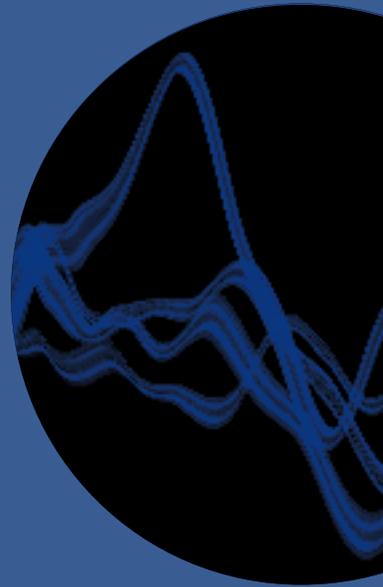
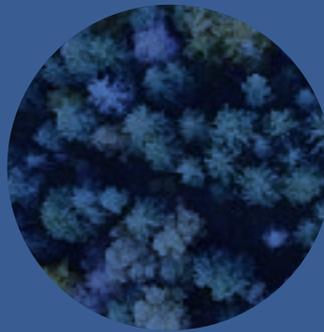


Review

ERICSSON
TECHNOLOGY



5G AND INDUSTRIAL AUTOMATION



ERICSSON

Industrial automation enabled by

ROBOTICS, MACHINE INTELLIGENCE AND 5G

The emergent “fourth industrial revolution” will have a profound impact on both industry and society in the years ahead. Robotics, machine intelligence and 5G networks in particular will play major roles in this revolution by enabling ever higher levels of automation for production processes.

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The combination of robotics, machine intelligence and 5G networks will provide a wealth of opportunities for cooperation between robots and humans that can improve productivity and speed up the delivery of services for citizens.

■ Most analysts agree that smart manufacturing is likely to represent the biggest portion of market revenues for the Internet of Things (IoT) in the near future. Smart manufacturing is dependent on industrial automation, which relies heavily on the use of robots and machine intelligence. The factory of the future will be realized through the digitization of the manufacturing process and plants, which will be enabled by 5G networks and

all their building blocks. As a leader in 5G infrastructure – including cloud technologies, big data analytics and IT capabilities – Ericsson is well placed to take a leading role in this transformation and partner with industries to develop solutions that are tailored to fit their needs. Our fruitful collaboration with Comau, a world leader in industrial automation, and the Sant’Anna School of Advanced Studies, a highly regarded academic center of excellence in robotics, is the first step.

Understanding Industry 4.0

The German government launched the Industry 4.0 initiative in 2011 to foster the competitiveness of its industries for the decades to come. Seven years later, we can see that leading industries are

implementing breathtakingly innovative concepts as a result. For example, the 2017 Hannover Industry Fair showcased several innovations such as collaborative robots, smart materials, adaptive production, and self-learning systems, which were on their way out of labs and onto real production shop floors. German industry is committed to making Industry 4.0 the new benchmark in production efficiency, with plans to invest EUR 40 billion annually until 2020.

The strength of the Industry 4.0 initiative lies in the fact that it has been a joint effort of government, universities and industries since day one. Together they foster growth, using fewer resources, reducing risk and boosting productivity and flexibility. The initiative has developed many groundbreaking concepts that have resulted in a quantum leap in the networking of humans, machines, robots and products. Manufacturing leaders are combining information technology and operations technology

to create value in entirely new ways. These cyber-physical production lines are cutting-edge today, but will be the standard of tomorrow. By the end of 2017, Industry 4.0 had grown into a truly international initiative with contributors and users all over the globe, changing the basis of competition in production automation for good.

Guaranteed real-time communication between humans, robots, factory logistics and products is a fundamental prerequisite of the Industry 4.0 concept. Real-time data will generate transparency and actionable insights, while edge analytics will help reap maximum machine value and optimize production. All of the above concepts clearly require standardization and (data) security. With its standardized networking capabilities, built-in security, guaranteed grades of service, as well as distributed cloud and network slicing concepts, 5G is a perfect tool for advanced industries that want to take advantage of digital transformation.

Terms and abbreviations

IoT – Internet of Things | **OEM** – original equipment manufacturer | **PLC** – programmable logic controller |
PoC – proof of concept

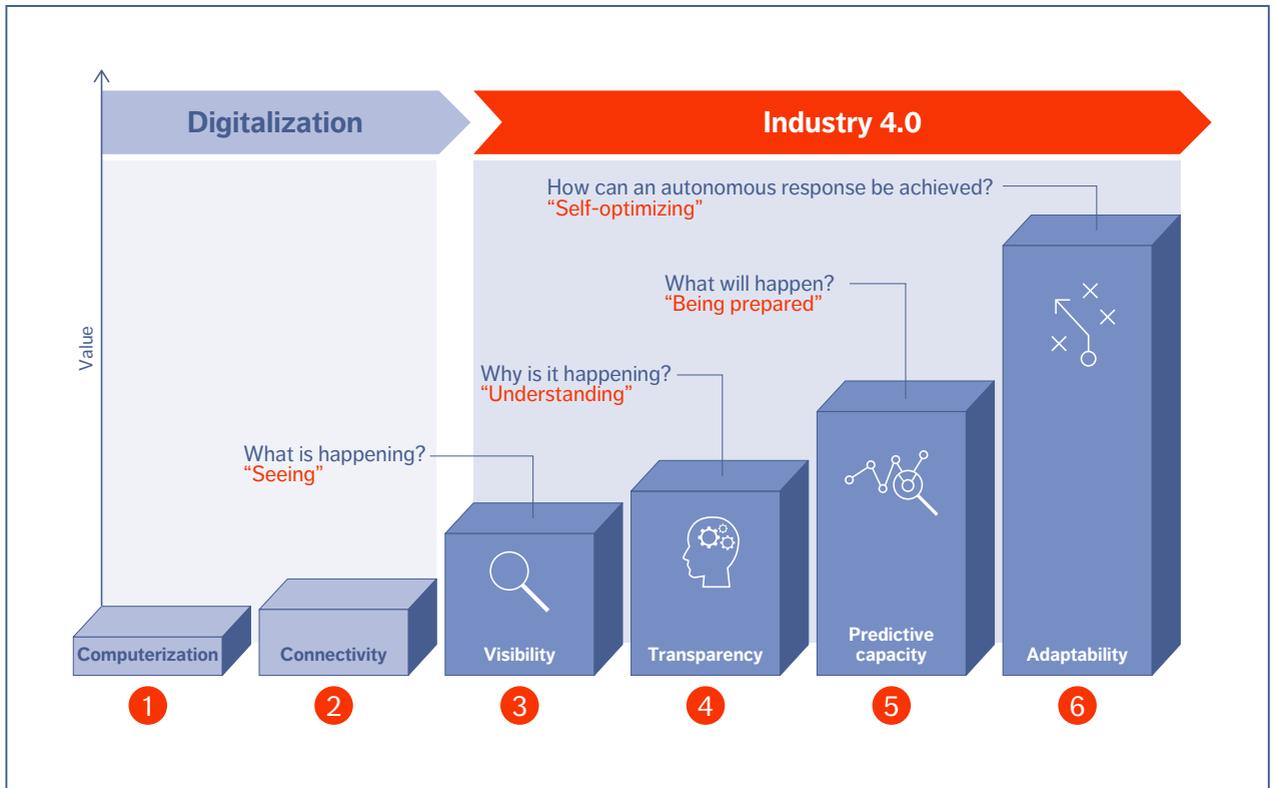


Figure 1: The Industry 4.0 maturity index

Figure 1 shows the development path that allows industries to evolve step-by-step toward the full Industry 4.0 transformation process [1]. It consists of six stages with each building on the previous one. Each stage includes a description of the necessary capabilities and the consequent benefit for companies. Connectivity is the second stage, immediately after computerization, and it enables the ones that follow.

The transformation of manufacturing

The transformation of the manufacturing industry [2] from mass production to mass customization through digitized factory operations is illustrated in Figure 2. Although the industrial revolution at

the end of the 18th century led to the advent of mechanization, industrial production remained at an artisanal level until the 20th century, when true mass production began with automotive manufacturing. Assembly-line production became a paradigm for mass production and had far-reaching impacts on society. In fact, what is called "Fordism" in social science describes an economic and social system based on industrialized, standardized mass production and mass consumption. The key concept is the manufacturing of standardized products in huge volumes, using special-purpose machinery and, at that time, unskilled labor. Although Fordism was a method used to improve productivity in the

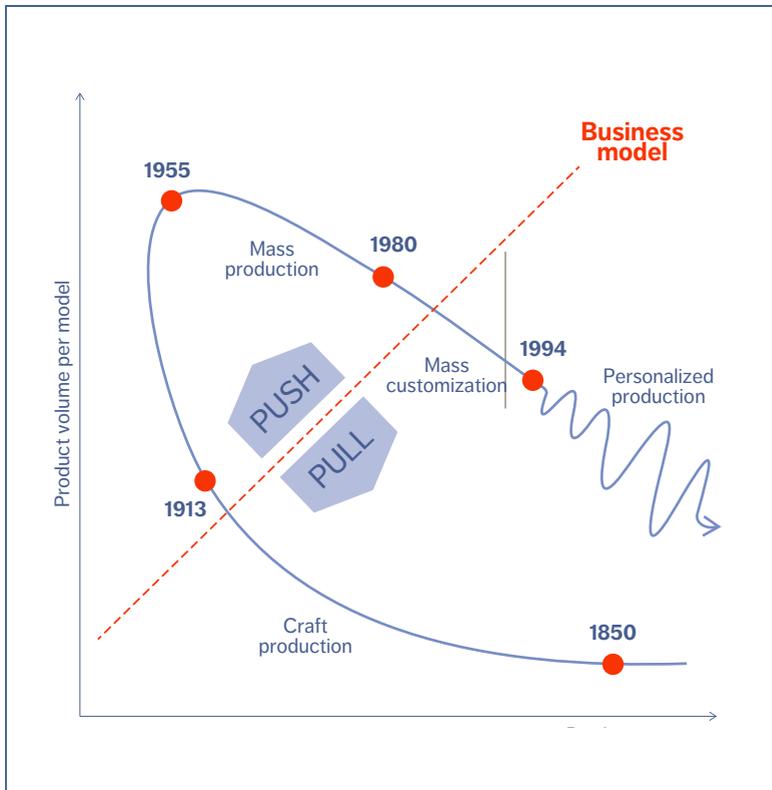


Figure 2: Evolution of the production paradigm toward Industry 4.0

automotive industry, the principle applied to any kind of manufacturing process.

In recent decades, there has been an increasing need for customization to allow manufacturers to differentiate from competitors and broaden their product offerings. In a way, the product variety stimulates the consumer market, provided that manufacturing costs are kept low enough to have sustainable margins. The final step of the trend is “personalized production.” Based on the Industry 4.0 paradigm and leveraging on new technologies across the complete value chain from suppliers to customers, it is possible to significantly increase the flexibility of the production line, and shorten production lead times. This leads to more affordable

and scalable customization.

The trend for “personal” product customization is growing, along with a preference for online purchasing. Therefore, current processes need to be adapted to be more flexible and customizable, while still protecting initial investments in the production line. High speed wireless infrastructure such as 5G networks can facilitate the modification (required by customized products) of OEM machines with minimal impact.

The digitization of factory operations enabled by IoT technologies promises to make that happen. Digital tools will be able to monitor and control all tools of production, collecting data from thousands of sensors to create a digital image of the product

being realized, usually referred to as a “digital shadow.” Once a digital shadow has been created for a physical product and bears its specific DNA, it is possible to manufacture that product more efficiently and with a higher degree of quality in the digitized production facility. In this way, it is possible to optimize the manufacturing process, detect quality issues early to prevent defects at the end of the production line and make continuous improvements. It is also possible to carry out predictive and preventive maintenance.

The combination of wireless sensors and high-capacity communication networks such as 4G and 5G plays a key role in this context, by enabling data collection from shop-floor level (production lines) and data transfer to cloud systems for continuous monitoring and control.

Virtual controllers that combine control, data logging and alarms into a cloud platform also help the process of digitization and save costs, panel space and maintenance activities compared to traditional systems. They can control a wide variety of production tools and are also a solution for remotely located machines and portable systems that can run standalone.

Key automation trends

Making good products is important for the success of a manufacturer, but it is not enough to be profitable and to sustain business. Production costs must be low enough for a suitable margin. This can be achieved by increasingly improving the efficiency of a manufacturing system. Automation is vital for that. Manufacturing systems require heavy investments and must be designed so that they remain profitable for the long term. If manufacturers are to remain competitive in an ever-changing marketplace, they must continuously improve both products and the production systems. Virtual commissioning is therefore necessary to continuously upgrade a production system with reasonable incremental investments. This requires a virtual (computer-based) environment that can simulate a manufacturing plant.

Virtual commissioning involves a virtual plant and a real controller. The simulated plant model has to be fully defined at the level of sensors and actuators. A major benefit of this is that it replaces the need for real commissioning with real plants and controllers, which is very expensive and time consuming. Instead, virtual commissioning allows for the identification of possible design defects and operational mistakes before investments are made in physical plant infrastructure. The digitization of the manufacturing plant allows its designers to enhance the efficiency of the production process, increase the automation density and optimize the handling of materials necessary to realize the products.

Digitization allows the introduction of the “just in sequence” concept, where components and parts arrive at a production line according to schedule, right in time for assembly. In addition, it can enable a truly lean enterprise, allowing for a much richer understanding of the customer demand and the immediate sharing of the demand data throughout complex supply chains and networks. Smart factories can produce at a faster rate with less waste. Industry 4.0 enables a much quicker flow of customized products. It has the potential to radically reduce inventories throughout the supply chain.

Finally, it is important to highlight the “zero-defect” concept. In some cases, relevant percentages of production can end up as scrap because of manufacturing defects. A “zero-defect” process requires automatic monitoring of the entire manufacturing process, from the quality of raw materials entering the production line to variances in tools and processes during each production run. As a closed-loop system, controllers are immediately alerted to any defects, and changes can be made immediately to eliminate the source of the problem. The approach has the potential to dramatically reduce scrap by detecting production errors instantly, eliminating the propagation of defects along the process stages. The manufacturing system could include knowledge-based loops, providing information and feedback to other levels of the manufacturing chain, to minimize failures via continuous optimization of the production process

and the manufacturing system.

The factory of the future could consist of flexible production islands, able to realize different types of building blocks, without the rigidity of conveyors and with truly standard robotized working stations. As a result, agile shuttling robots are needed to transfer assembled blocks from one production island to another without the need for physical or virtual rails.

Digital factory elements and the role of 5G

The virtual plant concept makes it possible to carry out global system design, simulation, verification and physical mapping at a much lower cost than what is possible with a physical plant. To do so, however, the virtual plant requires new kinds of robots with the ability to increase the flexibility of the global production system. These robots need to be multipurpose and intelligent enough to adapt, communicate and interact with each other and with humans, based on a remote control that can globally manage a complete set of robot systems.

High-quality wireless connectivity is essential to the virtual plant concept. Wired connectivity, with its complex cabling, would not be feasible in this type of ever-changing environment due to the fact that cable upgrading entails high operational expenditure. The wireless connectivity must connect all physical elements of a production plant with machine (computing) elements that are able to collect and process huge amounts of data and/or with a cloud that is responsible for those operations. Communications among all these elements must work in a challenging environment characterized by electromagnetic interferences, and distributed over a large area that could span several buildings. While LTE connectivity is robust and capable enough to cope with that environment today, stringent latency requirements will soon demand 5G connectivity.

Once a huge amount of data has been collected through the wireless connectivity, it is necessary to use new methods to handle, process and transform it into a format that can be used by humans or machines or both, and to tap into the potential of

cloud computing.

Big data and analytics systems are therefore essential in the digital factory. Eventually, a cyber-physical system will be needed to handle the complex production process, consisting of IT systems built around machines, storage systems and supplies. All the above leads to further efficiencies in the factory, by allowing preventive and predictive maintenance that reduces the time the plant is off-service, minimizing production delays and avoiding faults. One interesting effect of the efficiency boost is the reduced energy consumption. Process reengineering is something that will be done at a lower cost than today.

The challenge of connecting robots

A previous article in Ericsson Technology Review [3] explained the benefit of cloud robotics for various areas of industry (manufacturing, agriculture and transportation) in different logistics contexts such as harbors and hospitals. The rising level of intelligence in robots allows them to adapt to changing conditions, which is positive for development but significantly increases their complexity. Connecting robots and placing this complexity (intelligence) in a cloud will make it possible for affordable, minimal-infrastructure smart robot systems with unlimited computing capacity to evolve. As partners in the “5G for Italy” program, Ericsson, the Sant’Anna School of Advanced Studies, Comau and Zucchetti Centro Sistemi have been carrying out research together in these areas for the past three years.

The current industrial control systems architecture has provided a stable, secure, and robust platform for the past 25 years. But these legacy systems are reaching end of life in many industrial applications such as robotized cells, and ongoing maintenance, and updates are becoming complicated and expensive. In addition, legacy equipment was not built to ensure effective data access within these systems, which severely limits their potential for remote monitoring and control.

High-speed communication networks, wireless



Figure 3: Experimenting with cloud robotics in Comau's industrial automation lab in Turin, Italy

infrastructure and cloud computing technologies make it possible to enrich robotized plants with new relevant capabilities, while reducing costs through cloud technologies. As a result, it is possible to create smarter robots with “brains” (virtual controllers) in the cloud. The “brain” consists of a knowledge base, program path, models, communication support and so on, effectively transferring the intelligence of the controller into a remote virtual controller. This approach offers many benefits, including:

- » on-premises cloud capability that can reside alongside legacy critical infrastructure, allowing for an evolution of legacy services and a platform for new services
- » lower operating expenses as a result of maximizing the performance and capacity of a virtualization platform, which provides high reliability and performance
- » fault tolerance to single and multiple software and hardware faults, with minimal loss of service
- » comprehensive fault management, isolation and recovery
- » high scalability and performance.

At the outset, 4G systems and Wi-Fi will be used to provide cloud robotics with the necessary connectivity, but 5G is the target technology truly capable of delivering the performance needed to support the applications of the future.

The proof of concept (PoC) that Ericsson, Comau and TIM (Telecom Italia S.p.A.) have realized together is a relevant example. Illustrated in *Figure 3*, the PoC consists of a working cell with two robots and a conveyor. The first robot is a manipulator that picks an object and places it in front of the second robot, which emulates soldering using a welding gun. The final object is then placed by the manipulator on the conveyor to send it to the next work cell. In this PoC, we have moved the control logic that drives the working station responsible for the concurrent actions of the two robots and the conveyor. It would normally reside in a control cabinet referred to as a station PLC (programmable logic controller), but in our PoC we have moved it to a cloud platform. Moving a relevant part of the control to the cloud enables the virtualization of those functionalities that can run as virtual machines on general purpose hardware.

We used an indoor LTE network installation to connect the elements of the working cell with the cloud server, which was possible because the LTE connectivity ensures a few tens of milliseconds of round trip latency. As shown in *Figure 4*, the next step will be to move the control functionalities that reside in each robot controller – the task planner, trajectory planner and inverse kinematics – to the cloud as well. That step, requiring a latency of the order of 5ms, requires 5G technology. The last step would be to move the control loop of the robot into the cloud as well.

This PoC represents a key element of the factory of the future, allowing easier implementation of new

control features, avoiding the need for new PLC hardware when new actuators are deployed, and permitting the deployment of a different level of control functions on the same platform: factory, cell, actuator level. Cooperative device control is also possible.

Cooperation between humans and robots

One of the most interesting aspects of the fourth industrial revolution is the emergence of human-robot cooperation. The present and future challenge is to develop robots that can support human workers in a meaningful way to perform manipulation and assembly tasks according to a

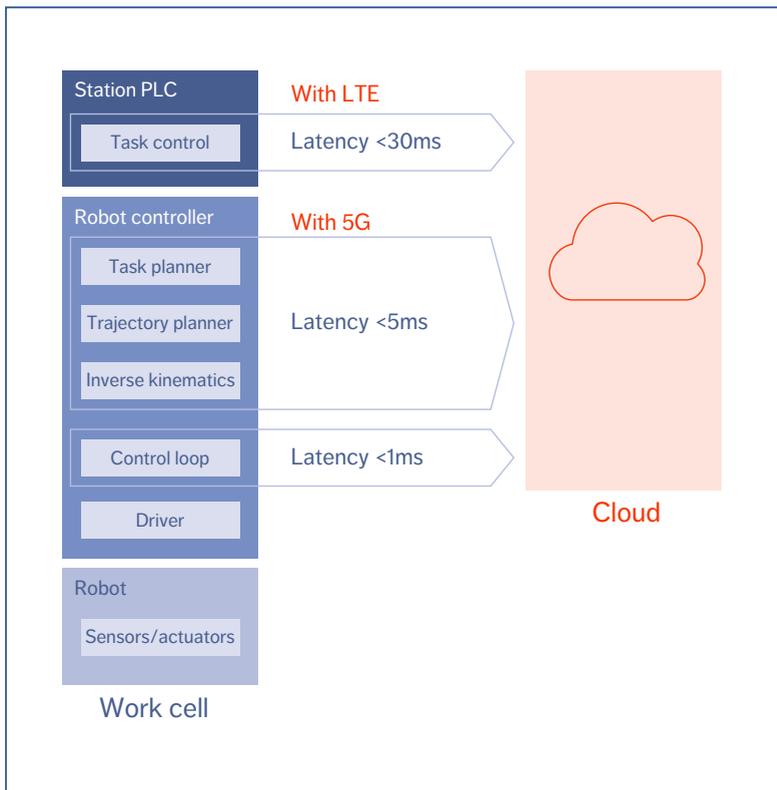


Figure 4: Virtualization of control in the cloud: steps toward true cloud robotics enabled by 5G

ROBOT-HUMAN COOPERATION IN THE FACTORY OF THE FUTURE WILL MAKE COMPLEX DECISION-MAKING ADVANCEMENTS POSSIBLE

production program. A robot that works close to a human worker must interact safely and be able to ‘understand’ and interpret direct user commands and support the worker in executing different actions.

Collaborative robotics is a novel paradigm of human-robot cooperation that is based on lightweight and flexible robots that are safe, smart, and easy to program, and are intended to operate in close symbiosis with human workers. Compared with the previous generation of robots, collaborative robots require sensory systems to detect and prevent collisions and impacts, as well as human-robot interfaces to understand and interpret human intentions. For these reasons, massive efforts in robotics and automation research are dedicated to the development of sensory skins and proximity sensors, and to the design of novel interfaces that enable different kinds of commands from the user to the robot.

Robot-human cooperation in the factory of the future will make complex decision-making advancements possible. For example, collaborative robots can help humans by:

- » evaluating complex realities and providing synthesized and understandable representations that enable better decision making
- » helping them to understand risks in advance and thereby reduce the probability of faults or fatalities
- » making time-sensitive decisions when a human is not available to do so.

Conclusion

Cooperation between humans and intelligent machines is a new reality that will have a profound effect on both industry and society in the years ahead. Already today, it is possible to leverage a combination of human wisdom and intuition together with the strong elaboration capabilities of artificial intelligence, artificial learning and thinking, to create solutions that provide a high level of industrial automation. The next step, the factory of the future, will be realized through the digitization of the manufacturing process and plants, which will be enabled by 5G networks and all their building blocks.

As a leader in 5G infrastructure, including cloud technologies, big data analytics and IT capabilities, Ericsson is committed to playing a leading role in this transformation. The first results from our cooperation with Comau and the Sant’Anna School of Advanced Studies are very encouraging, and suggest that we are in a good position to be a key partner for many industries in the years to come. *

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Further reading

- » **Ericsson white paper, 5G Systems, January 2017, available at:** <https://www.ericsson.com/assets/local/publications/white-papers/wp-5g-systems.pdf>
- » **Ericsson white paper, 5G Radio Access, April 2016, available at:** <https://www.ericsson.com/assets/local/publications/white-papers/wp-5g.pdf>

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The authors wish to acknowledge Marzio Puleri and Giulio Bottari at Ericsson Research and Guido Rumiano and Pietro Cultrona at Comau for their valuable contributions to this article.



ISSN 0014-0171
284 23-3312 | Uen

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