

**How Connected  
Robots are  
Transforming  
Manufacturing**

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## HOW CONNECTED ROBOTS ARE TRANSFORMING MANUFACTURING

Robots are a well-established and widely accepted feature of modern manufacturing plants, carrying out dangerous and unergonomic tasks such as welding, metal cutting and assembly of large parts such as car chassis and doors. Many robots work alongside manufacturing employees, tending machines, fetching and carrying parts and materials and performing tasks such as stacking, parts assembly and product finishing.

Increasingly, robots are no longer stand-alone machines, but are connected to other machines and software applications as part of automation and Industry 4.0 strategies. The vision is of a seamless automated process from order through to dispatch and delivery. Machines can communicate with each other as well as report on their own status, producing data that can be aggregated across multiple machines or an entire process. This data can be analyzed and used to continuously optimize production, anticipate bottlenecks in the production process, and forecast when machines need servicing, saving costs in machine downtime which can run to millions of dollars per minute.

The digitization of parts or all of the manufacturing process gives manufacturers transparency across the full end-to-end production, enabling them to maximize efficiency along the full value chain. For example, Bosch, a global supplier of technology and services, has implemented connected solutions in virtually all its 280 plants. The company claims that by using intelligent software it is able to increase productivity every year – at some locations, by up to 25 percent – while also reducing stock levels by up to 30 percent<sup>1</sup>. Siemens says that digitalization has enabled its smart factory in Amberg to produce 13 times more with the same number of 1300 employees as in 1989<sup>2</sup>. Automotive manufacturer VW expects productivity to increase by 30% by 2025 due to digitally connecting machines to ecosystems capable of analyzing the data being produced<sup>3</sup>. Manufacturers are also able to gain an exact picture of material and energy use, enabling them to minimize waste, cut energy use and – as a result of both – reduce emissions.

While relatively few companies have as yet implemented a fully automated manufacturing strategy, many are linking up parts of the process, with connected robots playing a key role.

In this paper, we look at the benefits of connecting robots to various parts of the production process. We discuss the main ways in which connected robots are currently transforming manufacturing and give an overview of future technology developments and their impact. Finally, we discuss how these developments will affect skills requirements in manufacturing and implications for policy-makers.

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<sup>1</sup> <https://www.bosch-presse.de/pressportal/de/en/industry-4-0-at-bosch-the-power-of-an-idea-177024.html> accessed 13 04 20

<sup>2</sup> [http://www.xinhuanet.com/english/2018-04/24/c\\_137133861\\_2.htm](http://www.xinhuanet.com/english/2018-04/24/c_137133861_2.htm) accessed 03.05.20

<sup>3</sup> [Sensors as drivers of Industry 4.0: Transforming businesses](#), EY 2019

# How Connected Robots are Transforming Manufacturing

## EXECUTIVE SUMMARY

**Connecting robots to other machines and programs in the production process brings various benefits to manufacturers** including:

1. **Increased flexibility** to quickly adapt production and respond to changes in demand and smaller batch sizes
2. **Improved resilience** to deal with production peaks and withstand systemic shocks such as COVID 19
3. **Energy and resource efficiency** through optimized performance
4. **Improved productivity for manufacturing employees.** Robots are assistants to manufacturing operators. Decision making for engineers, technicians and production managers is improved through better information from machine performance data that can be analyzed for machine and process optimization

**The IFR has identified five common scenarios in which robots are connected within broader automation strategies:**

1. **Automated production:** Linking the first stages of production such as order entry and product design to downstream processes such as parts ordering and machine scheduling enables manufacturers to immediately understand the resource implications of producing a new product or order and to better optimize the organization of production.
2. **Optimizing performance:** Connecting robots and other machines to a central computing server enables manufacturers to extract and aggregate data that can be used to optimize machine performance in real-time or retrospectively, avoiding unplanned machine downtime which can cost manufacturers over \$1 million per hour.
3. **Digital twins:** Virtual representations of robots and other production machines enable manufacturers to simulate operations and the impact of changes to parameters and programs before they are implemented, enabling improved production planning, and avoiding costly downtime.
4. **Robots as a Service:** Adopting robots on a pay-per-use basis can be particularly beneficial for small-to-medium-sized manufacturers, sparing them up front capital investment and unpredictable maintenance costs, and giving them predictability of operating expenditure.
5. **Sense and Respond:** Sensors and vision systems enable robots to respond to their external environment in real-time, expanding the range of tasks the robot can perform - such as picking and placing unsorted parts - and expanding robot mobility. Mobile robots are key to enabling flexible manufacturing, in which production is split into discrete processes and production cells running in parallel.

**Future developments focus on four key areas:**

1. **Hardware:** Advances in vision technologies, sensors and grippers enable robots to support employees in a continuously expanding range of tasks.
2. **Software:** Intuitive programming interfaces, 'out-of-the-box' robot applications and robot-as-a-service business models will continue to lower the barriers to robot adoption. Increasingly sophisticated machine learning and predictive algorithms and an increase in cloud-based analytical solutions will improve decision-making, production scheduling and machine performance.
3. **Communications frameworks:** The main hurdle to full automation strategies is the integration overhead between machines and software applications in the production process. We can expect this overhead to significantly reduce as programming interfaces become more intuitive and communications protocols and semantic frameworks enable more

## Implications for manufacturers and policy makers

Automation is key to the competitiveness of manufacturing sectors globally. To reap the full benefits of automation technologies, manufacturers and policymakers must focus on three things:

- 1. Skills planning and development:** Manufacturers will need to map out pathways for upskilling an existing, experienced workforce to balance new digital skills with expertise in legacy systems. Close collaboration with education institutes is critical to ensure curricula are matched to skills requirements. Policy makers must ensure that the educational infrastructure needed for skills development is in place and that workers are able to access it.
- 2. Promoting careers in manufacturing:** Manufacturers, education institutes and governments must promote the benefits of a manufacturing career at the forefront of technology development to the next generation of manufacturing employees.
- 3. Policies to encourage adoption of automation technologies:** Policy makers need to ensure incentives and support are available for companies to adopt automation technologies. SMEs in particular will need support in developing and executing an automation strategy.

## THE BENEFITS OF CONNECTED ROBOTS

Connecting robots to other machines and programs in the production process brings various benefits to manufacturers including:

### FLEXIBILITY

Manufacturers must increasingly be able to respond to changes in demand that frequently result in smaller, customized orders. This requires the ability to quickly re-assemble production lines for small batches. As we discuss in various scenarios below, robots can now be directly connected to order systems with the right robot program automatically selected for the task. Robots are increasingly easy to program, through intuitive interfaces and demonstration methods in which the manufacturing operator leads the robot arm through the task to be performed. Simple applications can be programmed by manufacturing operators with no formal robot programming skills after a few hours of training. Many robots are lightweight, and some robot arms can be connected to mobile bases, enabling them to be moved between production cells.

### RESILIENCE

Small-to-medium-sized (SME) manufacturers are particularly vulnerable to fluctuations in demand, but larger manufacturers (such as automotive manufacturers) are also subject to tight profit margins and disruptions in demand due to geo-political and other external shocks. As a result, both SMEs and large manufacturers must be able to respond to changes in labor requirements. Given the current shortage of manufacturing labor, it can be very difficult for manufacturers to find experienced workers at short notice. Robots are increasingly used by SMEs – who cannot afford idle labor in slack times and cannot quickly find workers in peak periods – to smooth out production peaks. In many SMEs, robots are used in collaborative applications, assisting manufacturing operators who monitor the overall process. During peak periods, more robots can be assigned to specific tasks. The advent of the pay-per-use model for simple robotic applications – discussed in more detail below – makes it

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easy for SMEs to increase their robotic workforce to cover peaks as no capital investment is required in a robot that may idle during periods of lower demand.

Robots also enable manufacturers to respond better to the consequences of systemic shocks such as the recent COVID-19 pandemic. Robots can be positioned within a connected production line to enable adherence to social distancing rules, for example, and can carry out disinfection tasks that might put workers at risk.

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### RESOURCE AND ENERGY EFFICIENCY

Connecting robots to computer servers that analyze data extracted from robots and other production machines can lead to lower energy requirements and less material waste since the robot can be optimized to high levels of accuracy and energy use. Data from a series of robots or other machines can also be aggregated and analyzed to understand what causes variance in the performance of identical machines. Proposed changes to machine programs can be simulated in an offline environment and are only implemented on the production line when machines run seamlessly offline. This not only saves resources, but also means new production runs can be set up much faster, avoiding costly machine downtime and other unforeseen problems in the new line.

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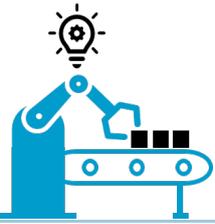
### IMPROVED PRODUCTIVITY FOR MANUFACTURING EMPLOYEES

Connecting robots within broader automation strategies offers benefits to employees at all levels of the manufacturing process. Robots increasingly work alongside manufacturing operators, supporting them by carrying out tedious and unergonomic tasks and enabling them to focus on tasks that require human skills such as re-programming robots and overseeing production lines.

The data generated by connected machines is a valuable resource for engineers, maintenance technicians and production managers, enabling them to make better decisions based on a detailed overview of the production process. For example, machine data can be analyzed to improve product quality and predict when machines will need servicing or replacing, avoiding machine downtime. In advanced automation scenarios, maintenance engineers can see from predictive maintenance applications exactly which part needs to be replaced and can therefore replace a pre-ordered part rather than having to first investigate the cause of the problem. Engineers can use 'digital twins' – described in more detail below – to anticipate the impact of changes in the robot program on other machines within the production process. Production managers can see and manage the status of all machines and transactions in the process and receive automatic alerts when performance is not within given parameters, enabling them to make adjustments and anticipate bottlenecks before they arise.

**CONNECTED ROBOTS: PRODUCTION SCENARIOS**

Below we look at five common scenarios in which connected robots deliver the benefits described in the previous section:

FIVE SCENARIOS FOR CONNECTED ROBOTS IN MANUFACTURING				
AUTOMATED PRODUCTION	OPTIMIZING PERFORMANCE	DIGITAL TWIN	ROBOT AS A SERVICE	SENSE AND RESPOND
				
The robot is connected to design and production systems (ERP /CAD) and/ or other production machines	The robot transmits data which is analysed for performance optimisation	The robot has a digital replica that is used for testing new applications and monitoring performance	A cloud-connected robot is offered on a pay-per-use basis	The robot can sense and respond to its external environment

**AUTOMATED PRODUCTION**

The production process begins many stages before machines are put to work on the shop floor. The vision of Industry 4.0 is that the entire process – from a customer order being entered, or a product designed, through to shipment – is digitized, each stage automatically triggering downstream processes and enabling production managers and technicians to monitor progress and resolve conflicts from laptops and even mobile phones. A number of manufacturers have linked the early stages of production - including order entry in enterprise resource and planning (ERP) system and product design in computer-aided design (CAD) systems - to downstream processes, automatically generating parts lists, selecting and notifying the relevant machines, including robots, and selecting the right robot or machine program for the task. This enables manufacturers to immediately understand the resource implications of producing a new product or order and to better optimize the organization of production – for example whether to run a linear production process or produce parts from multiple orders together.

## How Connected Robots are Transforming Manufacturing

### Case Studies: Linking ERP and CAD systems to downstream production processes



*MiR robots transport parts at Kamstrup.  
Photo courtesy of MiR*

Danish metering solutions company Kamstrup only produces to order. In order to ensure its maximum delivery time of 72 hours the company has linked its ERP system to machines on the shop floor. Kamstrup uses MiR autonomous mobile robots to transport parts between production cells. When a Kamstrup sales consultant enters a new order, the MiR robots receive a queue of taxi routes from the ERP system, to be driven by the first-available mobile robot (See the full case study [here](#)).



*Video: Automated production at Goldbach  
Kirchner*

German furniture-maker Goldbach Kirchner operates a fully automated furniture production process that starts with product designs in CAD systems. These generate parts lists and also machine programs which are transferred to a central controller in one of two manufacturing locations. The process controller distributes the piece list and the machine programs to different machines, including robots. These feed work pieces into the production line, taking them in and out of the line to ensure it moves at the right speed. The robot then automatically sends panels for further cutting or alternatively for labelling and further processing. The automated process means that customer orders can be combined so that similar parts from multiple orders can be processed together, reducing waste.

Production machines, including robots, can be linked together, either through a separate external controller, or by assigning one machine as the 'master' that controls the others. This means manufacturers can select as the master the machine that operators are most familiar with, so operators don't have to learn the operating software for the other machines

### Case Studies: Linking production machines through controllers

Austrian eyeglass manufacturer Silhouette linked up the milling machines and KUKA robot used in milling glass so that the robot could be controlled through the milling machine because the production operators were familiar with this tool, but not with the robot operating software. See the full case study [here](#)).



*A KUKA robot loads a machining tool at the Augsburg  
plant: Photo courtesy of KUKA*

Robot manufacturer KUKA has automated the production of robot parts using 11 connected robots working in 7 production cells at its Augsburg plant in Germany. The robots feed a variety of machining tools with required materials and then unload the machined part. Communication between the robot and the machining tool can be managed either through the robot or through an external controller. If the

robot is managing the process, it can, for example, notify the machine that the workpiece has been loaded and the door can be closed. See the case study [here](#).

Robot systems integrator Roboteco SpA has developed an automated welding production cell using Panasonic robots for Italian metal processor Steel-Tech. The robot and the welding machines are connected through the robot's central processing unit which also includes the robot programming interface, allowing operators to select and modify existing welding programs. The robot controls all the parameters of the process, such as the current, voltage and speed of the welding machine. Read the full case study [here](#).

## OPTIMIZING PERFORMANCE

Connecting robots and other machines to a central computing server enables manufacturers to extract and aggregate data that can be used to optimize machine performance in real-time or retrospectively, avoiding unplanned machine downtime which can cost manufacturers over \$1 million per hour. The server can either be local to the manufacturer or managed by a cloud-based provider. Cloud-based providers are able to aggregate anonymous data from hundreds of similar machines for analysis, and thus provide highly accurate optimization and trouble-shooting recommendations and applications.

### Case Studies: Optimizing Performance

German automotive supplier KOKI has connected 60 robots to ABB Ability Connected Services, which monitors the robots' state round the clock and alerts users to situations which could lead to unplanned downtime. This is particularly critical for KOKI since most of its automotive customers



A KOKI employee checks a robot's status. Photo courtesy of ABB

expect just-in-time delivery. In the past if a failure occurred KOKI had to convert another cell with the same robot model to duplicate the lost production, a time-intensive process with risks.

The service sends alarms by e-mail or SMS and operators can access data for analysis and decision-making through a web-based application. This data can also be used to better prepare service experts for more efficient on-site visits, for example giving them a snapshot of the system at the point of the failure. Read the full case study [here](#).



Connected KUKA robots at Jeep Wrangler's Toledo plant: Video courtesy of KUKA

KTPO, a wholly-owned subsidiary of KUKA Systems North America LLC, produces the body-in-white (unpainted car body) for Jeep Wrangler. The Toledo, US, plant produces 2 and 4 door car bodies at a rate of nearly one a minute. To ensure a seamless, 24/7 operation, KTPO built a software system that connects a fleet of 259 robots and 60,000 other devices to a powerful back-end digital monitoring system and a master data management system. The system enables KTPO to monitor and resolve abnormalities in production and also analyze data offline to optimize the production process. The system has since been

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expanded to monitor the entire value chain in real time, from receipt of materials to the actual production processes and goods dispatch, enabling KTPO to identify weak points and optimize capacity utilization. See the full case study [here](#).

Creating Revolutions, a US manufacturer of customer service paging systems for the hospitality industry, has linked its Universal Robot to the cloud. The robot is used for soldering, drilling, silicone dispensing and light assembly in manufacturing the pagers. The cloud connection means operators receive real-time production data and notifications when the robot requires attention. The data is also used for production planning since it provides details on the number of units the robots produces in a given period of time, enabling the company to plan its human resource requirements and ensure production runs at optimal levels. See the full case study and video [here](#).

At KUKA's Augsburg plant (mentioned [above](#)) all of the machines in the production hall, including the 7 robots, are connected to the cloud, enabling production managers to monitor all of them through a smartphone-like interface. If error-messages appear, technicians have access to a wiki-type database providing almost half a million proposals for solutions. The technicians can also access data enabling them to retrace the whole process to look for anomalies.

In the Steel-Tech example mentioned [above](#), data from the production process is extracted into a central software program where it can then be analyzed to look at the status of completed vs. ordered pieces, or divergence from the set welding parameters. The program also allows Steel-Tech technicians to operate the robots – and through them, the entire process – remotely.

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### Virtual simulation and the digital twin

Virtual representations of robots and other production machines enable manufacturers to simulate operations and the impact of changes to parameters and programs before they are implemented.

Some manufacturers are linking physical machines in real time to a virtual representation of the same machine – called a digital twin. This enables them to simulate the impact of changes to the machine's program and operative parameters in the digital twin and then automatically transfer those changes to the physical machine. Simulations in the twin enable manufacturers to forecast the impact of a continuation of ongoing processes, such as friction or other forms of physical stress. This means manufacturers can better forecast when a machine will require maintenance or replacement. The process also works in reverse – i.e. the performance of the physical machine is replicated in the digital twin. This enables operators and engineers to investigate causes of performance issues or machine malfunctions.

## Case Studies: Virtual Simulation and Digital Twins

Great Plains Manufacturing, an agriculture equipment manufacturer, needed a robotic welding solution to reduce their time to market as well as their overall production costs. The company's production runs were highly variable - between 5 and 1,000 pieces and with up to 30 production lines in operation. Systems integrator Genesis developed a virtual application for robotic welding that enabled Great Plains to test custom tools and processes before developing them and assess the gaps in their planned system. Using the virtual system design, Great Plains was able to develop the



*Digital twin of a KUKA machine tending robot*

custom tooling they needed in-house, and prepare offline programming while Genesis was building the system. The result was a streamlined integration project that saw the system fully operational on the same day it was implemented. See the full case study [here](#).

CNH, a global leader in capital goods that designs, produces, and sells a wide range of agricultural, industrial, and commercial vehicles and powertrains, wanted to test whether a digital twin of its chassis welding line could help it reduce maintenance costs. For global companies like CNHi a single minute of downtime

can run to upwards of \$160,000. Being able to predict and address machine failures before they happen therefore amounts to substantial cost savings. The welding line was chosen because one component in the welding guns - an electrical conductor which must flex during operation – can become worn due to the flexing movement, ultimately resulting in the whole component melting. While normally this component can be replaced in few minutes, it can take hours if the component has been damaged. The digital twin enables CNHi to change the component before it has reached this critical point. To enable the digital twin, each robot is fitted with a sensor which sends a signal about the robot's actual condition to the simulation model. Each robot twin uses a predictive model that forecasts the trajectory of the robot degradation based on the signals received. Users can run various scenarios through the twin to assess the impact of how changes to the production process could impact maintenance costs, such as spare parts and labor.

German food testing company Eurofins WEJ Contaminants and plant construction company Elbatron have built an automated robotic testing line, including a digital twin, to automate the process of extracting samples and transporting them to testing stations. Three ABB robots manage the whole process of extracting samples of foods, inserting the exact amount into test tubes and carrying them to the testing station. The robots complete 400 tests per day to a degree of precision that would not be possible through a manual process. Elbatron built a digital twin of the entire robotic process, enabling testing of the new system before it was installed. Eurofins can also easily test adjustments in the digital twin as required, only implementing the changes in the physical process when these are running smoothly in the twin. This gives Eurofins great flexibility to adjust a complex process requiring a high degree of accuracy, without incurring machine downtime, or causing unforeseen problems in the live process.

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## ROBOTS AS A SERVICE

The ability to connect physical equipment to the internet has opened up a range of possibilities for suppliers to offer machines – from printers priced by the number of pages printed to jet engines – as a rental service. Because the machine is internet-connected, the owner is able to monitor and charge for exact usage. Customers are spared both up front capital investment, and unplanned maintenance costs, giving them predictability of operating expenditure. A number of companies now offer robots on a pay-per-use or subscription basis. This can be particularly advantageous for small-to-medium sized manufacturers who do not want to sink capital into equipment, particularly during the early phase of robot adoption when they are working out the return. The robot-as-a-service (RaaS) model also enables manufacturers of any size with highly variable production runs to rapidly scale production up and down to cope with sudden peaks in production demand.

Some companies collaborate to offer a bundled service for a specific robotic application, comprising the robot, machine tools and equipment, and the necessary software for programming the application to the manufacturer's specific requirements.

### Case Studies: Robots as a Service

US-based Hirebotics specializes in RaaS solutions, offering Universal Robots' collaborative industrial robot series as ready-to-hire robots. Hirebotics has also teamed with partners to develop a pay-for-use welding solution comprising a robot, welding torch, table and peripherals, and the software to set-up and train the robot. See more information [here](#).



*An Abagy robotic welding solution*

Robotic solutions provider Abagy provides a cloud-based welding solution and also a painting solution on a pay-per-task basis. Customers pay for meters of weld seam, or area of painted surface. Abagy's software automatically processes 3D CAD models and production operation parameters into robot programs. 3D cameras and 2D laser scanners monitor the working area and send performance data that is used to update the master control programs, enabling continuous performance improvement. More information [here](#).

Robot manufacturer KUKA has launched a 'SmartFactory as a Service' solution aimed at flexible small-batch manufacturing, partnering with consultancy MHP and insurer Munich Re. More information [here](#).

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## SENSE AND RESPOND

Many robots are equipped with sensors and vision systems that enable the robot to respond to its external environment. For example, robots with in-built or attached sensors can detect when a person or object enters its path and can stop or slow down. Vision technologies combined with picking programs enable robots to identify objects and plan a trajectory and the required force for handling them. Meanwhile, the combination of external sensors, vision technologies and mapping software enables robots to move autonomously around factories.

In some cases, these applications are cloud-based, meaning that the processing of images and other data from the robot takes place on a remote server, with the results delivered back to the robot for further processing by the robot program.

Pick-and-place applications enable robots to carry out a wide range of tasks sorting and placing parts. These are highly complex applications that run in real-time. First the vision system must identify the required part, including parts that are entirely or partially covered by others. Algorithms process incoming data from the robot's camera against a database of similar images to determine the most likely fit. These algorithms may run locally, or on remote (cloud) servers. The advantage of remote processing is the access to a much larger aggregated store of images. Once the part has been found, the robot's software processes data to determine how to reach it, calculating the proper orientation for the gripper or other end-effector. Sensors in the gripper feed data to the robot's software. This is processed to enable the robot to pick up the object without damaging it by either exerting too much pressure, or too little so that the object slips. Pick-and-place applications are used in a wide range of manufacturing sectors for machine feeding, assembly, and packaging.

Vision systems and mapping algorithms are opening up significant new possibilities for mobile robots. Automated guided vehicles traditionally navigated on fixed routes, typically programmed through tracks on the floor. Many mobile robots now combine vision technology and mapping programs that are continuously updated as the robot moves through its environment. These advances, together with sensors attached to the robot and within the production environment, enable robots to move freely through factories and warehouses, stopping when encountering an object, and autonomously re-planning their route if required. Mobile robots can be connected to each other and integrated into individual production processes such as machine feeding as well as into back-end order systems. Connecting a fleet of mobile robots improves the accuracy of robot mapping, since changes to the inbuilt map observed by each robot can be centrally aggregated, with the updated map then transferred to all robots in the fleet.

Some providers such as Fetch Robotics offer cloud-based solutions for automating management of mobile robots. Software updates, scheduling of the robots to perform specific tasks, and enabling communication with other equipment and machines such as doors, RFID scanners and conveyors, is managed in the cloud. The advantage of this approach is that manufacturers and logistics providers can up- and down-scale their fleet without having to up-scale associated resources such as server capacity and robot programmers.

## **Case Studies: Sense and Respond**

Janssen-Ortho LLC (a Johnson & Johnson Company pharmaceutical partner) in the US reduced scrap by 400% through an automated blister packaging system for tablets which were previously difficult to handle due to a soft external coating. The application uses an EPSON vision system that identifies the exact position of each pill and sends this information to the robot which picks multiple pills and places them in the blister pack (more information [here](#)).

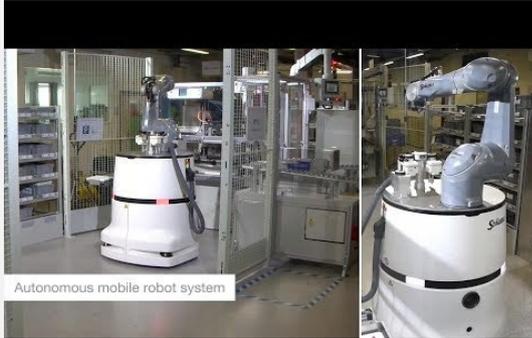


*Pick and place with ABB robots*

Pick-and-place applications are used extensively in food packaging where there is frequently a requirement to handle non-standard, fragile objects. In this video, for example, ABB robots are used to pick and stack pancakes coming off a conveyor belt.

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Mechatronics solution provider Stäubli has integrated a fleet of mobile robots into its production system at its component manufacturing factory in Allschwil, Switzerland. The robots fetch and carry parts to and from separate production cells and perform specific tasks at each production station. In



*Mobile robots at Stäubli*

the example shown in this video, a mobile industrial robot fitted with an automatic tool changing system navigates itself to a workstation and uses sensors to align itself accurately to a loading machine. It loads a rotary table for the manufacturing of pneumatic couplings. It then moves on to a different workstation and, thanks to an automatic tool changing system, selects the appropriate tool and begins a new task. The robot stops automatically if an employee approaches. (See the full case study [here](#)).

As described [above](#), Kamstrup has integrated mobile robots are integrated with the company's order system.

The entry of a new order automatically triggers the dispatch of mobile robots to bring materials to production cells to complete the new order.

## FUTURE DEVELOPMENTS

Going forward, manufacturers can expect advances in four key areas: Robotic hardware; software – in particular robot programming, machine learning and AI; communications frameworks; and the organization of production.

### CONNECTED HARDWARE

Advances in vision technologies, sensors and grippers enable robots to support employees in a continuously expanding range of tasks.

Vision systems are becoming increasingly sophisticated, moving from 2D to 3D and able to work in sub-optimal conditions such as low or mixed lighting. Machine learning algorithms continue to improve, making vision systems easier to train, and faster and more accurate in identifying the right objects.

Collaborative robots made from lightweight materials and with in-built sensors are enabling robots to serve as human assistants and tools. These robots perform unergonomic and tedious tasks in a production process, working alongside employees.

### Case Studies: Future grippers



*Robotic skin from TU Munich*

Robot grippers continue to evolve to handle fragile and non-standard objects. A [robot gripper that can absorb external shocks](#) and therefore hold very fragile objects without breaking them is in development at the University of Buffalo, for example.

Researchers at the [Technical University of Munich are working on the development of a robotic skin](#) that can detect contact, acceleration, proximity and temperature input from multiple sensors.

## SOFTWARE DEVELOPMENTS

Programming interfaces continue to become increasingly intuitive, enabling factory operators to program and re-task robots – a job previously requiring specialist programming skills. Robots can be programmed by demonstration, with an employee guiding the robot arm through the task to be completed. Programming interfaces abstract the underlying programming logic into simple commands that can be executed by production workers for simple robot applications. Many suppliers are providing ‘out-of-the-box’ robot systems for standard applications such as tightening screws or applying adhesive. These systems include the pre-programmed robot arm and necessary peripherals. Increasingly sophisticated algorithms will bring additional intelligence to robots and to automation processes. Although many manufacturers have been wary of potential data security issues with cloud computing, we can expect cloud solutions to increase, giving small-to-medium sized manufacturers (SMEs) access to program libraries and real-time solutions they would not otherwise be able to afford. Manufacturers of all sizes benefit from access to a far wider, continuously updated range of data than they could individually assemble or purchase, improving the accuracy of applications from predictive maintenance to pick-and-place. Cloud connectivity also enables robots and other machines to be offered on a rental basis, with updates and applications provided on a subscription basis. This is also of particular benefit to SMEs as it removes the need for up-front capital investment.

Machine learning and predictive algorithms will continue to evolve in sophistication, improving the accuracy of vision systems and reducing implementation and training time for applications using vision and mapping algorithms. Robots will be able to recognize a far greater range of items, and the accuracy of automated robotic quality inspection will continue to improve. Predictive algorithms that can be used to forecast and choose the right option for overcoming production bottlenecks will also increase in sophistication.

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## COMMUNICATIONS FRAMEWORKS

Integrating various components of manufacturing systems – from the components within robotic systems to complete production cells and plant-wide production systems – represents a substantial percentage of the cost of a robotic or other production system. As peripherals such as grippers and vision systems increase in sophistication and applicability, the extent of integration is likely to increase in future. However, a number of developments continue to reduce the integration overhead.

First, as discussed above, robotic programming interfaces continue to become more intuitive. We can also expect an increase in pre-programmed, ‘out of the box’ robotic applications (see the section on [Robots as a Service](#) for more detail). Most important for reducing integration costs and installation time is the fact that communication between robots and other machinery from different vendors will become easier, enabling manufacturers to gain a holistic view of the performance of all of the machines involved in the production cycle. Standard interfaces and controllers will enable swifter integration of machines in a production cell. Increasing abstraction in programming into semantic layers that can be associated with multiple vendor programming terms and code will enable more seamless communication between machines within a production system. For example, members of the OPC Foundation and the VDMA recently collaborated on a standard semantic model to enable communication between robot system components from different vendors and the aggregation and analysis of data from them (see the [IFR blog](#) for more details).

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## ORGANIZATION OF PRODUCTION

The ongoing trend towards customization means many manufacturers have adopted ‘flexible manufacturing’ strategies in which production is split into discrete processes and production cells running in parallel. This means that one production cell can produce components common to a number of products, while others focus on customized parts. Each cell can be quickly reconfigured to

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accommodate changes in orders. Typically, mobile robots will fetch and carry materials and finished components to and from cells as well as operate machines.

Developments in the three areas outlined above - hardware, software and communications frameworks – all come into play in flexible manufacturing. The wider range of end effectors, improvements in vision and mobility technologies and increasing ease of programming mean that robots can be automatically moved between cells and re-tasked. As the [Stäubli](#) example above shows, the process can be automated such that robot automatically selects the right tool for the new task. In a fully automated production scenario, the combination of more advanced communications frameworks, together with developments in machine learning and predictive algorithms, will reduce the integration overhead of connecting each cell, and the machines within it, to the manufacturer's order entry and CAD systems. Algorithms will determine the most cost-efficient way of organizing production across different cells and trigger the automatic downloading of the required programs to the machines within the cells, and to the robots transporting material and finished parts between them.

### IMPLICATIONS FOR MANUFACTURERS AND POLICY MAKERS

Automation is key to the competitiveness of manufacturing globally. For many countries, a vibrant manufacturing sector is critical for GDP growth, particularly given manufacturing's role as a multiplier, creating jobs in upstream supply sectors, as well as in service industries. Both policy makers and manufacturers have an important role to play in paving the way to increased adoption of automation technologies in manufacturing.

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#### CLOSER COLLABORATION BETWEEN AUTOMATION TECHNOLOGY SUPPLIERS AND MANUFACTURERS

Providers of automation tools and technologies need to work closely with their customer base to develop solutions specific to manufacturers' needs. Many manufacturing sectors - and particularly those dominated by SMEs - have low levels of automation and need support in assessing the potential of automation technologies for their particular requirements. In general, the lower the barrier to installation and return on investment, the higher the adoption rate. The move to 'out-of-the-box' robotic applications is one example of this. For more complex applications, bespoke solutions may be required. Automation technology providers must work with manufacturers in these sectors to develop tailored solutions. Policy-makers have an important role to play in stimulating the adoption of automation technologies among SMEs through appropriate incentives and dedicated support programs. Policy-makers also have a role to play in incentivizing the establishment of a pool of systems integrators able to support companies of all sizes in developing and implementing automation strategies and solutions. Robot industry associations are also becoming active in this regard. For example, associations in the US and UK have developed certification programs for systems integrators. External certification enables companies, particularly SMEs, that may be unsure how to evaluate a potential supplier of automation solutions, to select from a pool of proven providers.

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#### SKILLS DEVELOPMENT

As connected robots and advanced automation technologies change the production landscape, manufacturers will need to assess and plan for current and future skills requirements. A number of studies predict that the current skills shortage is likely to increase as the 'baby boomer' generation (born between 1954 and 1964), retires<sup>4</sup>.

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<sup>4</sup> See for example Cedefop, Eurofound (2018). Skills forecast: trends and challenges to 2030

There is an imperative for manufacturers to upskill current workers. As robot programming becomes easier and as robot suppliers and integrators move to 'out of the box' solutions for simple applications, manufacturing operators can be trained to use and supervise robots and production cells. Many of them will find themselves supervising a number of different cells at one time.

As we have seen from the five automation scenarios in this paper, the digitization of the production process creates opportunities for performance and productivity improvements across the entire supply chain. To take advantage of those opportunities, technicians, engineers, and production managers will increasingly need high levels of digital literacy – and across a wider range of systems than in the past. As communications protocols and semantic frameworks develop, the complexity of working with many different machine and application programming languages will decrease, but all three job profiles will require an ability to analyze and respond to data from different sources. Indeed, consultancy McKinsey predicts that by 2030, manufacturing workers will spend almost 60% more of their time using technical skills and around 40% less using physical and manual skills<sup>5</sup>.

Manufacturers are faced with the challenge of acquiring new skills while still preserving expertise in legacy production systems and processes which will be around for many years to come. Upskilling an existing, experienced workforce is therefore key and manufacturers will need to map out pathways for achieving this. Larger manufacturers may be able to institute and manage proprietary skills training programs. Small-to-medium-sized manufacturers may need to pool requirements and work with external providers. Either way, it will be important for manufacturers to work closely with education institutes to ensure curricula are matched to skills requirements.

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#### PROMOTING THE BENEFITS OF A CAREER IN MANUFACTURING

Attracting the next generation of manufacturing workers will require an effort from manufacturers, education institutes and governments to promote the benefits of a manufacturing career at the forefront of technology development to young people considering a career path.

Policy makers have an important role to play in ensuring that the educational infrastructure needed for skills development is in place and that workers are able to access it. This may include providing financial and other incentives to manufacturers and to workers for providing and attending skills training.

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<sup>5</sup> Skill Shift: Automation and The Future of the Workforce, McKinsey Global Institute 2018

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## CONCLUSION

Already for decades, robots have proved their worth on the production floor, taking on dangerous tasks and providing a level of precision impossible for humans. Connecting robots into more advanced automation strategies offers new opportunities for increased precision, performance optimization, accuracy in planning, and cost reduction – particularly in relation to preventive maintenance. Rapid advances in grippers, sensors and vision technologies are expanding the range of tasks that robots can perform, with digitalization increasing accuracy and efficiency through performance feedback. The main hurdle to full automation strategies is the integration overhead between machines and software applications in the production process. However, we can expect this overhead to significantly reduce as programming interfaces become more intuitive and communications protocols and semantic frameworks enable more seamless communication between systems. SMEs may need guidance in assessing the right point of entry into a networked automation strategy. However, companies of all sizes must start to assess their skills requirements and map a skills development and acquisition pathway to ensure they are resourced to derive full benefit from the possibilities offered by connected robots and more extensive automation strategies.

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## CASE STUDIES:

Kamstrup / MiR autonomous mobile robots <https://ifr.org/case-studies/service-robots/the-autonomous-way-to-industry-4.0>)

Silhouette <https://ifr.org/case-studies/industrial-robots/perfect-vision>

KUKA Augsburg plant <https://ifr.org/case-studies/industrial-robots/robots-are-us>

Robeteco <https://ifr.org/case-studies/industrial-robots/an-interconnected-arc-welding-robot-solution-fit-for-industry-4.0>

KOKI <https://ifr.org/case-studies/industrial-robots/abb-ability-connected-services-helps-keep-koki-in-high-gear>

KUKA Jeep Wrangler <https://www.kuka.com/en-de/industries/solutions-database/2016/04/kuka-toledo-production-operations>

Creating Revolutions <https://ifr.org/case-studies/industrial-robots/challenges-in-creating-revolutions>

Great Plains Manufacturing <https://ifr.org/case-studies/industrial-robots/virtual-solutions-for-complex-agricultural-equipment>

Hirebotics <https://blog.hirebotics.com/introducing-botx-your-for-hire-robotic-welder>

Abagy <https://ifr.org/case-studies/industrial-robots/increase-in-small-batch-production-productivity-using-robots>

KUKA SmartFactory as a Service <https://www.kuka.com/en-de/future-production/industrie-4-0/smartfactory-as-a-service,-c,-home>

Janssen-Ortho [https://www.robotics.org/content-detail.cfm?content\\_id=296](https://www.robotics.org/content-detail.cfm?content_id=296)

Stäubli autonomous mobile robots <https://ifr.org/case-studies/collaborative-robots/helmo-mobile-robot-system-on-the-connector-assembly-line>

University of Buffalo robotic gripper <http://www.buffalo.edu/news/releases/2019/09/017.html>

Technical University of Munich robotic skin <https://www.tum.de/nc/en/about-tum/news/press-releases/details/35732/>

VIDEO LINKS:

Goldbach Kirchner: <https://youtu.be/6-MsE5oRicY>

KUKA Jeep Wranger: <https://youtu.be/7Jma-5rzis0>

KUKA Digital Twin: <https://youtu.be/fg1oTMAFowU>

Stäubli mobile robots: <https://www.youtube.com/embed/iYEdGx-94xY?feature=oembed>

ABB pick and place: <https://youtu.be/wg8YYuLLoM0>

TUM Artificial Skin: <https://www.youtube.com/watch?v=M-Y2HW6JcGI>