Complimentary article reprint

How I learned to stop worrying and love the future of manufacturing

BY MATT ADAMS, GLENN SNYDER AND MATT SZUHAJ
> ILLUSTRATION BY IGOR MORSKI
During a dinner attended by Silicon Valley leaders in 2011, President Barack Obama directed a question to then-Apple CEO Steve Jobs: What would be required to make Apple products in the United States? When Mr. Jobs answered that “those jobs aren’t coming back,” did he mean that developed country manufacturing is a dying breed, or that the future of manufacturing is a more distributed model? Is the very nature of manufacturing competitiveness changing? Could it be that his product—the iPhone—is a symbol of the forces of technology innovation at work to enable such a shift?1
If Moore’s Law were to continue defining the performance of processors through 2050, the average personal computer would have the same processing ability as all of the human brains in the world combined.\(^2\) Even if the rate of performance increases slows, this growth of processing power will almost certainly transform the fields of robotics and automation. Imagine a factory where all redundant and many—if not most—complex, decision-based tasks are done by machines; there are fewer low-skilled jobs in this scenario that are prone to labor arbitrage but proportionally more high-skilled jobs (to support the machines) that are less attractive to offshoring for cost advantages.

Manufacturing decisions have for so long been driven by cost reduction efforts that production has effectively become a commodity to be procured at the lowest possible cost. The viability of new technologies, combined with other factors, creates long-term options with the potential to set companies apart, if they can maintain the research and development commitment to realize long-term benefits. Though many companies are withholding capital reserves in response to the uncertainties of the current economic and political environment, the significant corporate capital in developed countries affords an opportunity for forward-thinking companies to activate manufacturing as a strategic lever, rather than just a cost to be reduced.

**A MANUFACTURING RENAISSANCE?**

For years, developed economies have been hemorrhaging manufacturing jobs as companies have found low labor cost advantages in developing markets to be such that they can afford higher employment rather than implementing even basic automation. Yet trends in automation and robotics technologies are rapidly changing the equation, enough so that the next 15–20 years could see a significant shift of manufacturing toward concentrations of resources and end-user markets, including new growth of manufacturing in developed economies sometimes written off as part of manufacturing’s history.

Against a backdrop of developing economy labor cost inflation and other economic trends, automation advances are becoming cost competitive with the alternative of high labor staffing, ultimately decreasing the importance of labor cost as a critical location factor for new manufacturing. As increases in computer processing power, sophisticated sensor technology, artificial intelligence control systems and other technology advancements drive the next generation of automated production, the future of the manufacturing footprint seems poised for dramatic change in many industries.

Ultimately, companies that view the intersection of technology and
geography as a strategic manufacturing opportunity are likely to be better positioned as automation changes the game.

**SHIFTING THE PLAYING FIELD**

The United States has had a tenuous relationship with manufacturing over the past several decades. Many U.S.-centric manufacturers, as well as those from other developed countries, have pursued cost arbitrage by growing manufacturing outside the U.S. Since those initial forays into manufacturing growth outside the country, U.S. companies have contemplated the trade-offs associated with automation technology versus relocation. While U.S. manufacturing employment as a percent of total nonfarm employment has decreased significantly, from 28 percent in 1962 to less than 9 percent in 2011, it has largely remained constant until recent recessionary periods. Meanwhile, real output in manufacturing has increased steadily over that same period.³

![Figure 1. U.S. manufacturing: Production and labor](image-url)

For many industries, the default decision has long since been to channel manufacturing growth internationally to gain from labor cost advantages, as
CHARMED BY ROBOTS

In the 1980s General Motors, besieged by more efficient Japanese auto manufacturers, devised a plan to reduce costs and regain competitiveness by investing heavily in robotics and automation. Ultimately, what was praised as a visionary idea turned into a cautionary tale for decades to follow for manufacturers envisioning automation as the key to increased efficiency.

When CEO Roger Smith committed to shift the company’s primary manufacturing capabilities from direct labor to robotics, he was lauded as an innovator and visionary. The early 1980s saw Japanese automakers, particularly Toyota and Nissan, begin to erode GM’s 48 percent market share. Smith saw robotics as the solution to increase efficiencies and slash long-term labor costs through short-term capital investments. GM went on to invest nearly $45 billion to automate its manufacturing, a sum larger than the combined market caps of Toyota and Nissan at the time.

While GM’s approach to automation today is lauded as a success, its initial foray was described as a disappointment at best. Despite the investment, GM’s market share continued to slide, falling to 30 percent by the mid-1990s, while never realizing operational efficiencies. Toyota continued to manufacture nearly five times as many vehicles per employee as GM. What went wrong? GM failed to account for the indirect labor costs, operators and technicians needed to transition to automation. In addition, Toyota was operating more efficiently not solely through automation but also through strategic practices such as lean manufacturing and Just-in-Time delivery. As one GM executive remarked, by simply using the technology without the prepared workforce, “all you can do is to automate confusion.”
suggested by the lack of employment growth in U.S. manufacturing. But productivity gains suggest that automation and process efficiency have heavily influenced employment as well. Essentially, the people, processes and technology behind manufacturing have enabled companies to do more with less. At the same time, an emphasis on college education and the growth of nonmanufacturing sectors of the economy suggest that the country’s comparative advantages have become increasingly consistent with a knowledge economy.

While these trends may seem intuitive and unlikely to change, the next evolution of manufacturing automation may stem the outflow of manufacturing from developed markets. Manufacturing in the future may not be the high employment haven it once was, but it will likely take advantage of the knowledge economy by tapping into the technical talent produced by universities, accessing software developers, and fostering the culture of innovation already existing in developed countries.

RISE OF THE MACHINES (AGAIN)

Though there has been a gradual advancement of automation in manufacturing, the oft-promised automation revolution has yet to materialize. A variety of factors are aligning to change the assumptions under which companies have made manufacturing investment decisions.

Erosion/shift of labor arbitrage: Over the five years from 2006 to 2010, average real wages in China and India increased 75 percent and 175 percent, respectively, (compared to 5.5 percent growth in the United States.) This rapid growth rate is expected to continue, particularly in China where the Economist Intelligence Unit predicts another 50 percent increase in real wages by 2015. These trends are even more pronounced if focused on the locations that are attracting the majority of inbound investment. Many companies that have found their labor costs doubling are reconsidering the decision to grow manufacturing in these areas, particularly those organizations for which labor cost arbitrage was the primary factor for locating facilities there.

Waning of economic colonialism: Business globalization is shifting from a version of economic colonialism—one in which companies in developed markets expanded first to access developing economy labor pools, then to access their markets. Increasingly, strong companies are emerging from these developing countries to be competitive in the United States and Europe. This is forcing companies in developed countries to consider not only how to be opportunistic
entering new markets but also how to defend their own turf. Tata Motor’s purchase of Jaguar Land Rover is in some ways emblematic of this, as a corporate giant from a former British colony purchased the two venerable and iconic British brands.

Energy cost increases: Fluctuations in global energy markets have been well-publicized, with a recent trend toward higher energy costs. This suggests that companies will be under increased pressure to produce locally to insulate themselves from fluctuating transportation and logistics costs, an effect compounded by concerns around sustainability and reducing the carbon footprint of individual products and the operational network overall. This impact is already evident as companies contemplating large-scale manufacturing investments have become increasingly thoughtful about the source of the power their plants would use. Carbon-emitting sources, such as coal, can be cost-effective but give companies pause due to sustainability initiatives, related corporate image concerns, and the risk of carbon-based taxes.

Footprint balancing: Many companies have experienced a cycle of rapid growth, including mergers and acquisitions, and reactive cuts over the past decade. Combined with a dynamic global environment, these activities can result in a corporate footprint that no longer aligns with corporate objectives. Footprint redundancy, locations that have become more expensive, and shifts in talent profiles for existing facilities require proactive rebalancing that few companies routinely undertake.

The automation and technology company Emerson is a recent example of a company announcing the benefits of their own rebalancing of global operations.6 The company, with a strong history of acquisition and global expansion, has long focused on where it conducts business, consistently seeking to localize not just manufacturing but also engineering and development operations within its growth markets.

Precision information: Approaches to manufacturing such as Just-in-Time and lean manufacturing are emerging as competitive requirements that demand immediate information for production. The need for precise information can most efficiently be served by an automated system that produces data as part of its routine and on demand. Similarly, advanced manufacturing technologies that can enhance flexibility will likely position companies to react most efficiently to the data produced by such a system.
Table 1. Manufacturing 2020 and beyond

<table>
<thead>
<tr>
<th>Emerging technology</th>
<th>Description</th>
<th>Production characteristics</th>
<th>Sector(s) potentially affected</th>
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<tbody>
<tr>
<td>Additive manufacturing</td>
<td>3-D printers(^1) eject superfine powders that form a hard finish, building up or “printing” an object one layer at a time. The technology is rapidly evolving beyond rapid prototyping.</td>
<td>Little to no production waste, short changeover times, and no tooling changes or direct labor required</td>
<td>Industrial products (especially aerospace) manufacturers with low-rate or make-to-order assembly lines, products with intricate internal structures</td>
</tr>
<tr>
<td>Affordable humanoid robotics(^2)</td>
<td>Smaller, less capital-intensive humanoid robots</td>
<td>Smaller capital investments and simpler setup costs are decreasing the barriers to entry—allowing medium-sized enterprises to harness robotics and automation with humans working side by side.</td>
<td>Consumer and industrial products with small-scale assembly operations</td>
</tr>
<tr>
<td>Driverless industrial robots(^3)</td>
<td>Automated trucks performing simple field applications, including preprogramed routes</td>
<td>Typical automation benefits: reduced or eliminated direct labor costs, precise scheduling, etc.</td>
<td>Mining, shipping, construction, forestry, warehousing &amp; distribution</td>
</tr>
<tr>
<td>Swarm and modular robotics (\text{highly speculative and experimental})</td>
<td>Near “artificial intelligence” allows robots to change their function and shape by configuring their own parts in order to perform different tasks or adapt to new conditions. These robots are able to work autonomously in groups to perform a complex task.</td>
<td>With self-configuration and adaptation, engineering changes and new product launches as well as changes to work distribution and take-times become headaches of the past.</td>
<td>Nearly all sectors of manufactured goods, many services</td>
</tr>
</tbody>
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\(^1\) 3-D Printing  

\(^2\) For example, FRIDA—the latest ABB robot  

\(^3\) Caterpillar plans to develop remote controlled machines and expects to develop fully autonomous heavy robots by 2021. Some cranes already are remote controlled.  
A variety of factors make the current environment more conducive to an automation revolution than we have seen in the past. These technologies are emerging in incubator environments, and the supporting technology is fairly mature. For example, additive manufacturing, frequently referred to as 3-D printing, already has been used effectively for rapid prototyping of aircraft parts. The technology has low barriers to entry, demonstrated by the story of a Northwestern University engineering student who recreated a detailed three-dimensional replica of the university’s campus by himself during the three week holiday break.7

Julio M. Ottino, the dean of the McCormick School of Engineering and Applied Science at Northwestern University, has characterized this next generation of manufacturing talent by its aptitude for “whole-brain” thinking. His view, increasingly shared at other leading schools, is that top talent driving the innovation to enable future manufacturing will require both technical skill (left-brain) and creativity (right-brain).

The knowledge gained from such university and corporate incubation environments and experimentation can be used to identify opportunities, challenges and lessons learned to transition to higher-volume production. Similarly, as demonstrated in the example of the engineering student, the computing capacity and programming skills required to manage and execute complex automation are powerful and nearly ubiquitous. In that respect, it is vastly different
from the types of capital-intensive manufacturing automation available several decades ago.

PREPARING FOR THE ROBOTIC REVOLUTION

Companies are better served in most cases to consider their future footprint and proactively anticipate capacity constraints by investigating and piloting new technologies now. Similarly, countries are unlikely to see a return of already vacated manufacturing capacity, but they have a clear opportunity to participate in new manufacturing growth. To prepare for this future, companies and countries should focus on three interrelated areas to take action now: research and development incorporating new technologies; talent development; and long-term strategic planning.

Nurturing technology

Designing for automation: A key aspect of the GM case study was that its Japanese competitors designed components specifically to enable use of automation technology. In that case, simplicity of design was critical to take advantage of the technology’s strengths of repeatability and speed. One former Chrysler executive familiar with the competition at the time indicated his astonishment at the degree to which product design enabled automation success for the Japanese companies stating, “I thought we were pretty adept at automation until I walked through the doors to tour a Toyota plant in Japan and saw how well their products fit their processes.”

For many companies, product development and research are conducted in an environment isolated from the full-scale production technology they will eventually use. This can result in an optimal “theoretical” product that is hard to produce at scale with the same quality. Companies considering automation and other advanced manufacturing technologies today need to incorporate a process for product design that complements the chosen production technology, accounting for its weaknesses and capturing the benefits of its strengths.

Joint business planning for manufacturing: Joint business planning is an emerging approach gaining traction with retailers and consumer product companies in which objectives, product development trends and sales data are shared to aid in collaboratively developing plans for product flow and customer outreach. Manufacturers could benefit from a similarly collaborative approach with companies and research institutions developing automation and other manufacturing technologies. This type of interaction has long been the norm.
for manufacturers working with materials and subassembly suppliers. In a parallel
to arming consumer product developers with detailed customer insights, manufac-
turers can extend their relationships to include the organizations supplying their
production technology and research, providing an open exchange that can enable
them to better respond to a manufacturer’s specific needs.

Technology incubation: Given the aforementioned interaction between product
design and manufacturing technology, gradual implementation of new manufac-
turing technologies is critical. Companies are piloting new production technologies
on small scales to better understand how to apply the benefits of the technology
to their specific needs and adjust their products to fit the technology. This
approach addresses the need to broaden typical R&D beyond solely product de-
development to incorporate manufacturing research and feedback in the product
development process.

Clarks, a British shoe company, uses additive manufacturing (3-D printing) for
rapid prototyping of multicolor shoe designs. While other shoe manufacturers have
received some recognition for experimenting on larger scales with mostly mono-
tone, radical shoe designs, Clarks has been starting slowly but with styles more sim-
ilar to its mass-produced varieties. In addition to the design benefits and accrued
experience, this is giving the company insights on the potential of the emerging
technology and therefore a head start on its use in mass production should Clarks
make that decision.9

Homo-robo relations

Addressing the skills gap: Perhaps even more critical than nurturing and adapting
technologies applicable to specific products is the need to acquire the skills required
to make the next generation of automation technology successful. Given the history
of automation versus offshoring decisions, manufacturers have sought a specific la-
bor profile to produce products, one ill-suited to the new automation environment.
Much of manufacturing for the past several decades has been characterized by high
labor requirements but with relatively little education required for the majority of
the workforce. Even as higher skill requirements have emerged with the automation
in place, companies in many countries have relied on on-the-job training and expe-
rience as the foundation for this skill.

Companies and countries alike must start identifying and training a more skilled,
autonomous workforce that can operate more independently to manage a portfolio
of production activities. Julio M. Ottino, the dean of the McCormick School of En-
gineering and Applied Science at Northwestern University, has characterized this
next generation of manufacturing talent by its aptitude for “whole-brain” thinking.
His view, increasingly shared at other leading schools, is that top talent driving the innovation to enable future manufacturing will require both technical skill (left-brain) and creativity (right-brain). The education systems in developed markets, particularly in the United States, encourage the flexibility to simultaneously develop both perspectives, though educators must focus on enabling rather than suppressing that flexibility.10

RETURNING MANUFACTURING JOBS TO THE UNITED STATES—TRAINING FOR TECH

At the end of 2011 there were nearly 3.2 million job openings in the United States, a number equal to nearly 20 percent of the country’s 14 million unemployed. According to the Internet job posting site Dice.com, in California there are nearly three times as many open technology jobs as there are computer graduates.11 The clear signal in these numbers: There is a significant and growing skills gap in the United States.

The training gap for technical talent has been the subject of political and business discourse, and recent U.S. manufacturing investment suggests that a collaborative effort between government and industry is an effective solution to bridging the gap. For example, the North Carolina governor and other state leaders,12 in collaboration with the biotech industry, has invested to create North Carolina’s Biotechnology Center, a training and workforce development resource that implements training programs specifically designed for bioscience industries. The pre-employment training is provided on machinery and in environments that are typically seen only in private industry. As a result, North Carolina is considered one of the top states for bioscience employment and a national hub for contract research and testing.13

The state of Georgia’s Quickstart program has also used customized training to win industrial investment. The Quickstart program develops customized training programs for qualified new investments in the state of Georgia, using technology to develop workforce skills specific to a company’s needs. The program has been a motivating factor for manufacturing companies such as Kia Motors, Gulfstream and Caterpillar to invest in new Georgia production facilities.14

The winning formula for both Georgia and North Carolina has been workforce development in direct collaboration with industries that need to develop technical skills to remain competitive on a global scale. The benefit of such collaborative training programs is that they address technical skill gaps based on real-time industry needs. Companies that can acquire a technically trained workforce may face lower risk in ramping up capital intensive automated investments. Companies can then access the employees they need for a modern manufacturing environment, and states earn sought-after manufacturing investments and jobs.
Empowering employees: Most of the next-generation manufacturing technologies enable greater flexibility in production, but to capture that benefit companies should endeavor to develop a more empowered production workforce.

A foundational example of this approach in action is at Wisconsin-based Miller Electric Manufacturing, a maker of welding and cutting equipment. In some areas of the organization, Miller provides employees with an expected weekly output, then allows them to determine how best to achieve it without production planners or foremen typically found in similar operations. These employees work together and coordinate with other areas of the company, including supply chain and staffing at times, to achieve their goals. This type of approach can become increasingly valuable as technologies such as affordable robotics and additive manufacturing enable more customization and more flexible production.\textsuperscript{15}

Depending on the production technology selected and how it is used, advanced technologies could permit operating model differentiation through a more flexible manufacturing infrastructure. Such an infrastructure would facilitate the implementation of innovations as well as product customization. This represents a trade-off of short-term cost reduction for long-term cost-effectiveness. In addition to a more technical, educated workforce, this flexibility will require production managers who can operate a portfolio of processes and execute changeovers based on dynamic product demands. This employee empowerment will be more enticing for the required educated workers but will demand a culture shift from traditional production.

Securing a talent pipeline: In light of aging demographic profiles in most developed markets and an overall shortage of skilled technical and engineering talent, talent will be an especially important component of success in next-generation manufacturing. Private company support of secondary education programs in additive manufacturing, for example, can help develop a pipeline for needed talent and give companies access to top students. Some countries, such as Canada and Germany, have long dedicated a component of their education systems to producing trained talent specifically to support manufacturing.\textsuperscript{16}

Planning for the long term

Looking forward, developments in production technology will be an important agenda item in strategy discussions because they offer opportunities for potential long-term differentiation—a way to shift focus from manufacturing as a cost to be minimized to a strategic lever that can drive long-term success. As we have noted, this shift in vision will be challenging for many companies,
particularly those under pressure from public investors with a low tolerance for what may appear to be a contrarian approach.

Similarly, the notion of striving to optimize the corporate footprint requires a long-term perspective—in part because it is difficult to change overnight. But, as labor and energy costs, focus on sustainability, and emerging market growth drive production localization, companies will need to consider where to locate new production facilities well in advance of reaching capacity constraints. In many cases, automation and other advanced technologies will make production in developed economies cost-effective, enabling a shift of existing facilities in low-cost countries to facilities more advantageously positioned to serve local markets, while reducing the logistics costs and environmental impacts of serving existing customers.

Nor is this simply an internal analysis. Most industries should at least consider production technology trends in terms of both the company’s own long-term plans and those of competitors to provide flexibility for future adoption, potentially reducing the initial investment or developing smaller facilities to enable easier change as technologies are adopted. Further, with regard to

Table 2. The changing face of talent

<table>
<thead>
<tr>
<th>Practical skills</th>
<th>Traditional manufacturing labor</th>
<th>Modern trends in manufacturing labor</th>
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<tbody>
<tr>
<td></td>
<td>Primarily mechanical (assembly, machine operations, tool and dye development)</td>
<td>Technical/software skills, computing, problem solving, interpersonal collaboration</td>
</tr>
<tr>
<td>Education</td>
<td>Apprenticeships, vocational school programs, high school</td>
<td>Technical colleges, collaborative training programs (colleges and industry), university degrees (computer sciences and robotics)</td>
</tr>
<tr>
<td>Career path</td>
<td>Limited growth, focused on position, potential line foreman</td>
<td>Measure and recognize strong performance at all employee levels using clear metrics and methods of evaluation; potentially creative compensation strategies recognizing standout performance</td>
</tr>
<tr>
<td>Business involvement of employees</td>
<td>Limited knowledge of business strategy/focused on specific role</td>
<td>Clear communication of business strategy and objectives to employees</td>
</tr>
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</table>
flexibility, it can be useful to include a cross-check of more easily implementable automation technologies against immediate needs and to incorporate automation opportunities among the scenarios during location decision processes.

Lastly, the development cycle for products and manufacturing technologies that make their adoption viable requires action well in advance of the need. With a variety of technologies available and myriad potential industry and product applications, it will require analysis to match specific manufacturing needs with the best technology options and initiate the research cycle in advance of the need. Small, simplistic manufacturing processes will be easier to automate in the near-term with technologies like 3-D printing and in the long-term with artificial intelligence. Larger or more complex manufacturing will benefit from more affordable robotics but may still rely heavily on traditional production labor.

The emerging trends in the next phase of the automation evolution have already begun to alter the competitive landscape. Companies that treat manufacturing as a core strategic lever rather than a cost management exercise will expand their options. Those that can identify the emerging production technologies most suited to their products; encourage a convergence of product and production research and product development; nurture a pipeline of talent that can lead change and deliver on the technology’s promise; and proactively manage their footprint to balance talent access and cost management will be well positioned as the next generation of manufacturing takes hold. DR

Matt Adams is a manager with Deloitte Consulting LLP.
Glenn Snyder is a principal with Deloitte Consulting LLP.
Matt Szuhaj is a director with Deloitte Consulting LLP.

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The Automation Evolution

Endnotes

6. Conversation with Dean Julio Ottino, the dean of the McCormick School of Engineering and Applied Science at Northwestern University, April 2, 2012