies are instituting programs, such as “Get Skills to Work,” to enable the transition of veterans from military to civilian careers. Women are another untapped source: While they constitute nearly half of the US workforce, they account for less than a quarter of the workforce in manufacturing. Programs like the Manufacturing Institute’s STEP Ahead initiative provide an avenue for companies to motivate women leaders to pursue careers in manufacturing and to showcase the opportunities manufacturing can offer.

Accessing new sources of talent also means questioning old assumptions and challenging stereotypes about what skills are necessary and who may
ultimately be successful. For example, do skilled production workers require college degrees, or can vocational programs produce qualified applicants? A recent article noted that while 60 percent of German young people train in “dual training” apprenticeship programs that combine secondary education with vocational training, only 5 percent of American youth do so. Manufacturers can also use readily available tools to bring the needed skills to the table. For example, the Manufacturing Institute’s system of certifications—designed by and for the industry, and endorsed by the National Association of Manufacturers—represents skill standards manufacturers can use while posting jobs and evaluating applicants. These certification standards also serve as a toolkit manufacturers can use in working with colleges and technical schools to ensure that training programs align with current and future job requirements.

Production workers come from different sources (junior colleges and vocational programs) than STEM professionals (traditional four-year colleges and universities). Skilled production workers can be “made” through vocational training programs; however, the challenge of finding STEM professionals must be addressed earlier in the educational pipeline. Only 16 percent of high school students are proficient in mathematics and interested in STEM careers. To address this deficiency, President Obama has set goals to develop, recruit, and retain 100,000 excellent STEM teachers over the next 10 years, and for colleges and universities to enable an additional 1 million students to graduate in STEM majors.

Recruiting means marketing: Image matters when recruiting new talent. Moreover, the proliferation of benchmarking publications and social media provides prospective employees with a wealth of data about companies’ business models, talent management practices, and culture. According to the previously mentioned annual survey of the American public, Millennials (aged 19–33 years) indicated that some of the most “desirable” companies to work for are in the technology industry, where innovative products or software solutions are highly visible. In addition, 64 percent of them report that one of their career priorities is “to make the world a better place.” Manufacturers can increase their attractiveness to these applicants by highlighting the link between innovative products and societal outcomes (such as sustainability and infrastructure development). Another recent study found that Millennials seek to gain skills that enhance their future career prospects. Manufacturers can enhance their attractiveness to this demographic by marketing the use of additive manufacturing (3D printing) technologies, advanced analytics, robotics, and other innovations. Finally, Millennials value a collaborative, flexible, and open work environment where technology is central. Manufacturers can market their work environments in innovative ways that highlight these traits. One major manufacturer, for example, has used gaming technology to help prospective applicants learn about its work environment and culture.

MANAGING TALENT

Manufacturing companies can take advantage of HR data and empower their HR leadership team to help achieve business goals.

Manage the talent pipeline like a supply chain: Analytics-driven approaches to workforce planning can enable companies to get ahead of talent shortages in the same way that they manage lead times in the supply chain. Changes in economic conditions or business strategy, or a decision to introduce a new product, may require companies to adjust workforce strategies. For example, the decision to introduce a new product using a disruptive technology will require a company to forecast the competencies required throughout the new product’s life cycle, assess its current employees for required skills to identify competency gaps, and design strategies for closing those gaps. As in supply chain management, one size does not fit all. This model allows manufacturers to apply lean concepts such as “just in time” and “right part, right time” beyond manufacturing and production to the management of their workforce. A successful program may include a mix of balance sheet employees (in whom the company has made a long-term investment to “buy”), consultants with specific and/or high-priced skill sets that the organization needs to only “rent,” and contractors whom the organization may not have the time or resources to develop and who represent “variable capacity” that can be
flexed up and down based on program needs. Managing this talent requires standardizing roles, skill descriptions, and competencies (for example, employing the National Association of Manufacturers’ manufacturing competency model) to support both internal resource deployment/redeployment and external sourcing of resources (for example, from schools that train students in specific competencies).

**Redesign and re-skill the HR function:** Traditionally, HR employees focus on managing day-to-day activities such as employee salary and benefits administration, administrative activities (such as processing human resources information system changes), and employee relations. Manufacturing HR departments should transition from delivering HR services to designing and driving HR strategies where HR outcomes are business outcomes. The HR function can be more valuable to the organization when it is empowered and responsible for designing and driving strategies to recruit, develop, and retain employees. There are some key principles that can guide manufacturing companies in redesigning their HR functions:

- Establish a service delivery framework and automate transactions for day-to-day employee needs. Until HR professionals have the ability to step away from day-to-day tasks, they will be not be able to provide real value to the business.38

- Embed HR professionals in the business and provide strategic human capital consultative services. This move will address the human capital challenges unique to each department. For example, many engineers struggle when promoted to manager, a transition often complicated by a lack of training.39 An HR specialist who is well-integrated with the business could pinpoint this challenge and design appropriate talent programs to address it.

- Reduce the need for HR generalists, and create HR specialists. When individuals can focus on developing skills in specific areas, the entire department can work like a “network of expertise.”40 For example, empowering one individual to focus solely on recruiting can help the organization develop deep expertise in areas that matter most, such as supporting the development of local STEM talent and attracting top candidates. All of these changes can help HR transition from “just getting by” to developing strategies and driving changes that bridge the skills gap.

**DEVELOPING TALENT**

Unlike the post-World War II boom when beginning a career meant committing to long-term employment, people today change jobs more frequently.41 Retention beyond five years is uncommon. Somewhat counterintuitively, though, employee development is one of the biggest drivers of retention and engagement.42 Manufacturers can invest in training and development programs to build the capabilities needed to meet business goals and improve retention. To paraphrase a recent discussion with a manufacturing leader: “I am less afraid of developing my people and having them leave than I am of not developing them and having them stay.”

**Foster long-term career development and growth:** Learning doesn’t happen only through programs and courses. Manufacturing companies must shift from “pushing” training to employees to allowing employees to “pull” the information they need and want. Manufacturers need to evaluate what capabilities are required to achieve business outcomes and invest in learning, using the right mix of media—hands-on training, apprenticeships, virtual classrooms, traditional classrooms, and social media. Employees should be able to find information on their own in real time, educate themselves, and share knowledge with others. Online or mobile portals allow employees to take training at any time, and new knowledge tools let them literally “Google” the right answers.43 Employees can also develop skills through their work networks, by seeking feedback from peers, and by working with managers for coaching and mentoring. It is important to evaluate the learning function with the same rigor as other functions—funding and expanding programs that deliver results and eliminating those that do not. Finally, companies must create reward structures that focus employees on continuous versus episodic learning, and that create an expectation of learning throughout one’s career. Nissan, for example, as part of its corporate strategy, helps employees design their own careers by creating a culture of
continuous learning. Employees gain specific skills not only in their area, but also participate in training that extends their skills in the field of their choice. Once they acquire new skills, they apply for positions in the area of their interest.44

**Invest in experiential development:** An important part of development comes from employees’ experiences. Millennials value rapid advancement, flexibility, and mobility across a variety of assignments.45 Unfortunately, these characteristics are not traditionally associated with manufacturing. This can be changed through the implementation of non-traditional developmental assignments and career paths. Companies can facilitate short-term assignments or deployment outside current roles. The founder of LinkedIn, Reid Hoffman, has popularized the term “tours of duty” to describe this concept. Employees on tours of duty in different parts of the company, in other regions, or on cross-functional teams learn new skills rapidly. These experiences can help make employees both more capable and more loyal.46

With US manufacturing likely facing a shortfall of 2 million workers in the next decade, it will be essential to examine the impact of the skills gap and take a new approach to talent management. The contributing factors—a shortage of workers with adequate STEM skills, the impending onslaught of Baby Boomer retirements, expected industry expansion, and a lack of interest in manufacturing among the next generation of workers—cannot be ignored by business leaders or government policymakers.

This skills gap may be manufacturing’s Achilles’ heel which—with nearly 3.5 million jobs at stake over the next decade, could swell to become the Achilles’ heel of the entire US economy. It is no longer simply a short-term issue of filling current hard-to-fill open positions, or one that can reasonably be expected to be solved in time by government policymakers. A holistic look at the issue, as well as an examination and understanding of the key variables contributing to the gap, will be crucial.
ENDNOTES


28. Ibid.


37. Ibid.


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46. Josh Bersin et al., Corporate learning redefined.

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