Inside the Factory of the Future:

AI, Robotics, and Software-Defined Automation

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How Intelligent Robots Will Change the Factory

The field of industrial robotics is at the center of significant innovation, fusing technologies including AI models, novel robotics, next-generation compute, and the communications platforms promised by Industry 4.0.

Legacy industrial robots often experience breakdowns or faults. Modern industrial robots can now monitor their own maintenance status, notifying operators of maintenance needs or returning to a maintenance station to swap battery packs, thereby reducing the need for maintenance calls. The new capabilities of contemporary robotics are creating opportunities for deployments in new areas, bringing to life the reality of humans and robots safely working side-by-side through the power of AI-enabled vision systems for safety and navigation. AI-powered vision systems are also enabling the automation of adaptable, complex pick-and-pack tasks that were previously impossible. Dexterous manipulation capabilities, combined with AI-powered vision, allow the accurate pulling, identification, and sorting of packages and items of varying sizes and weights.

Task-Flexible Robots vs. Task-Specific Robots

Traditional industrial robotics has been focused on task-specific applications where robots could vastly improve efficiency. These fixed-function robots have been in discrete manufacturing for decades. Advancements in technology have enabled task-specific robots to continue evolving and improving. Robots are especially suited to extreme environments that are dangerous for humans to operate in, such as those with hazardous gases, extreme temperatures, or confined spaces. These platforms have been developed for many years with successful deployments by industry leaders, and the technology has evolved to the point where it can be rapidly integrated into existing processes.

During this evolution, there has been a substantial focus on "humanoid robotics" in the industrial space. What the robotics industry hasn't fully defined is what a humanoid robot actually is. Traditionally, this has been seen as a bipedal robot, with arms and a head, but is that the most efficient form factor for a robot? Would a humanoid torso, arms, and head with a wheeled chassis count as a humanoid robot? Humanoid robots may have utility in specific areas explicitly designed for operation by someone with a human body, but more often, a more efficient design may exist. Autonomous mobile robots (AMRs) with arms, vision, and mobility can fill human roles and be flexibly assigned to various tasks as needed, similar to how a human might, but they may not take a traditional humanoid form.

Safety in Robotics Deployments

Legacy industrial robots can often be more efficient than human operators in terms of the total hours worked between breaks for servicing and consistency; however, they usually can't safely move faster than a human operator would. Robots being designed now are enabling higher operating speeds than human operators, while incorporating advanced safety mechanisms. Traditionally, robots in manufacturing have been utilized in isolated areas with no human operators nearby as part of safe design practices. Innovations in robotics are driving the deployment of collaborative robots, also known as cobots, that operate alongside human operators. Industrial robotics operating in proximity to humans requires specific safety considerations. OT systems already have inherent safety risks, and manufacturers are familiar with enacting strict safety protocols to ensure operator safety with safety-by-default systems, such as those found in safety PLCs. Robots should be considered in the same way as any other OT machine, including a comprehensive safety risk assessment to develop operator safety protocols and a detailed training plan.

"In some legacy industrial technology, safety was shoehorned in at the end. As robots and automation expand to autonomy in industrial settings, we're ensuring that the safety component is a holistic consideration from the outset of the process. Sensor technology is allowing us to take robots out of safety cages, but having cobots work side-by-side with humans requires an understanding of the risk and safety designed by default."

- Milt Walker, Director Of Business Development, NexCOBOT

Safety-by-default at the chip level is one way to embed intrinsic safety into robotics at the base level. Defining "safe mode" behavior for that robot and process based on various triggers in the sensor data or networked data streams. This could trigger defined safety responses, such as slowing or stopping operations when a human is within a certain radius, or stop all robots for a process or facility due to a line stoppage or a cybersecurity breach.

"As industrial robotics technology evolves into the next generation, Intel is building safety, security, and the necessary performance into the chip at the base level. You can't build a house on sand; you need sound foundations. Safety for robotics is absolutely critical. ... Real-time technology at the chip level, which integrates safety, allows this assessment to be made extremely rapidly, allowing the robot to adapt its movement to reduce risk when a person is detected. We need to bring safety, security, and performance together intrinsically to deliver the best platform for the best outcomes to optimize robotics safely."

- Ricky Watts, Sr. Director, Industrial & Robotic Division at Intel

The Future of Intelligent Robotics

What are the demands driving the next robotics advancements, and what technologies will open those doors? Next-generation robotics is being shaped by the demand for dynamic capabilities, flexibility, and the ability to operate in environments previously considered prohibitive for automation. As we aim to enhance the capabilities and intelligence of robotics, we require advanced battery technologies and innovative advancements in energy-efficient computing to enable the flexible robotics designs of the future.

> Next-generation robotics is being shaped by the demand for dynamic capabilities, flexibility, and the ability to operate in environments previously considered prohibitive for automation.

One key component for decision-makers implementing next-generation robotics will be ensuring that the robots and systems they implement leverage open-architecture hardware standards to reduce single-source risk for manufacturers. Open architecture development standards for interoperability enable the connection of different hardware ecosystems. These standards allow companies in the robotics industry to innovate and differentiate rapidly by preventing vendor lock-in for industrial users based on past purchases. For example, this will enable AMRs from two vendors, a single-function arm on a production line from a third vendor, and a QC vision and sorting system from a fourth vendor to send and receive data and receive direction from a single orchestration layer. Standards-based design reduces vendor single-source risk for manufacturers and enables the spooling up of robotic operations, and the maintenance of robots, at scale.

As they plan for the next generation of robotics, decision makers need to remember that technology alone doesn't drive transformation; people do. Successful robotics and automation deployments depend on collaboration between engineering, operations, safety, and frontline workers who understand the nuances of day-to-day production. This cultural alignment not only prevents costly missteps but also fosters a sense of ownership among employees, leading to smoother adoption, safer workflows, and a clearer understanding of where automation truly enhances performance.

"One overlooked aspect of deploying robotics in any operational environment is the cultural piece of having a cross-functional team to help plan a robotics deployment, integrate it, and measure its success. … Bringing in the people who will be interfacing with, using, and managing the robots from the very beginning adds value and ensures a safe and effective deployment. Involving a cross-functional team from the start helps identify potential issues before they occur, as well as providing valuable feedback after deployment on where robots are adding value and where they aren't."

- Milt Walker, Director Of Business Development, NexCOBOT

Software-Defined Automation

How Software-Defined OT Systems Enable Scalable, Intelligent AI

The modern economy is increasingly presenting technology and workforce challenges that require manufacturers to adapt.

Equipment upgrades or replacements, or scaling to meet demand, can result in unexpected downtime. Handling upgrades, new technology, and dynamic security compliance needs has traditionally been very challenging in industrial settings. Balancing the need for these changes with the primary priority of minimizing production disruptions and maintaining uptime can leave decision-makers in an impasse. This problem has led technology providers to develop solutions that enable operational infrastructure, originally designed with a fixed-function approach, to reap the benefits and knowledge of the IT world while maintaining the operational world's priorities.

"Scaling from small machines to whole plants, the decoupling of hardware and software is a key element for the future. Most organizations will eventually hit a wall with their hardware, necessitating a complete replacement of the current infrastructure, which can be very painful. So really, this decoupling provides a path forward so that processes can evolve over time without hitting that brick wall."

- Andre Babineau, Country Director, Software Defined Automation, Schneider Electric

Software-defined automation (SDA) is the concept of creating a virtualized, programmable control layer. By abstracting operational application assets from underlying hardware through virtualization, businesses can decouple hardware management from the equipment itself, achieving the best of both worlds. Software has managed manufacturing for decades, but this approach places critical operational software on its own layer, enabling it to benefit from IT standards, such as robust cybersecurity and backups, while actively managing production. Decoupling software from hardware is emerging as a key strength for future-proofing operations, enabling seamless changes and updates in a dynamic business environment.

Safety in Robotics Deployments

A high percentage of manufacturing automation systems are 20 years or older. These systems have reached a limit in terms of the efficiency companies can achieve with them. Legacy hardware with proprietary systems compounds the challenge. Without abstracting the software layer, the existing equipment may not even be able to work alongside new components. In addition, institutional knowledge is often a key aspect of operating legacy proprietary equipment. By abstracting software controls into a dedicated layer, this institutional knowledge can be captured and maintained over time, reducing the risk of loss.

By managing the hardware lifecycle separately from the software controls, manufacturers create substantial flexibility. This allows hardware choices to be made based on what is best for the business over time, whether that is centralizing control management, developing digital twin simulations of an entire facility, or quarantining software to prevent changes to hardware and vice versa. Decoupling hardware and software delivers significant flexibility to support rapid adaptation. Companies can choose their own architecture: fully centralized or fully distributed, tailored to specific application needs. This strategy enables the concept of agile, modular manufacturing, bringing even legacy equipment closer to the MTP promise of "plug and produce" functionality. This is achieved by building a foundation and framework to support future upgrades and adaptations.

> **By managing the hardware lifecycle separately from the software controls, manufacturers create substantial flexibility.**

"The idea of interoperability is moving up from the engineering to the management standpoint, hardware and robots from different suppliers, and an abstracted, open management plane that allows for that interoperability across all of these different suppliers. As this evolution is taking place, those concepts are being applied more broadly."

- Kelly Swift, Sr. Director, Head of Industrial Business, Red Hat

Organizations naturally have concerns. Functional blocks, such as real-time capabilities, must maintain existing standards at both the hardware and software levels. Uptime requirements and SLAs have to be met. SDA, once implemented, ultimately allows manufacturers to remove complexity, minimize downtime risk, and increase efficiency.

Beyond equipment or software changes, the software abstraction layers can combine traditionally siloed data repositories across a facility or company. Data exists at all levels of the organization and must be leveraged in unison, outside of traditional process-level or department-level data silos. This can enhance decision-making across enterprise systems, allowing operational data and IT-type systems like resource planning, supply chain, manufacturing execution systems, and asset management to communicate through the abstraction layer. These data foundations and frameworks are also a core requirement of organizational-level AI agent solutions that can provide predictive and prescriptive efficiency suggestions to decision-makers.

SDA Makes Operations Scalable and Replicable

A broad industry acceptance is starting to emerge for the abstraction of software from hardware due to its flexibility and ability to adapt to future changes. The idea of evolving deployments by adding functionality as existing deployments are proven is becoming the norm. At the process level, organization-wide data analysis paired with AI models can optimize workforce allocations and prioritization, deliver specific maintenance optimization information, or help onboard new operators. For AI to be deployed at scale to optimize operations and meet defined goals, software abstraction and data unification are essential components.

Working directly with SDA offers a lower-impact option for trialing optimizations. You're not replacing hardware; you can build the abstraction layer and start experimenting with new solutions. When you add new hardware or replace existing machines, SDA forms the basis of an open-architecture hardware ecosystem that reduces or eliminates the single-source vendor risk associated with proprietary equipment, a challenge manufacturers have faced for decades. Interoperability and portability are critical for manufacturers in the modern, dynamic business environment of shifting customer demand.

"SDA is really there to upgrade the legacy system, number one. Make sure it does what it says on the tin. Does it work? Does it provide the infrastructure flexibility we are looking for? ... Let's say you start by augmenting operators with an HMI. Once you've got that functionality, what information can we start bringing in? Can we give them access to manuals and diagrams? We can look at other things and evolve."

- Ricky Watts, Sr. Director, Industrial & Robotic Division, Intel

The foundations of software-defined automation provide a solid basis for customization, adaptability, scalability, and replicability. They also minimize upgrade downtime, reduce single-source risk, and offer a framework for implementing AI analysis and monitoring to drive efficiency improvements. In essence, it's the connective tissue for the industrial world of the future.

Deploying Industrial AI

When implementing an AI solution in an industrial environment, what foundational elements should be in the checklist?

Sometimes you'll hear that your AI journey should start with data, infrastructure, or organizational readiness. Before these critical considerations can be effectively addressed, decision-makers need a thorough, accurate view of the real-world organizational challenges and goals that AI may address.

> Next-generation robotics is being shaped by the demand for dynamic capabilities, flexibility, and the ability to operate in environments previously considered prohibitive for automation.

"The most important piece is cultural. Is the organization ready for the change? Are you looking at AI technology differently, and a rules-based inspection system, as a tool that will grow with you? Unless you have this system properly integrated into your process, positively impacting your P&L, it's going to be a tough business case to justify and scale."

- Erin Barrett, CEO, Eigen Innovations

This process will require insights from a cross-functional team drawing from levels of the organization. This team can set goals, document existing challenges and opportunities, identify data quality or availability issues, and raise potential concerns, all of which can save time and money when planning or implementing an AI solution. Look for mature use cases that have strong industry solutions already in the ecosystem. Foremost in the evaluation process of defining goals and challenges is setting metrics to measure the ROI of any deployment and demonstrate its value.

Examining AI Foundations

Once the process audit identifies the challenges and opportunities with the best use cases for AI deployment, the foundational considerations for operational infrastructure need to be assessed.

Understand Data

Data availability and visibility are two separate and vital considerations. Are machines generating data? Where is it stored? Is there enough data? Data formats are often varied and need to be standardized and annotated in real time for practical use in AI. Real-time data allows you to run simulations, refine your models over time, and more easily expand to new use cases. Data is inherently messy, and the use of components from various eras and vendors compounds this. As you scale AI across an organization, those data mismatches compound. This is what makes data standardization critical.

Decentralized data silos also exist for IT-style systems such as ERP, MES, and PLM software. Unifying data through a data governance strategy that defines where data comes from, where it's stored, how it's standardized, and how it's used can enable whole-plant simulation or even AI analysis across entire organizations. This starts at the process level, moves up to the facility level, and, if it makes sense, can expand to the organizational level.

These solutions can be inherently application- and organization-specific. For example, data sharing across facilities is not required for scale. Data can remain at the facility, and federated learning AI can share models between facilities to scale without directly sharing data. Another option is a hybrid model where models reside at the edge in a plant, while necessary calculations remain on the plant floor. A cloud deployment handles model training, advanced analytics, simulation, and model management at scale. This drives the benefits of both on-premise real-time inference and the power of the cloud for scaling across facilities.

The "care and feeding" of AI models is another data consideration. How do you make sure an AI deployment provides value over time? Understanding model drift and monitoring models for efficacy can keep deployments providing value over time. Access to data, data governance, and robust data processes enable model refinement and maintenance over time.

Plan for People

Organizationally, there needs to be buy-in from all levels for success. Culture can be the most essential aspect of success. The value proposition of single-function, rules-based systems is fixed in function and scale. AI-driven solutions are designed to grow with the business. Integrating the system into your process and driving automation supports future organizational scaling. Part of understanding the human aspect of AI implementation is the IT/OT divide that manufacturers have been hearing about for years. For AI deployments to be successful, close coordination between operational and IT teams is essential, along with understanding and addressing all stakeholder concerns. IT and OT teams will have unique insights into the process, and establishing robust coordination early can lead to better execution of future deployments and upgrades.

Open-Architecture Hardware

Legacy infrastructure deployments can be difficult or impossible to integrate with other components, primarily proprietary fixed-function hardware. As components age, the risk of single-source vendor dependency for parts and support increases. Open-architecture, standards-based hardware solutions can be easily scaled and easily integrated with existing and future hardware. With the advantages of software-defined Automation, open-architecture hardware will enable you to add compute, storage, or other hardware and to change or adapt AI models as needed.

AI infrastructure, especially at the edge, is very application-specific. Another critical consideration when evaluating hardware choices is understanding the specific needs of the process and the environment the process requires. Choosing models and hardware that fit within the process's limitations will improve the project's success.

Another consideration is evaluating the chosen hardware against the end goals stated during planning. There is a balance between deploying only the hardware you need and planning for scalability. Over-spec systems can substantially increase ROI timeframes. Right-size the hardware for your applications, start with a constrained problem, and a measurable solution to avoid scope creep. By leveraging open-architecture infrastructure, scaling isn't necessarily dependent on initial choices.

"Once you integrate over-spec'd hardware, it's very difficult to scale back. Start with the end in mind. Deploying numerous over-spec systems can turn your ROI calculation upside down. For example, leveraging silicon from Intel to deploy AI on premises without excessive hardware can help you 'right-size' your deployments."

- Hunter Golden, Sr. Product Manager, Industrial & Server Lines, OnLogic

Plan for Scaling

AI automation, such as sending a signal to a PLC to reject a part or stop a line, empowers AI to make decisions without human intervention. These models need to be scalable so that thousands of models aren't required to meet plant use cases. AI needs to be easy to use and interpret, and to scale and integrate easily into processes. This means both the hardware and software need to be scalable. Some solutions providers offer managed services to help organizations manage and scale models.

Orchestrating hundreds or thousands of devices across an organization can be streamlined through IT practices. IT has solved the scaling problem; leveraging IT expertise and best practices can help manage OT scaling and AI-enabled processes across lines and sites.

What's on the Horizon for Industrial AI?

The hardware needed to deploy AI is getting cheaper every year. The AI capabilities of lower-cost hardware will reduce the total costs of AI deployments across many use cases. Broad industrial acceptance and deployment of AI across various functions and processes will accelerate this by creating demand, enabling the development of more suppliers and mature solutions. As more solution providers offer out-of-the-box solutions, businesses can avoid "pilot purgatory" and either shorten or eliminate pilots entirely. Solutions providers that can deliver models trained on data from a specific industry and implementation use case already exist, and the availability of robust trained models will only increase.

"AI is not always going to be a 'killer app' — it's a new programming paradigm. It has become simply part of the background operations, delivering feature sets within existing applications. There may be dozens running as background operations on any PC at any one time. Measuring ROI on these sorts of AI 'enhancements' will require different metrics from broader AI deployments."

- Todd Matsler, Sr. Director/GM, Manufacturing Segment, Intel

> The factory of the future will not emerge from a single breakthrough in robotics or AI, but from the convergence of intelligent systems, open architectures, and human collaboration.

As industrial environments evolve into dynamic, data-driven ecosystems, success will depend on how seamlessly manufacturers can integrate adaptive robotics, scalable software-defined systems, and AI-driven intelligence into their operations. The shift toward interoperability, safety-by-design, and cultural readiness will define the next era of industrial progress — one where people, processes, and machines work in concert to achieve sustainable efficiency. Ultimately, the manufacturers who view AI and robotics not as isolated tools but as integral partners in continuous improvement will lead the transformation toward truly intelligent, resilient, and sustainable production.

Acknowledgements

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900 Victors Way, Suite 140, Ann Arbor, MI 48108 USA

734.994.6088 | **automate.org**