The interplay of human and robotic workers promises flexibility, savings and new competitive capabilities when deployed as part of a holistic robotics strategy that incorporates design thinking, human behavior studies and partner ecosystems.
EXECUTIVE SUMMARY

An emerging generation of physical robots promises to transform manufacturing with its ability to communicate and collaborate, both robot-to-robot and robot-to-human, opening the way to greater innovation and productivity. Achieving these benefits, however, is not as simple as investing in a handful of new robots.

Manufacturers must develop integrated strategies that reflect the powerful new ways in which manufacturing data, information systems, robotic capabilities and human workers can intertwine. To reach optimal productivity, these strategies need to incorporate design thinking, anthropological workflow design and new partnership ecosystems.

Manufacturing and robotics are natural companions, and the images of rigid single-arm robotic installations on a factory floor are very familiar. The emerging vision, however, features smaller, lighter, nimbler robots. These robots are not confined to a single workspace or task; instead, they can move, learn and generate real-time data that flows through control, planning and logistics systems, enabling them to make basic decisions about their tasks and motions in milliseconds.

Further, these robots are designed to safely share workspace with humans, aiding in and collaborating on a variety of tasks, from inserting shock absorbers, to packaging medical supplies,1 to cutting meat on an industrial food preparation line.2 Using a holistic robotics strategy, manufacturers can take full advantage of the intelligence and data flows from the new robots to augment the human workforce, streamline workflows, design new features and products, and open new market channels. The result: unprecedented levels of productivity, innovation and cost advantage.

This white paper examines the key opportunities and challenges of this new approach to human-robotic partnerships and provides a plan for how manufacturers can create an integrated robotics strategy built on the requirements and benefits of new collaborative possibilities, including design thinking, human-robot interactions, centers of excellence and integration into the operations environment.
Manufacturers can take full advantage of the intelligence and data flows from the new robots to augment the human workforce, streamline workflows, design new features and products, and open new market channels. The result: unprecedented levels of productivity, innovation and cost advantage.
NEW GENERATION OF ROBOTS

The new generation of smaller, mobile robots is being designed to work safely with humans virtually anywhere. These programmable, sensing robots recognize their proximity to other robots, materials and humans to avoid collisions and/or reduce their work speed. With prices averaging less than $30,000 per unit vs. more than $100,000 for a typical rigid unit,3 these robots are relatively affordable, even for smaller and medium-sized organizations.

Collaborative robots are also designed to collect and share data in real time with different systems, such as manufacturing execution systems (MES) and warehouse management systems (WMS). System interfaces are facilitated through supervisory control and data acquisition (SCADA) systems on the shop floor, leveraging an “information bus” construct with programmable logical control (PLC) layers.

These systems fall under the broader umbrella of closed-loop feedback control systems, in which there is continuous sensing, processing (analysis) and physical action, usually automated through a robot or electromechanical device. Further, built with embedded cameras, lasers and sensors, as well as limited cognition and self-programming capabilities, many robots can take in ambient data – temperature, humidity, speed of the line, etc. – and make decisions about their next best course of action and execute on it, in a millisecond or less.

The combination of robotic sensibilities with the experience and higher dexterity of human workers is a formidable combination. Robots can extend human senses, such as hearing and vision, and amplify human strength and movement.

Conversely, humans can teach robots new skills. In a warehouse, humans could use specialized robotic arms to help robots learn how to pick and pack by watching gestures. The robot scans and creates a 3-D image of the part or product for reference; cloud-based data sets also increase its familiarity with the warehouse stock. Using vision guidance systems, robots can learn to sense objects and maneuver around obstructions. In certain applications, these robotic systems are part of the operation itself. From there, the robot does the picking and packing, while humans handle the sorting.
The New Generation of Robotics

The core competencies of human-robotics workflows are mobility, workspace flexibility, communications and intelligence. As the robots’ capabilities evolve in each of these areas, so do their levels of autonomy and collaboration (see Figure 1).

Companies will need to continuously assess how humans and robots interact at behavioral and workflow design levels to take full advantage of the unique capabilities of each.

**Evolution of Robotics in Manufacturing**

<table>
<thead>
<tr>
<th>Mobility</th>
<th>Rigid</th>
<th>Guided</th>
<th>Limited autonomy</th>
<th>Full autonomy / collaborative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workspace</td>
<td>Separate workspace from humans</td>
<td>Limited space sharing with humans</td>
<td>Limited space sharing with humans</td>
<td>Open workspace between humans and multiple robotic systems</td>
</tr>
<tr>
<td>Communication</td>
<td>Enterprise systems Tactile</td>
<td>Camera Laser Pressure sensors Geospatial</td>
<td>Cellular DSRC / Wi-Fi Satellite</td>
<td>3-D vision Gestures Emotions Voice</td>
</tr>
<tr>
<td>Intelligence</td>
<td>Programmed</td>
<td>Programmed and sensing</td>
<td>Self programmable Limited cognition Basic decisions Remotely controlled</td>
<td>Artificial intelligence</td>
</tr>
<tr>
<td>Example</td>
<td>Robotic welding</td>
<td>Automated guided vehicles</td>
<td>Autonomous mining equipment</td>
<td>Collaborative robots</td>
</tr>
</tbody>
</table>

**Figure 1**
Manufacturers that have deployed human-robotics workflows report greater productivity than when humans and robots work independently of each other. The robots generally take on dull, dirty and repetitive tasks, while human workers focus on tasks requiring greater skills and cognitive abilities. MIT researchers found human-robotic teams at BMW were about 85% more productive than either alone.\(^4\)

Manufacturers say other benefits of this new approach to work include:

- Accelerated time to market at reduced cost for new products.
- New markets and higher sales gained through increased capacity and line flexibility.
- Less time required to change product configurations.\(^5\)

**REDESIGNING WORK FOR HUMANS AND ROBOTS**

Many next-gen robots are designed to work out-of-the-box, with application programming interfaces (API) for quick customization and deployment. To achieve the full cost and productivity benefits of these robotics strategies, however, manufacturers must rethink their workflows and how robots and humans will interact.

For example, new time-and-motion and ergonomics studies must be conducted to envision how experienced, skilled humans and smart robots should partner on a task, such as cleaning oil from a part before assembly, or specifying where holes should be drilled, or fixing a seat in a moving car assembly line.

Wearable devices such as smartwatches and fitness monitors could also be incorporated into the strategy. A robot might message a human co-worker’s smartwatch to alert her of an otherwise imperceptible millisecond slowdown on the line to help avert issues. Or a human’s safety device could signal a rise in temperature to a robot in the cell, triggering an alert.

What is the best way to communicate this data? Should it be communicated at all? These data points have ramifications for new process dynamics and, therefore, productivity, safety, quality and on-time delivery performance of the line and the shop.

Rethinking processes requires an understanding of the social and anthropomorphic context of human-robotics partnerships. How will humans manage their emotions when working with machines that are able to learn yet are not intuitive or creative? Robots can respond in less than an instant; how will their speed mesh with slower human response times? How will experienced humans, who may intuit a problem, communicate that insight effectively with a mechanical co-worker? Can a robot cracking a joke help reduce a human’s stress level and keep the line running smoothly?

Combining industrial engineering and anthropological design principles is necessary to anticipate these types of questions, understand the personas of the humans involved and create workflows that incorporate responses to such scenarios.

Manufacturers must also become continuous learning organizations to gain the full benefit of their robotics strategies. Human partners will need to keep up with the new capabilities their robotic co-workers gain through software upgrades, while robot hardware and software maintenance will likely require new skill sets. Incenting and rewarding continuous learning will be important to ensure continued smooth operation of robots and humans working side-by-side.
A New Workflow to Reduce Machine Downtime

Humans and robots have been shown to be more productive working together than either working alone. Human behavioral studies and workflows created through design thinking are necessary to ensure humans and robots do the work to which they are each best suited.

Here's an example of a human-robotics workflow designed to reduce machine downtime.

An asset manager determines a machine in an engine assembly plant must be serviced or it will break down.

A robot is automatically triggered to inspect the machine; it sends visual reports of the affected area. These reports corroborate the machine performance insights.

The asset manager orders the maintenance team to address the problem.

The robot quickly calculates the optimal work plan to divide the necessary labor; it will lubricate the hot and dirty underside of the machine.

The robot sends augmented reality instructions for an intricate maintenance procedure to the human’s smart glasses.

The maintenance team quickly wraps up the procedures, preventing the asset from breaking down and causing production delays.
Integrating Human-Robotic Workflows into the Operations Environment

It’s also vital to consider how human-robotic units contribute to the rich flow of data generated from production line workstations and sensors. The new robots can be instrumented (if they are not already) to generate data and thus contribute to an organization’s Internet of Things (IoT) initiative. Robots can also be integrated with the manufacturing execution system (MES). Predictive analytics can reveal insights from the data generated by the integrated human-robotics team, enabling organizations to anticipate production events or spark innovation, such as opportunities for customizing a part or finished product.

Managing the resulting data requires a high-performance computing environment that can distill and act upon insights in real-time by humans and/or their robot partners. These connectivity and infrastructure requirements underscore why it’s necessary to align human-robotic partnership efforts with an overall robotics strategy.

COLLABORATING TO WIN

Creating a center of excellence (CoE) provides a focal point for developing an integrated robotics strategy. The CoE can work to identify pilot projects across the organization, understand how they fit into a broader operations picture, manage them, report on their results and champion scaling these efforts when warranted. Without a CoE led by a strong senior executive, human-robotic workflow initiatives risk being relegated to individual business units or niches instead of being a key aspect of next-generation manufacturing.

The CoE also should lead the organization’s efforts to develop and/or participate in an ecosystem of partners. These programs are intertwined with far too many systems for any single company to build or supply a complete solution. Instead, companies will need to pool their complementary strengths.

The CoE can work to identify pilot projects across the organization, understand how they fit into a broader operations picture, manage them, report on their results and champion scaling these efforts when warranted.
A typical ecosystem could include robot designers and manufacturers, integrated robotics strategy advisors, design thinking experts, systems integrators, digital technology experts and academic researchers. These emerging ecosystems are not traditional vendor-to-supplier relationships but rather cross-industry partnerships designed to create and share technological advances, develop new revenue streams and build new market channels, all while achieving unprecedented cost reductions.

This “ecosystem of partners” concept is still a work in process. One example is Microsoft and KUKA Robotics; other ecosystems are emerging from academia, such as the National Robotics Engineering Center founded by Carnegie Mellon University, and from government sponsors, such as the U.S. Department of Defense’s Advanced Robotics Manufacturing Innovation Hub.

PUTTING HUMANS AND ROBOTICS TO WORK

While ecosystems take shape, manufacturers can begin achieving productivity increases and cost savings by exploring possible applications in their own facilities. CoEs should work closely with business function owners to understand existing processes and pain points and evaluate human-robotic workflow options for addressing them. It is also critical to work with industrial engineers and design thinking experts with the skills and experience to develop workflows that take advantage of the unique strengths of humans and robots. (For more on design thinking, read our white paper “Human Centric Design: How Design Thinking Can Power Creative Problem Solving, Drive Change and Deliver Value.”)

Where and How Humans and Robots Collaborate

<table>
<thead>
<tr>
<th>Manufacturing Area</th>
<th>Use Case</th>
<th>Human-Robot Interaction Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouse</td>
<td>Picking, sorting and packing</td>
<td><img src="image" alt="Visual gestures" /></td>
</tr>
<tr>
<td>Production</td>
<td>Prevent slowdowns</td>
<td><img src="image" alt="Emotions" />, <img src="image" alt="Voice" />, <img src="image" alt="Smartwatch" /></td>
</tr>
<tr>
<td>Inspection</td>
<td>Semi-autonomous inspections</td>
<td><img src="image" alt="Visual gestures" /></td>
</tr>
<tr>
<td>Maintenance</td>
<td>Reduce machine downtime</td>
<td><img src="image" alt="Visual" />, <img src="image" alt="Cellular" />, <img src="image" alt="Augmented Reality" /></td>
</tr>
</tbody>
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Figure 2
The success of these experiments can be measured in cost and time savings, productivity gains and less tangible results, such as experienced human operators recognizing that their robot partner makes it possible to offer new “markets of one” options or to assemble a part or product in a more efficient way.

Human-robotic partnerships extend to any process involving a physical flow of materials, whether making finished goods, kitting or packing and shipping. These solutions can apply to a wide range of functions inside, outside and around the factory and warehouse (see Figure 2, previous page).

For example, airborne drones can become the eyes of security officers charged with securing a vast container yard. Autonomous mobile robots capable of learning and making basic decisions could augment post-production inspections. In an aircraft factory, a human supervisor could give the finished product a quick inspection, then direct a robot to take a detailed inventory of faults. In turn, that robot could summon other robots to the area to ensure that section of the airframe is fully surveyed while it follows the human leader to the next part of the aircraft. The robots could then upload complete inspection reports with images. Analytics tools could unearth patterns and issues in the reports that lead to improvements in production techniques and materials.

The success of these experiments can be measured in cost and time savings, productivity gains and less tangible results, such as experienced human operators recognizing that their robot partner makes it possible to offer new “markets of one” options or to assemble a part or product in a more efficient way. Experiments should have mechanisms for capturing these kinds of insights and innovation.

NEXT STEPS FOR BIG BENEFITS

While deployment of next-generation robots is under way, many organizations have not fully considered the concept of integrating this new approach into their overall robotics strategy. Taking the following actions will help ensure the new workflows are part of a larger whole so organizations can earn maximum return on their collaborative robotics investments.
IT, industrial engineering and anthropological design experts should be engaged at the outset.

- **Establish product and market portfolio imperatives and identify high-impact areas.** Business needs and desired outcomes should drive the robotics strategy development and deployment. New offerings from competitors, customer requests for more customization and pricing options, and concerns about bottlenecks and breakdowns from employees are all great sources of intelligence for guiding deployment priorities.

- **Establish a CoE.** This should be a multidisciplinary effort, led by a senior executive and involving input and membership from employees at all levels of the company. IT, industrial engineering and anthropological design experts should be engaged at the outset, as their perspectives are vital to evaluating the robotics strategy and how commercial robotics offerings complement it.

  Further, CoE participation should be promoted as an opportunity to be on the leading edge of manufacturing’s evolution and as a way to shape the organization’s future and employee career paths. The existence of the robotics CoE also may help organizations recruit more tech-savvy millennials to the manufacturing field.

- **Create a charter.** Robotics is a vast and evolving field, so the CoE must ensure its activities – such as guiding the formation of the partnership ecosystem – are aligned with the needs of the business. A formal charter can act as a touchstone to keep CoE activities on target to achieve short- and long-term business objectives.

- **Build a partnership ecosystem.** Evaluate the various public and private consortia to understand their focus areas and their alignment with the organization’s charter. Investigate the robotics strategies and/or needs of supply chain partners to scope complementary priorities and activities. These shared areas can become the focus of the organization’s ecosystem.

- **Chart a roadmap to realization.** As with any change management project, it’s critical to understand the gaps between the current state and the desired future state and outline detailed steps toward closing them. The multidisciplinary robotics CoE is important to fully detail the activities necessary to achieve the vision. Some desired robotic abilities may not yet exist; these can be areas that drive the activities of the partner ecosystem.
The required data flows, interfaces and integrations should be scoped out at the start. These will influence workflow design throughout the company, from the facility floor to decision making in the executive suite.

- **Integrate digital infrastructure and operations with robotics deployments.** Human-robotics partnerships generate tremendous value when integrated with a manufacturing organization’s network. The required data flows, interfaces and integrations should be scoped out at the start. These will influence workflow design throughout the company, from the facility floor to decision making in the executive suite. IT, industrial engineering and anthropological design expertise all are critical to these integration tasks to capture the full potential of human, robotics, digital and systems integration and data points.

- **Experiment and conduct pilot programs.** Small, controlled deployments are test beds for manufacturers to gain experience with new robotics applications. It’s important to build in strong feedback mechanisms with these programs to understand the human experience, as well as the mechanical and IT results, and adjust processes accordingly.

- **Introduce humans to robot co-workers via virtual reality.** Build familiarity and comfort levels about working alongside robots by using virtual reality training tools that simulate specific tasks.

- **Evaluate pilot programs for scaled deployments.** Establishing metrics on sustainable operations at the outset of a pilot is necessary for deciding whether a robotics experiment can and should be deployed more widely. Current-state performance issues must be documented, including the “soft” human impact.

- **Share lessons through consortia memberships.** Apply lessons learned from partners and robotics deployment in other industries. Cross-industry experiences provide a new perspective on how human-robotic workflows can be implemented.

- **Identify and prioritize initiatives on specific products/market segments.** Some pilots and experiments may themselves not be suitable for mass rollout but still yield vital lessons and experience. It will be important not to be seduced by the “cool factor” of robotics to ensure deployments at scale are clearly aligned with business priorities and delivering necessary outcomes.

Finally, it’s important to recognize a successful integrated robotics strategy will be a fluid, adaptable one. Advances in robotics and related fields, such as artificial intelligence and machine learning, will continue to open new possibilities for how humans and robots work together. It will take imagination – a uniquely human characteristic – to make the most of this nascent field.

Organizations that deploy human-robotic workflows now as part of a broad strategy will gain intelligence about its impact on their operations that will fuel a continuous flow of ideas, inspiration and innovation, in turn feeding their ability to increase collaboration between humans and robots to gain even more value.
Artificial intelligence (AI) used to be confined to relatively narrow dimensions of very structured and tightly focused data. Today’s available data streams are much more diverse and unstructured. In an autonomous car, for example, AI uses data from onboard and freeway cameras; speed, temperature, precipitation and lighting condition sensors; and cloud-stored data about a driver’s specific preferences to make decisions about a car’s speed and motion. Similar AI capabilities will influence how humans and robots interact.

AI can enable today’s robots to have greater autonomy and collaborative abilities. As multiple units are networked and become part of the manufacturer’s infrastructure, AI agents can draw insights from multiple data streams to guide the robots and/or alert humans when intervention is required.

Cloud-based AI can bring new robotic devices into the manufacturer’s network and apprise them of workflow design practices – and the personalities and preferences of their human partners – virtually immediately. Further, AI will prolong the usefulness of robots by enabling them to learn new uses for their physical capabilities so they can adapt to new production lines and other functions.

Finally, humans and AI-enriched robots will collaborate more creatively. The AI-derived insights and patterns from data streams created by all the networked robots in a facility can fuel human ingenuity, sparking the continual innovation that will be the hallmark of successful next-generation manufacturing.
ABOUT THE AUTHORS

Rajaram Radhakrishnan is Senior Vice-President and Global Markets Head of Cognizant Business Consulting’s Manufacturing-Logistics/Energy & Utilities Practice. In this capacity, he has P&L responsibility spanning client relationship management, consulting, and revenue and business development. Rajaram has 25-plus years of experience in global consulting, technology and business process operations in North America, Europe and Asia Pacific regions. Previously, he led Cognizant’s pharmacy benefits management, intermediary and provider practices, and managed strategic healthcare client relationships in the Eastern and Central U.S., ensuring the successful delivery of complex technology, business process services and infrastructure solutions. Rajaram holds master’s degrees in business administration and electronics and software systems. He can be reached at Raj@cognizant.com.

Prasad Satyavolu is Global Head of Innovation within Cognizant Business Consulting’s Manufacturing-Logistics/Energy & Utilities Practice, where he focuses on the connected world (connected products, processes and infrastructure), including connected car and telematics services, IoT solutions for urban mobility and smart cities. He also focuses on customer fulfillment (integrated supply chain management that spans visibility planning and manufacturing execution) and general manufacturing industry challenges. Over the last 25-plus years, Prasad has held leadership roles in manufacturing and logistics and incubated a start-up in IT services and consulting that served the manufacturing industry. He holds an advanced degree in mechanical engineering from Dayalbagh Educational Institute, Dayalbagh, Agra, India, and completed a General Management Program (MEP) at Indian Institute of Management, Ahmedabad, India. He can be reached at Prasad.Satyavolu@cognizant.com.

Sachin Chadha is a Senior Consultant within Cognizant Business Consulting’s Manufacturing-Logistics/Energy & Utilities Practice. His 11 years of experience includes working in the automotive sector and working across innovation consulting engagements with leading auto and industrial manufacturers, helping clients in their transformation. His areas of expertise include data monetization, IoT, telematics, product planning, next-generation loyalty management, program management and warranty management. Sachin has a bachelor’s degree in mechanical engineering from Thapar University, Patiala, India and a master’s degree in management from MDI, Gurgaon, India. He can be reached at Sachin.Chadha@cognizant.com.
FOOTNOTES


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