MIND + MAKER

An Insider's Perspective on the Robot Revolution in Manufacturing

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Introduction: Welcome to the Manufacturing Revolution

As in all revolutions, disruptive change is happening fast. The innovation afforded by collaborative robots is making it happen even faster. Harnessing the potential requires that you filter through the noise to understand the what, how and why of these advances, quickly. That's the purpose of this collection: to offer informed perspective, pragmatic advice and commentary from visionaries that can help you move more quickly and with greater confidence.

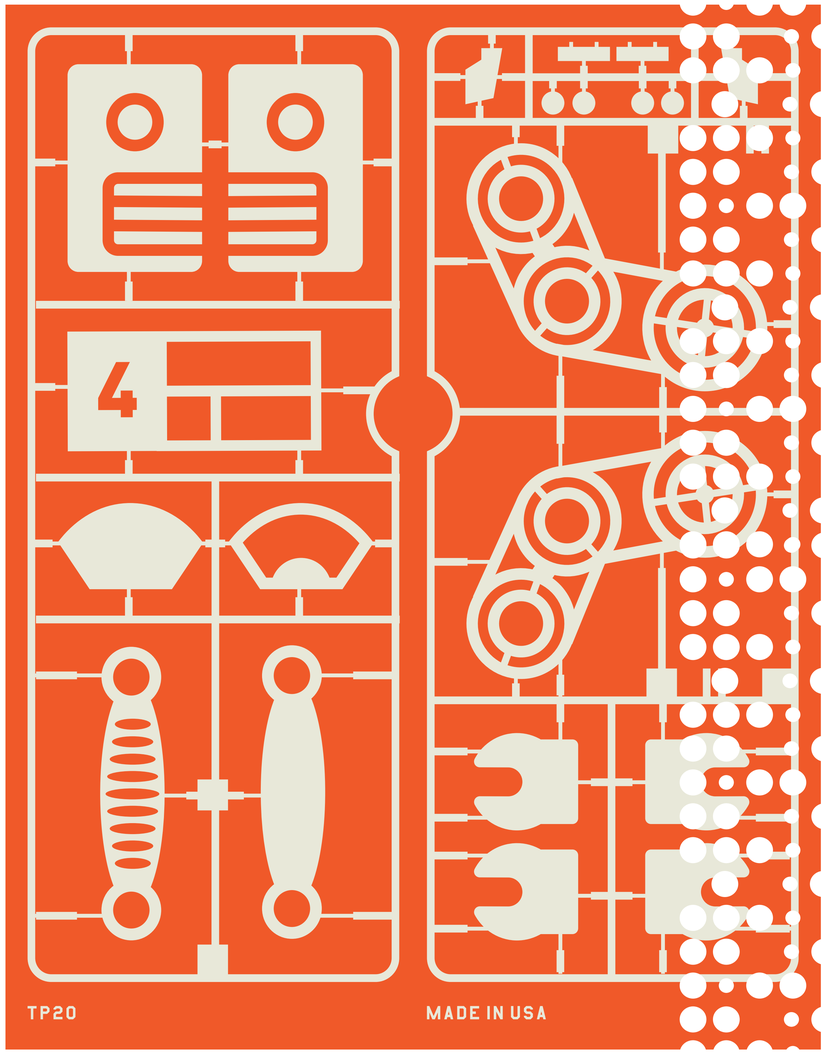
In here, you'll read about the ways in which collaborative robots are tearing down barriers to efficiency and effectiveness. Safe enough to work alongside people; able to automate a wide range of tasks and built with "brains" that allow them to sense and respond to market opportunity and the variations inherent in modern manufacturing environments these robots are more than machines. They are making it possible for manufacturers to focus on growth and innovation.

The collection is designed to answer some questions, challenge institutional thinking about automation and offer a glimpse into how smart, collaborative robots are revolutionizing automation today and how they will contribute to the transformation of the business of manufacturing in the not-so-distant future.

It would not have been possible without the companies who've put these robots to work on real tasks, in real manufacturing environments. They've shown that, not only can it be done, the benefits are real, compelling and yes, revolutionary.

01

Get to Know Smart, Collaborative Robots



Mind + Maker: Manufacturers Rethink Robots

Say 'robot' and images of Rosie, or the Terminator, or R2D2 come to mind. Star Wars meets The Jetsons. Today's reality, however, looks more like a fleet of industrially colored robots purchased by car makers to weld and assemble vehicles and move heavy metal.

But this reality is changing. Fast. Robots are smarter than ever before, safe enough to work among humans, and can perform physical tasks once considered impossible.

So, what does it mean to have robots among us? Advances in technology are paving the way for a new breed of robot that delivers entirely new ways of performing physical tasks. And when combined with the revolution in big data and advanced AI, these smart, collaborative robots are going to profoundly change how manufacturing gets done .

Breaking the Barriers to Widespread Automation of Physical Tasks *Today, more than 90 percent of physical tasks performed in manufacturing environments can't be practically or economically automated. Why? Robots can't adapt to the real-world variability in the workspace or operate effectively in semi-structured environments. Being agile enough to stop working on one task and shifting to another quickly and without requiring reprogramming extends beyond the capability of most existing automation. The list goes on. But advances in compliant motion control, integrated vision, extensible software platforms and advanced AI are tearing down these obstacles even as you read this.*

Sense, Adjust and Learn: Automating Cognitive Tasks. *Some speculate on the arrival of malevolent robots that, through conscious volition, harm the human race. In truth, the opportunities over the next three, five and ten years are mundane by comparison but also much more practical.*

Robots are now able to apply basic common sense to reduce the cognitive load of the user. Consider a robot picking parts out of an egg carton-type grid. If the robots learns that one of the parts has shifted and is now in a different location, it can infer that the other parts have

shifted as well and can calculate the new locations without the intervention of a user. Robots are now able to sense the world around them and adapt on the fly to the changes typical in semi-structured, manufacturing environments.

The automation of cognition exponentially increases scalability of learning across the enterprise – and ultimately inter-enterprise – as well. Cloud robotics leverages cloud computing, storage and advanced analytics to coordinate the actions of large numbers of robots and allows one robot to benefit from the experiences of others. These advances replace the old model where robots are manually re-programmed one-at-a-time, increasing cost and risk and delaying the benefits of new knowledge.

The bottom line? Robots in the near future will gain knowledge from experience, learn from each other and leverage cognitive computation to make themselves, their processes and the products they produce better.

What does all this mean for manufacturing? Manufacturers recognize that they need to be more responsive to market changes, ready to deliver on customer preferences, and able to innovate faster and more efficiently. All adding up to the overwhelming demand for environments that are agile enough to meet all those needs.

Smart, collaborative robots will engender this agility. Factories will be smaller, and located more closely to markets and design centers, accelerating new product introduction and competitive advantage. Production lots of smaller sizes and mass customization will become economically viable, increasing customer loyalty and reducing risk. Companies will be able

to retool their manufacturing systems to provide new roles for these mechanical "workers" as well as new roles for human workers.

The result? Yes, productivity and efficiency improve. Better yet, manufacturers find new ways to ignite creativity and fuel innovation.

Think You Know Industrial Robots? Think Again

Peter Drucker said "Culture eats strategy for breakfast". In my experience there's no industry where that wisdom holds more true than manufacturing. I'm not a hardened cynic, just a pragmatist, having spent the majority of my career bringing technology that disrupts the status quo – from inventory optimization and managing risk in the supply base to collaborative robots. Manufacturers are among the most skeptical buyers and for good reason – what they do is hard, complex and things are done the way they are done because it's been proven to work.

There are times though when the opportunity to transform the business is so compelling that – as Drucker said – executives need to spend whatever time is necessary to tear down the cultural barriers getting in the way.

In the category of robotics and industrial automation, now is one of those times. It's been more than 50 years since Unimate went to work at a GM plant unloading heavy parts and welding them onto automobile frames. Manufacturing has changed a lot and today is on an evolutionary path toward the 4th industrial revolution. Unfortunately, while executives may be ready to move quickly toward the factories of the future for first-mover advantage, many automation engineers remain entrenched in 20th century thinking about robots — when they were highly customized solutions, designed to perform one task over and over again, with a price tag to match.

New Robots, New Truths *Manufacturers who think they know industrial robots need to think again. The new category of smart, collaborative robots have changed everything once held true about robots for manufacturing.*

(1) Cost is no longer a barrier: *With a robot that costs around $25,000, manufacturers can recoup the initial investment in less than one year and more importantly are able to deploy the robot for multiple tasks without expensive reprogramming.*

(2) You do not need a PhD in robotics to put one of these to work: *the best person to train a smart, collaborative robot is the person who actually does the work. Because the robots "learn" by doing the task, guided by a human colleague, they can go to work immediately.*

(3) No more monuments: *One fundamental challenge with traditional automation has been the static nature of the machines. The permanent nature of these installations required first, that the manufacturer design its process around the robot and second, that once the process changed, the robot become not much more than – as one of our customers calls them – monuments. Today, robots operate in support of the process – not the other way around.*

(4) The world isn't perfect, and your environment doesn't have to be for the robot to work: *Variability is a reality – parts won't always be placed exactly where or how they should. Rather than assume a perfect world, which can come at the expense of flexibility and agility, the new category of robots are able to deal with the changes and normal fluctuations that are inherent in most modern manufacturing environments.*

Pick a Project, Prove it Works and Repeat
When Unimate was introduced, telephones were tethered, computers were kept in warehouse-like spaces and the news was printed on paper. All of that has changed and so have the robots.

Remember my earlier point about skepticism and reluctance to run full tilt toward change shared by many in the field? In all honesty, I think it's a good thing to hold fast to the 'prove it' mentality. And the good news about this new category of robots is that it is possible to demonstrate quickly how effective they can be. With smart, collaborative robots, you don't need to change a single thing about how you run your production lines today. Find a task that people should NOT be doing. Get those folks to show the robot what needs to be done. Measure the increase in efficiency

and productivity. And move on to the next task. It really is that simple.

Embracing now the new truths about these robots is essential to exploiting Industry 4.0 and the advances in manufacturing technology that will transform how products are delivered.

Legos Lessons: How Robots Should Work

I grew up in Newport, RI, a city rich with breathtakingly beautiful vistas. Most Saturdays, I'd be walking the ocean cliffs at Brenton Point or hiking out to Hanging Rock at the Norman Bird Sanctuary overlooking Second Beach.

Fresh air and nature were great, but what I really loved to do was build things. Out of my head and into my hands, I would put things together with Legos or an Erector set and make them work. When I got bored, I would take something I'd already built apart and put it together in a different way.

I share this because I see that traditional automation solutions come together a lot like the skyscrapers I would make from those bricks. You start with a big bucket of parts – arms, cameras, conveyors, PLC's, lots of wire. After many hours of assembling components and programming customized code, a unique solution is deployed on the manufacturing line or in the distribution warehouse. It's a model that's worked for decades.

Assembling one-off solutions is great for an 8-year-old growing up or for a manufacturing line dedicated to building one SKU ten million times. But many sectors of manufacturing today are experiencing a shift toward mass customization. From cell phones to cars, manufacturers are moving toward delivering customer-defined products. For example, BMW Individual was a previously little-known program that has gone mainstream, delivering individualized cars to consumers globally.

Cost effectively achieving lot sizes of one is hard—and won't be accomplished without looking at the problem of automating the factory of the future in a different way. And even if you aren't seeking that nirvana, today's manufacturing reality is that market shifts are measured in months rather than years and the appetite for continuous innovation is voracious. This requires greater and greater levels of flexibility and ability to deal with this constant change cost effectively. It requires responsiveness and interchangeability.

For humans, this comes naturally. We change tasks without very much thought at all. From creating a presentation to loading the dishwasher, we shift gears constantly. This seamless transition between tasks has been

beyond the reach of robots. To meet the needs of the new age of manufacturing, robots must behave as multipurpose workforce enablers — not the highly customized, single-task installations they are today.This will allow the robot to be put on the job that is required. If today, you need it on line #1 performing task A and tomorrow you need it on line #2 doing task B, getting the robot to make that switch has to be easy and something that can be done by personnel currently in the plant.

To make multipurpose robots a reality, I think Buckminster Fuller said it best, "You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete."

That model is a robot driven more by software than hardware. Hardware in robotics is,

of course, a given. But software is where the opportunity for a game-changing model lives. Driven by software, multipurpose robots bring an entire new ability to automate physical tasks. These robots are able to perform a wide range of tasks, change between those tasks with just the click of a button, continuously add new skills, and store the skills needed to perform tasks previously performed when needed.

Just a few of the features that multipurpose robots bring to the 90 percent of tasks in manufacturing not yet automated include the ability to:

- *see and pick up parts on a conveyor, using cameras that are embedded in the robot.*
- *"touch" and "feel" to perform tasks designed for human hands.*
- *accommodate the changes and normal*

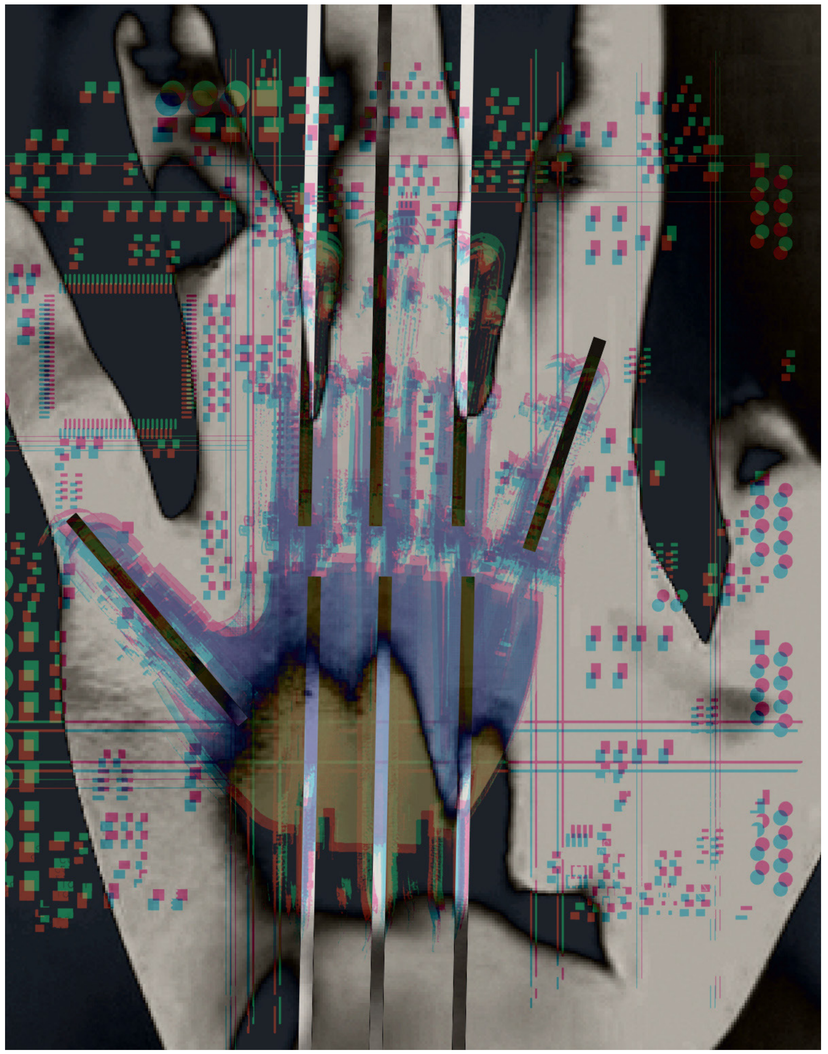
fluctuations that exist in most modern manufacturing environments.

- *be outfitted with new hands and start operating those hands immediately.*

Much more able to operate like humans, multi-purpose robots are going to change how manufacturers are able to achieve the dual objectives of efficiency and innovation. I see it like this: today, when I buy Legos for my kids, they are pre-packaged to build a specific design—just like traditional automation solutions. It's a great way to sell more Legos, but a creativity-killer from where I sit. I'm not saying robots that are flexible and able to do more than a single task are going to make manufacturers more creative – but I do believe that when automation can be deployed to solve the repetitive, less cognitive tasks and do more of them, then humans will be free to do what they do best – solve problems and innovate.

02

The Software-Driven Robotics Revolution



Robots and the Human Touch *Have you thought much about what touch means to us as humans? Wonder at the range of sounds created by the seemingly simple touch of a pianist's fingers on the keys. Count how a furniture craftsman's hands meet wood to measure smoothness, shape and feel. Consider how a watchmaker uses the perfect level of tension to tighten gears and screws in creating a masterful timepiece.*

Our ability to touch and feel the environment around us is an extraordinary aspect of what

makes us human. It also allows us to perform a wide variety of delicate and intricate tasks without harming the people around us or the objects with which we interact.

It may seem odd to write about human touch in a piece on robots and automation, but until now, lacking this ability has sorely limited the use of robots in manufacturing environments. That's all changing. While robots may never experience the emotions conjured in humans by the feel of a baby's breath on their neck, they are more and more able to apply the incredible value of touch to tasks.

Consider what it takes to test a printed circuit board (PCB). A worker picks up an untested PCB, moves it through the air and carefully inserts it into a fixture that may have no more than 100 micron clearance. Once

the results are known, the PCB is passed on to the next step in the manufacturing process or is set aside to be reworked or scrapped.

Humans are not particularly precise creatures. And yet without thought to what needs to happen, thousands of workers perform this task extraordinarily well every single day. How is this possible?

First, the worker can move the untested PCB through free space, stably and purposefully, into the test fixture. While high precision is not necessary for this step, collisions, erratic movement and rapid acceleration must all be avoided.

Next, the worker feels the forces being applied by the fixture as the PCB is inserted. They dynamically adjust the stiffness of their

armto securely snap the PCB into place without damaging the PCB or the fixture of the tester. The direction and the forces applied change constantly until the task is achieved.

Rigidity is not an option in this scenario or in many others. This spring-like nature of our limbs allows us to use our arms to guide a dance partner or our legs to navigate uneven terrain and myriads of other tasks.

Why is this easy for humans and so hard for robots? Consider the difference between a bouncing ball and a human jumping. The ball hits the ground, forces interact, power is transferred, and the ball bounces back up. Unlike the ball, humans jump through free space, absorb the initial impact of the ground through the springiness in their legs, and then gradually stiffen the leg muscles to stabilize position.

Until now, robots have not been able to master this give-and-take that gives humans the ability to apply just the right amount of pressure to respond and react as needed:

Point-to-point, position-controlled robots work based on careful alignment of the object in play. This approach is fine, until the object isn't exactly aligned or something gets in the path between point A and point B. The robot will keep applying force until the object is aligned, removed or more likely, damaged. Avoiding this requires sophisticated vision systems or complex, integration-heavy fixturing. These solutions are costly and very inflexible. The result? Robots are rarely used to perform tasks like PCB test.

Alternatively, force-controlled robots interact with objects more gracefully and are better suited to tasks that require the finesse exemplified by the

insertion of the PCB into the tester. Again fine, until we talk about moving around in free space. Then the robot becomes dangerous as it will move faster and faster until it finds something to stop it.

Neither option offers that "spring-like" nuance so essential to not damaging limbs or objects.

Today, cheap sensor technology and advances in robot design architecture make it possible to combine mechanical compliance (the ability to mimic the give-and-take of a human arm) and impedance control (dynamically controlling stiffness or springiness as described by the differences between a human jumper and a bouncing ball). As a result, smart, collaborative robots now bring the long-sought after ability to "touch" and "feel" their way through tasks like humans do. Today, robots can load PCB's for testing.

It's hard to imagine our lives without the ability to touch. As manufacturers look to build the factories of the future, where human brain power will be more essential in every corner of the operation, robots able to perform tasks that require the abilities made possible through touch will be a critical asset.

Software Rules the Road and Robots

When I am not working on robots or playing with my children, chances are good I am driving – or reading about driving – cars. So it is no surprise that I read with great interest the news from Tesla about Autopilot. With just the push of a button, Tesla changed a car that you drove to one that now – under certain conditions – drives for you.

For a software guy like me, Tesla's breakthrough illustrates just how far the power of software to change almost everything about how hardware works has come. For more than 130 years, cars

have been about motors, transmissions, and suspension systems. Now, software rules. In the case of cars, it will forever change what it means to drive. I see it, too, in the world I live in – where the truly incredible innovations in robots are being driven by a new class of software.

Of course, we can't have automation without the physical robot – after all, the arms still have to be there to complete the task. But the mass adoption of robots over the next 5 years is not going be driven by the hardware. It will be driven by software that goes well beyond the code that programs the robot to perform a specific task to define everything from how robots interact, perform and deliver value.
Today, software is:

- **making it easier to work with robots.** *From the ability to communicate through human-like gestures to take the spoken word – in context – and translate these words into a serial set of Cartesian actions, robots are now able interact with humans beyond the screen. Software brings to robots the artificial intelligence that reduces the cognitive load required by humans to work with robots – making collaboration with smart, collaborative robots truly possible.*
- **enabling robots to work like humans do.** *Humans bring the nuance of touch to completing nearly any action – whether fastening a seatbelt or tightening a screw. With software, robots are now able to master the give-and-take that gives humans the ability to apply just the right amount of pressure to respond and react as needed*
- **giving robots the flexibility to work in variable environments.** *For traditional robots, manufacturers need to create a tightly*

controlled, perfect environment where everything was just-so, so that the robot could always find the object or target it needed to complete a task. But like the world, manufacturing environments are not perfect. Driven by software, robots are no longer stymied by a misaligned part on a conveyor belt or a cardboard box with a lid that's partially closed—they are able to adjust to the conditions, complete the task and move on.

- **creating robots that are both smart and Smart.** *Robots today are able to apply logic and make simple inferences. Going forward, look for digital and information technologies to come together with advanced manufacturing in ways that allow robots to cognitively understand, reason and learn. Not only will robots learn from the past, but they will be able to predict the future and prescribe actions they can take that drive positive outcomes.*

All of these advances are already changing the way manufacturers deploy automation – bringing robots that improve efficiency and productivity to tasks that have been out of the reach of traditional industrial robots. Companies like GE, Jabil and Donnelly Manufacturing are using robots in complex, varied and low-volume, high-mix environments.

An Expansive Opportunity *The amazing thing about software is that – unlike hardware – the possibilities are infinite and the costs are much lower. As we've seen with our phones and now cars, improvements come without additional cost. So too, will robots improve how they work and what they are able to do with software upgrades. You won't have to buy a brand new robot every time you need it to do a new task, as you once did with traditional robots.*

As the 4th Industrial Revolution takes hold and factories of the future run more and more on autonomous machines, robots will be an integral part of the fabric. These robots will be able, not only to perform tasks, but also to collect data on the performance of the task and analyze it for interpretation and action by human colleagues. The now nascent field of cloud robotics will allow the knowledge robots gain to be shared with other robots, creating a way for robots to train robots. With the advances made possible by software, robots will make themselves, their processes and the products they produce better.

Manufacturing is changing. Robots are changing. Every day, we see new possibilities for product transformation processes as customers push the boundaries to reach a new level of productivity and efficiency – and ultimately – innovation and growth.

Robots in the Real-World: When Change Happens, Adapt

How long did it take you to get to work today? Me? A 12 mile trip took about 45 minutes. My daughter's bus was running a little late. My son forgot to pack his backpack last night – what a surprise. Construction workers had taken over my "secret" cut-through. And one of the elevators in my office building was out. Again.

Most days, barring a major accident, I get into the office about when I expect, plus or minus 10 minutes. Could I eliminate the variability in my commute time? Sure. Live at work.

But most days, I find ways to navigate the obstacles in my path.

Like my daily commute, there is variation in manufacturing. Raw materials from suppliers may not be exactly the same from batch to batch. Multiple pieces of equipment making the same part are not identical. The performance characteristics of parts they produce vary over time. In manufacturing parlance, these are often called common cause variations. Simply put, the real world is full of variability.

This ever-present variability challenges robots in manufacturing. For years, robots have required that everything around them be bolted down so that the environment in which they work is always controlled and exactly the same. Traditional robots can only pick a part from precisely the same place – every time. And put it back down, precisely in the same way, in the same place – every time. Any variation in the placement of the part or the path along which the robot moves the part and the robot simply stops working.

This inability to deal with variability is, in large part, the reason why as much as 90 percent of manufacturing tasks have not been automated. I recently visited a contract manufacturer in Guadalajara, Mexico, where except for the surface-mount technology machines, the equipment was on wheels. Spiders were going up and down the lines bringing parts and taking away assemblies. Production runs last only a few months or even a few weeks. The variability in these environments severely limits the practical application of traditional robots.

For large-scale implementations of traditional robotics solutions, the inflexibility has significant implications on the ability of the manufacturer

to recover the investment. I've walked through plants, where the plant manager can point out what product line a given piece of automation was created for and when the last time it produced anything was. One of the automation guys I know calls these "monuments" – they aren't much more than historical infrastructure. He has a sign posted in his office, "No Monuments."

No longer. A new breed of smart, collaborative robots are coming online that approach variability in a different way. Rather than assume a perfect world, which can come at the expense of flexibility and agility, these robots can accommodate the changes and normal fluctuations that exist in most modern manufacturing environments.

Advances in hardware and software are making it possible for robots to work seamlessly, cost-effectively and with little integration time,

in semi-structured environments. These robots understand the context of the task being performed and possess the cognitive and mechanical abilities to deliver that task. Like their human counterparts, collaborative robots are trained to do a task rather than be programmed to move an object from point A to point B via path Y. When change in the environment inevitably occurs, focus remains on the task at hand and getting the job done.

In these environments, there are two dimensions for which the robot must be optimized. The first is time. Robots must be able synchronize motion and task with machines and people through signals or directly with sensors. It's this ability that makes it possible for the robot to collaborate with people – who work at varying paces, who tackle things differently and who need a "colleague" able to accommodate the

unpredictability and variability that people bring to the environment.

The second dimension is space. While parts are expected to be presented in an organized fashion, these robots are able to accommodate a few centimeters of variability in part placement and tolerate changes in general location.

Robots today are able to:

- *use embedded vision to dynamically monitor workspaces designed for humans and adapt to changes to the work cell, such as a bumped table or misaligned cart on wheels.*
- *alter robot motion path planning in real-time to accommodate unexpected obstacles.*
- *use mechanical compliance to flex parts into position despite irregularities in pick and position placement without damaging the part, the fixture or the robot.*

These advances mark the beginning of a new era, where robots are able to move beyond assembling the same item for a long time and in volumes large enough to justify the high cost and semi-permanence of the infrastructure. These smarter and more capable robots are working in the real, imperfect and highly variable world and changing manufacturers' mindsets about where and how automation can delivery real value.

AI-Driven Robots: More Brains Than Brawn

Robots for manufacturing have come a long way since Unimate came online in the 1960's. Robots that manufacturers use today are smaller, safer and able to perform more than a single task without expensive programming. While these innovations have delivered great value, what's next will transform the industry in ways that we've not seen since the first industrial revolution.

The 4th industrial revolution or Industry 4.0 will be built on robots that are more brains than brawn. These robots integrate physical and

cognitive ability to do more than heavy, highly repetitive tasks. In the sophisticated, highly automated environments where manufacturing takes place, these behavior-based robots – fueled by new innovations in artificial intelligence (AI) – are changing the way factories are organized, operate and perform.

Building the Industrial Internet of Things from the Bottom Up *Advances in technology have always been the catalyst for transformation in manufacturing, but this time the technology is less about mechanization and physical automation and more about cognition. The Industrial Internet of Things makes it possible for manufacturers to orchestrate the production process in completely new ways.It also will automate – on a large scale –the analysis of mission-critical information in a continuous flow to enable informed, real-time decision making. It's an exciting*

time, but it's also daunting, and manufacturers are not simply going to go whole hog on rolling out an information- driven operation. They are skeptics, remember? The vision of Industry 4.0 will be achieved – in large part – by software-driven robots with innate cognitive abilities.

With AI, robots can work semi-autonomously on a much wider range of tasks. Beginning in the work cell, robots with "smarts" built-in draw from a cloud-based database of "lessons" and information to:

- *recognize equipment and parts in a work cell and perform applicable behaviors and make "auto-complete" suggestions, e.g. recognize a tool or piece of equipment and be able to use it correctly.*
- *use pattern matching to suggest error handling best practices.*

- *apply a database of corrective suggestions to help task designers (that would be the robot's human colleague) find ways to modify a task or work cell in response to a fault.*
- *analyze motion profile and behavior against a global fault database to identify opportunities to optimize a task.*

Just as smart phones and other internet-of-things -enabled devices receive software updates that add new features and functionalities, so too will robots expand their abilities. Optimizing production at the work cell level is only the beginning. Robots will eventually share information and insight that improves performance factory-wide and ultimately, across global operations, with the ability to:

- *learn from self and others.*
- *correct self and others.*
- *collect, analyze and share insights from data collected on the factory floor and from robots in other locations.*

Innovation: Only As Good as the Value it Provides

We've all seen the crazy stories about artificial intelligence and its potential to destroy life as we know it. But AI-driven robots deliver real value to manufacturers now, and more so in the future, such as:

- *drive continuous process improvement and improve quality.*
- *reduce costs and improve margins.*
- *accelerate the new product introduction process.*
- *build factories that can produce highly customized products at mass market prices.*

Beyond the hype, customers using robots in work cell-based models are proving it works.

03

Robots as Agents of Change

Robots AND Humans: The Answer to Manufacturing's Job Woes *Is it just me, or has the pace of stories about the rise of robots and threats to jobs increased substantially? NPR, The New York Times, bookshelves, both real and virtual, are crowded with commentaries about the impending arrival of smart robots able to do everything that we humans do and basically replacing us in the workplace.*

Ok, so maybe, since I work for a robotics company I take these stories a bit on the chin. I certainly am

making a loud and clear disclaimer that I can't speak to what smart, collaborative robots will be able to do in every single segment of human life.

What I can do is speak to the very real challenge that manufacturers face. Sure, everyone from the unions to the White House administration is looking to manufacturing to be the tide that lifts the US out of dismal unemployment numbers. For good reason. Many know about manufacturing's multiplier effect: every $1 spent in final sales of manufactured products supports $1.33 in output from other sectors—or through a different lens—for every one job in manufacturing anywhere from 1.5 to three manufacturing-related jobs are created. Regardless of how the reach is measured, those are compelling statistics for putting people to work in manufacturing. But here's an inconvenient truth about jobs in manufacturing as it is today. A while back Forbes reported that there are 200,000 jobs left unfilled in manufacturing today. More recently, Deloitte reported that by 2025 there would be an estimated 2 million unfilled jobs in the sector. Behind the numbers is one reality: the manufacturing workforce in place today is aging out and one perception: the next generation of workers doesn't want those jobs.

Manufacturers like Jabil recognize that the low-cost labor model that stretched supply chains around the world needs to be revisited. Manufacturing needs to be closer to the centers of design and innovation and closer to end markets. So factories of the future will be smaller, nearer to customers and operated by local talent. These operations will also rely more heavily on technology, will need skilled workers, with certifications and a very different kind of education than what's currently available in most high schools in the country.

So, here we are: more skilled jobs, with the inherent better wages are coming on-line. But working in production has a negative profile for many.

It's time to rethink the definition of work. One electronics manufacturer I know has a team that spends an eight-hour shift hunched over microscopes doing visual inspection of parts that are the size of a quarter, and paper thin. Would you want to do that kind of work? Would you want your children or grandchildren to do that kind of work?

Let's face it. Tedious, repetitive work that's mind-numbing for humans, like machine tending still has to get done. So do hundreds of other tasks in production that simply aren't suited for humans to excel.

So let's rethink the definition of work. It's happening now as savvy companies recognize that unlocking the potential for sustainable innovation lies in an integrated workforce where humans and robots work side-by-side. In this model, robots do the highly repetitive, low-skilled work and humans then are able to take on the roles that make a difference to customers and to the bottom line. Jobs that require cognitive skills and creativity. Jobs that contribute to product innovation and competitive value. Jobs that keep manufacturers – and the ecosystem they support – growing, thriving and contributing to the economy.

Nicholas Carr was spot on in positing that robots will always need humans. It's time to focus on how humans can work with robots and stop worrying about jobs lost that no one wants.

Robots on a Mission: Change Agents In Automation

When Henry Ford introduced the assembly line, manufacturing took a major leap forward. Productivity advanced in ways never before possible. It took 50 years for the next breakthrough to hit the factory floor, when Unimate came on line at GM. We're seeing another breakthrough now as robots evolve to be more than simply machines that can lift heavy objects and perform repetitive tasks over and over and over again. The convergence of muscle and "mind" – in the form of information technology – makes automation more than a productivity enhancer

and that changes everything. These robots will act as agents of change – for the better – better products, margins and working environments.

The evolutionary path for robots is underway. The innovations on the horizon will change forever how robots perform and what they are able to do.

Robots as More than Machines *Robots have come a very long way already. Smart, collaborative robots are safe, can work in imperfect environments and are able to perform more than a single task. These advances in robotics technology are making it possible to chip away at the nearly 90 percent of tasks that until have been beyond the reach of automation in manufacturing.*

These robots are driven by software, which makes it significantly easier and much more cost-effective to deliver new innovation, and

expands the universe of opportunities for work to be done by robots. Right now, these robots work on specific tasks, in work cells, alongside humans, increasing productivity and enabling greater flexibility.

Soon, robots will do more. The integration of hardware and software will raise the robots' ability to understand what needs to be done and execute the physical steps required to make it happen. They will direct activities and equipment in the workcell. They will learn from their work – and the work of robots globally, collect information on their performance and provide data analysis that can inform continuous process improvement.

The advances we'll see that make this possible in robotics technology include:

- **sensors** *that collect data in ways similar to humans – seeing, touching, engaging.*

- **behavior-based artificial intelligence –** *innovation in intelligence will make it possible for robots to integrate and interpret the information gathered by the sensors and then formulate and direct the appropriate action, overcoming the limitations set by "programmed-only" responses.*
- **actuators that can execute the required action–** *advances in the hardware take shape as robot hands and arms that work much more like human appendages – more flexible, dexterous and sensitive to the environment and the situation.*

More than 100 years after the automated assembly line, it's time for the kind of change that robots can bring.

Robots With Grit: Redefining Manufacturing

We've looked at the ways in which collaborative robots are changing industrial automation. But changing automation is only the beginning.

Robots will transform manufacturing in ways not seen since the last industrial revolution. And they'll play more than a part. In many ways, robots will be the catalysts and enablers of a new model: the agile factory.

Manufacturers need these robots and the changes they make possible. Why? For the past 100 years,

factories were designed to efficiently execute a plan. Make a plan. Execute the plan. But the real-world of the factory floor never works like the plan expected it to – suppliers miss delivery deadlines, equipment fails, yields fall short of the target. In any plant, there are scores of people who spend their days addressing all of the deviations from the plan. This system is flawed. It is hugely wasteful. I know. I lived it for years.

What's needed? Lora Cecere, a friend and one of the brightest influencers in the supply chain space, has been writing and talking about supply chain response for many years. She advocates for a future state of supply chain excellence where supply chains are able to sense and respond to fluctuations in demand. She's onto something and I'd take her argument one step further. The ability to sense and respond – not just to demand shifts, but also to potential "gotchas" like process variations, quality issues or production bottlenecks – needs to be part of factory DNA as well.

Breaking Through: Robots with Grit *There's a lot of talk today about "grit"– a simple word that conveys tenacity and perseverance. We recognize it as a characteristic that enables humans to succeed. As robots take their place in the workforce, grit will be essential for their success as well.*

Yes. Robots will need grit and here's why. Consider what it takes to give walking directions in large city: you're not likely to know every obstacle they might encounter – closed sidewalks, deliveries blocking the path, etc. Your instructions won't include "jog left at this doorway to go around the pallets of produce" or "step to the right to avoid an open manhole."

Like that person trying to navigate Manhattan, robots that work in manufacturing need to be able to persist in the face of obstacles. But since traditional robots need "a map" that programs every step they need to take in order to do even the simplest of tasks, they can't operate in the ways manufacturers need them to.

Everything they need is gleaned from the input of the robot's sensors; the robot uses that information and cognitive computing to adjust its actions according to the changes in its immediate environment. Robots driven by behavior show more biologically driven actions than their rules-based counterparts. It will recognize a flaw in the process – a misaligned part for example – and adapt to ensure that the workflow continues. That's a robot with grit. This new generation of robots – self-configuring, self-optimizing and self-healing – will be able to identify anomalies and adjust manufacturing processes in real-time. With these robots manufacturing operations will become more agile and less brittle in the face of normal variation. They will make it possible for manufacturers to quickly understand what's happening, accommodate change and variation, and keep the production lines running every day to deliver results.

We're just at the beginning of this transformation, but it's picking up speed. Companies like Jabil, GE and Wasion are demonstrating the potential and documenting the results.

Mind + Machine:
Changing the Business
of Manufacturing

We've been exploring the ways in which robots are acting as change agents – of the category and of manufacturing. There's a lot to be said for the ways in which those transformations are taking place now, and it's all good. There's a case though, that what lies ahead for robotics in the Industry 4.0 or the Industrial Internet of Things (IIoT) is where real excitement takes place. In the IIoT, robots that combine mind and machine change the ways in which goods are produced, and the entire business of manufacturing.

In the IIoT, agile factories are driven by "big data" – including quality metrics, market feedback and real-time demand signals. In these factories of the future, the production floor is linked to the back office which is linked to the customer and suppliers. The flow of information between these centers will make business move more quickly, efficiently and profitably, because they will sense, respond and act more quickly to shifts in market conditions, customer demand and internal variability.

Achieving the aspiration is daunting. It can be disrupting – and not in a good way. We know of one company that invested $1 million in IIoT and then came to realize that they were collecting the wrong data. Another shared that his executives were very excited and pressing hard on the effort to deploy "big data" but when asked what they planned to do with the data, the response

was a shoulder shrug and a quiet "I don't know." That won't fly. For companies who make things, the manufacturing process is the lifeblood of the business. It needs to run every day and deliver results. Manufacturers must have a risk-mitigated way of leveraging modern technologies and smart, collaborative robots are the answer.

Building the IIoT from the Bottom-Up *This is where behavior-based robots come in. Capitalizing on the perfect storm of low-cost sensors, devices, processing power, data storage, connectivity and ways to handle big data, these robots make it possible to start with a single work cell, without needing to make significant changes to the environment. The model is based on organic growth; manufacturers can add more to the work cell, and then add more work cells. Once a work cell is running, manufacturers can use native performance and task data collection and introspection*

to provide on-the-fly task tuning and Cloud-based cognitive insights. It starts small with localized awareness, such as "the part isn't there anymore, do something smart." It will grow, enabled by the Cloud's connectivity, process computation at a vast scale, deep learning and other advanced analytics to aggregate data with other structured and unstructured data and share learning with other robots within and across other factories.

By design, it allows an organization to safely deploy new technology, learn from the experience and modify the subsequent actions based on the learning. There is no big bet required. This is good. Manufacturers can't wait for the end of huge implementation to see value – it has to be created all along the way.

Building the IIoT from the bottom-up represents a huge departure from the top-down, multi-year, multi-million dollar implementations of traditional industrial robots. More importantly, it allows manufacturers to build operations where productivity and capacity increase and costs are lower. As robots grow "smarter" they will accelerate our ability to drive more from every aspect of the business. We'll be more agile and more able to meet customers where they live.

Smart, Collaborative Robots: Democratizing Manufacturing

Every morning, I read yet another article or blog or tweet about the resurgence – or not – of US manufacturing and the potential – or not – for good jobs to be won by the same. It's ok, because as I've said before, I love manufacturing. And I'll say it again, I love manufacturing.

As I travel around the country visiting our customers, more and more, I realize that I really love manufacturers who are considered small-to mid-sized businesses by the measure of number of employees. That's likely to be because in the U.S.,

more than 250,000 manufacturers have fewer than 500 employees. A big reason for my sentiment is because in spite of all the challenges these companies face – from labor shortages to lack of access to capital to help them scale, acquire new technology or even just repair worn-out equipment, they keep at it. Call it grit, call it optimism, call it good old American stick-to-it-iveness, they've got it and they keep going.

For too long, robots and the benefits they bring to manufacturing have been out of the reach of these manufacturers. Price, was one barrier. Complexity – and the need for highly specialized expertise, another. With those obstacles out of the way, manufacturing has been democratized. Now, manufacturers of all shapes and sizes can put robots to work in their operations. They are, for many different reasons, and to do many different kinds of tasks.

With equal access to smart, collaborative robots companies like Standby Screw and Vanguard Plastics gain a fast path to exploiting automation to improve productivity and lower cost. They are tackling repetitive tasks, lowering error rates and reducing the likelihood of an injury to a person. For many customers, these robots allow them to "staff" positions that have been left unfilled for weeks or months with stability. They are also working alongside people, and giving them opportunities to do more strategic work.

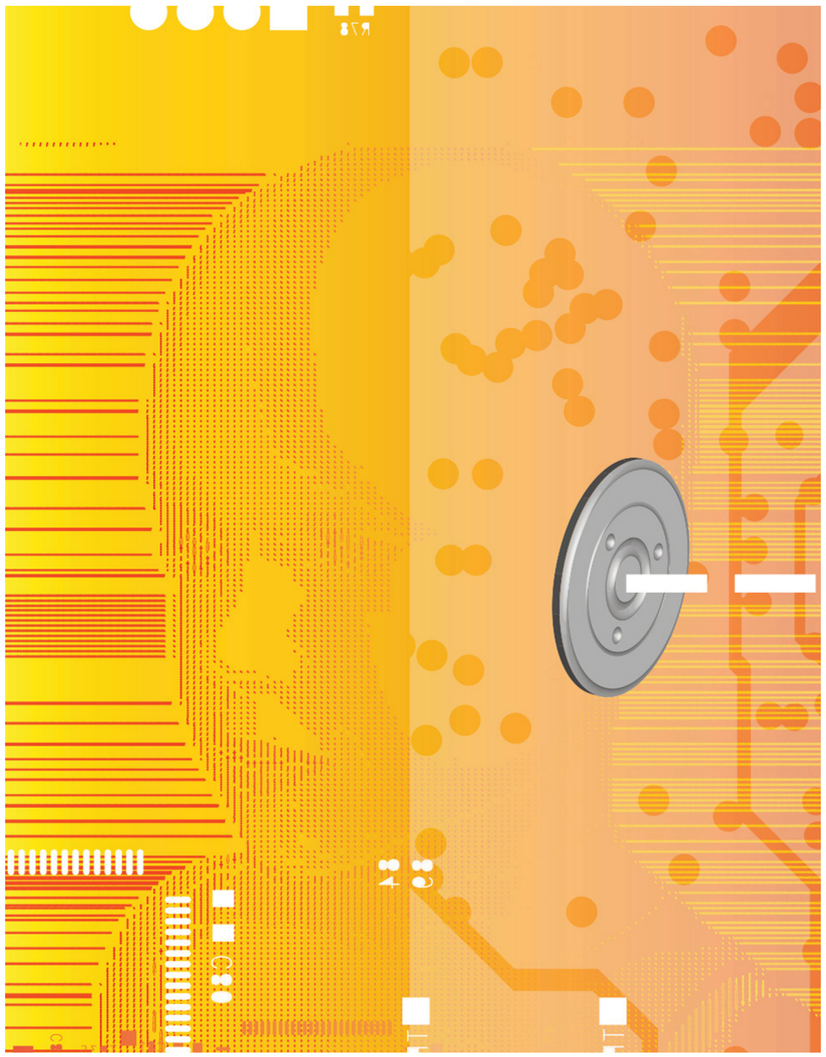
Perhaps, though, what I like best about working with these companies is the curiosity and optimism they bring to engaging with a robot. There's a focus on possibility that all too often seems limited at large manufacturers who are stuck in the old way of thinking about robots and automation. They are fearless when it comes to trying new applications

and undaunted by trial-and-error. And our team learns a lot from them.

When you consider that studies show that smaller manufacturers produce more innovation per employee than large manufacturers, the potential for the next great thing to come from one of these is that much higher, as employees won't be stuck doing work best suited for robots. So, no matter what tomorrow's headlines say, I believe that "small" is where it's when we look for big changes in manufacturing.

04

Visionary Voices



In the Factories of the Future: Jabil's John Dulchinos

Recently, electronics manufacturer Jabil Circuit launched its Blue Sky Center, a state-of-the-art facility designed to help customers engineer growth in a world of change. Automation is a key component of the center – with programs to help customers with design-for-automation, as well as, share expertise in deploying flexible automation.

I was fortunate to be at the grand opening and heard some of the most visionary manufacturers

in the world talk about how they are embracing the changes they see coming. Household names like Cisco, Tesla, and Honeywell, as well start-ups like Athos, and Tile, are working with Jabil to accelerate their strategies to optimize the factories of the future.

An aggressive strategy to deploy smart, collaborative robots is, according to John Dulchinos, Jabil's vice president of digital manufacturing, "a key foundational element" for the company as part of its initiatives to advance operational excellence. I took advantage of the time to talk a bit more with John about his vision and what's driving it.

Q: You've got a pretty clear vision for the factory of the future-can you sum it up for me?
A: At Jabil, we're on a path toward factories that are more responsive, more flexible and more

able to help our customers meet their customers' needs. It's likely to mean smaller operations, operations that can ramp up and scale back in much shorter timeframes and operations that are closer to the end market. And critical to all this – you'll find at the heart – the ability to collect, analyze and use information – both from within the operation and outside.

Q: What do you see as the forces or catalysts behind this change in manufacturing?
A: There are a couple of significant trends occurring in manufacturing – especially electronics manufacturing and consumer goods.

First, there's a move toward mass customization – consumers want products that are customized for them, and they don't want to wait for very long to get it.

Second, product lifecycles are shrinking – we've got customers that ramp a product just for the holidays. While an extreme example, it illustrates why we've got to be able to build operations that can be reconfigured and ramped in extremely short time frames.

And finally, the model that's served the industry so well for decades – locating in low-cost labor regions has reached its end. We're seeing a greater demand for higher-skilled labor, driven by the reliance on digital and advanced technology, requiring that we rethink how we deploy automation in our operations.

Q: That's a great segue – let's talk about automation in the factory of the future. What does your vision for Jabil's automation strategy include?

A: First, I have to confess – I'm a long-time robotics fan. I graduated from Rensselaer Polytechnic Institute, in the early 1980's – when robots were all the rage. I'm very excited that we're finally seeing the ideas we dreamed up then becoming reality.

At last we've moved beyond the traditional manufacturing robot, and are seeing real-world applications today of smart, collaborative robots that deliver three very key capabilities to advance manufacturing.

First, these robots are able to not only work beside humans, but work with them. That means that they need to be trainable on the line, by the people who do the work. It also means they can work like humans do – that means intuitively, undaunted by variability and able to change from task to task with little downtime.

Second, these robots are easy-to-deploy and fast to ramp. In the new world of continuous reconfiguration of lines, and processes, we have to able to change what the robots do as quickly as we change the production lines.

Third, and critical in the flexible environments that are the hallmark of the factory of the future, these robots must be able to perform increasingly sophisticated tasks. This means that robots will have greater ranges of motion, be able to work with fixtures small enough for human fingers and require more than one step for completion.

Q: So where do you see smart, collaborative robots taking Jabil in the future?

A: I'm excited about what we're seeing today—we've come a very long way in the applications. What's next though is what I really am passionate about. Think about it – every robot we deploy is a computer. That means, going back to what I said earlier about the role of data in production environments, is that these robots will become critical in that model. Robots will be information management systems that can collect and analyze data on the floor, in real-time and make it available for interpretation.

That represents a real break-through in manufacturing allowing us to not only see what is happening now, but able to apply predictive technologies to the information. Everything from when a machine needs to be serviced to when a process needs to be adjusted will become available to us. With that ability, we'll no longer be simply looking at the past, but able to see ahead – a significantly more powerful tool for increasing efficiency and productivity. More compelling though, may in fact be the contribution that it makes toward accelerating innovation and creativity.

GE's Roland Menassa: Manufacturing Wins with Robots and People

What companies come to mind when you think about continuous innovation? There are few more linked to the drive to innovate than GE.

Staying ahead requires more than vision. Building out the technologies, processes and strategies is critical to ensuring the success of any forward-looking effort. For GE, a lot of that work takes place at its Advanced Manufacturing and Software Technology Center outside of Detroit, Michigan. Here, Roland Menassa, the Center's leader shares his perspectives on manufacturing and smart, collaborative robots.

Q: You've been in the robotics industry for decades – what's next for manufacturing robots?

A: I'm a big robotics-believer. Prior to joining GE, I was with GM, and focused on the role of automation and robots in driving greater efficiency and productivity, in research and plant manager roles. With the rapidly evolving "New Robotics," we recognized that we needed robots that were safe enough to work beside humans, could be easily trained to do tasks by their "colleagues" on the line and able to perform more than a single task.

Today's innovation will change the model of where, how and why robots are deployed in exponential ways. I predict that soon production employees will get a robot when they are hired, just as we give engineers computers when they join. Like the computer, given to help the engineers do their job better, the robot will become part of the employee's team: there to help them do their job better.

Q: So, your vision is one where robots and people work as collaborative teams?

A: Absolutely. People are smart, they exercise judgment and they take direction. Today, we're requiring that workers and tasks conform to dedicated, inflexible machinery. In the factories of the future, robots will be assistive tools – **enabling, supporting,** *and* **enhancing** *the capabilities of highly skilled workers at many concurrent tasks. People will be able to respond rapidly to product line changes based on consumer demands, environmental regulations and changing market conditions, while producing customized, high-quality products.*

These teams will adapt to lower-volume assembly methods and product mixes instead of being tied to a specific product line or method, making it possible to grow their share of the manufacturing sector globally.

Q: What are some of the innovations making it possible to create these robot-human collaborative teams?

A: Manufacturing is very hard. When you break it down, you realize how much we take for granted what humans do and how challenging it is to build a robot that can emulate every action.

That said, there are several breakthroughs moving us forward. The first is that the "DNA" of collaborative robots is different. In this new category of robots, the arms are managed through force-control, as opposed to position control. So, they are safe to work alongside humans. More importantly, it opens up a whole new range of activities that use force-based capabilities. For example, in applications such as testing – whether printed circuit boards or safety belts— the robot "knows" how much force to apply to complete a task while achieving quality and reducing the likelihood of damage to the part or the fixture.

Second, these robots can be trained by colleagues. It's amazing to watch a line operator show the robot what needs to be done, and then watch the robot do it. This "train by demonstration" may be one of the most compelling selling points. Traditional robots, of course, had to be programmed by consultants and it would take months for that to happen – a production employee never got anywhere near the process. In my experience, when the robot is the interface, that's when people engage, and are ready to work with the robot.

Finally, we're seeing robots that can perform much more dexterous operations. I was part of a team that worked with NASA on building Robonaut, and that was a big part of what we

were after: force-sensing manipulation. There's a lot more to come in this space, and it will center on developing robots that perform tasks in the same way humans do.

Q: How are you preparing GE for the deployment of smart, collaborative robots?

A: Our environments are low-volume, high mix and so flexibility is key. Since 2013, we've been looking at ways to advance our automation strategies in these environments with the latest innovations in robotics technology.

We see immense potential for collaborative robots in GE's businesses. Today, we have robots from Rethink Robotics in use or being evaluated in GE Healthcare, GE Power and Water and GE Energy.

I find two things critical to adoption success. First, we've got to change how we think about the manufacturing process. In the old days factories were built around the robots and everything was configured to work around that installation. Today, robots must perform in human-centric operations – integrated into work cells, able to be moved to where the work is done, and making it possible for people to do their jobs better.

Second, production teams have to be involved in the rollout. When line operators help identify how the robot will be used, train the robots, and work with the robots from day one, skepticism, fear and intimidation evaporate. More importantly, we get the improvements in productivity, efficiency and innovation we're looking for much more quickly, as people focus on the work they are best suited to do and robots do the rest.

Q: What will the role of robots be in GE's Brilliant Factories?

A: We're leading in the development of software solutions that make our products more efficient, easier to manage and maintain, and part of integrated environments. The collection and analysis of many, many terabytes of data from the hardware is absolutely part of that vision. That means doing so in our factories, and robots will be key in that process.

In the not-too distant future, robots will help us manage that data to drive continuous process improvement, raise quality standards and more. That's when we'll see the true fulfillment of the promise of automation.

Mercedes-Benz: Pairing Humans With Better Robots

The robots are dead! Long live the robots! If you saw the news out of Mercedes-Benz yesterday that they've "fired" the robots they'd been using in their factories and gone back to using skilled humans, maybe you had the same reaction.

But there's more to it than that. Mercedes is replacing robots that represent technology \introduced more than 40 years ago. As Dylan said so well, "the times, they are a-changing" and the days of deploy-it-once-keep it-forever automation are gone. It's time to move to a new

breed of smart, collaborative robots – robots that can work with humans, that can navigate the unpredictability and imperfection of the factory floor and that can perform more than a single task. And that's exactly what the German automaker is doing.

Innovation in this new world is being led by manufacturers that heretofore were not able to take advantage of traditional automation. Companies like GE and Jabil are deploying collaborative robots as part of a broad strategy to be better positioned to meet demand for more responsive, resilient supply chains and support accelerated innovation cycles.

Mercedes' announcement that they're putting their sterling brand behind the movement is a milestone in the race to transform manufacturing. The leadership at Mercedes recognizes that the time to act is now, that the window for grabbing competitive advantage with these robots is short and they're going for it. If you're waiting to embrace this new model for automation innovation, take note.

Jim Lawton with Sawyer, Rethink Robotics, 2017

About the Author

James W. Lawton has dedicated his career to bringing technology and innovation to business. An inaugural fellow in MIT's Leaders for Manufacturing program, he has worked with dozens of the world's largest manufacturers and today believes that we're on the cusp of a renaissance in manufacturing.

As chief operating officer at Rethink Robotics, Jim and his team are changing the way

manufacturers view and use robots. Every day, he is inspired by the ways in which the integration of automation and cognitive computing will have a tangible and positive impact on the manufacturers' ability to create growth and value through innovation.

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