Capgemini engineering

REACHING A HIGHER LEVEL OF INDUSTRIAL PERFORMANCE

How Industry 4.0 capabilities can augment Lean Sigma practices

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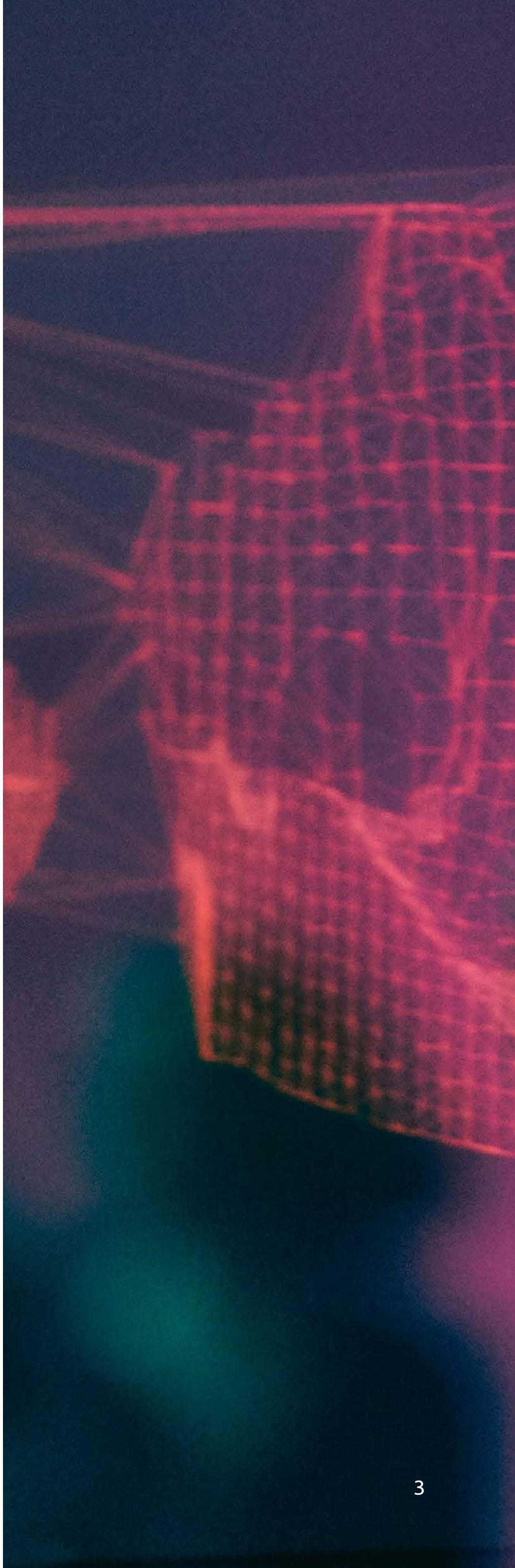
Executive summary

Three decades ago, Six Sigma and Lean Manufacturing ushered in an industrial revolution that focused on improving product and process quality, boosting productivity, and reducing waste and inefficiency. It began in the automotive industry but rapidly spread to all sectors, including aerospace, industrial, and life sciences.

A decade ago, the German government formally introduced Industry 4.0. It was a new industrial revolution focused on harnessing emerging digital technologies (such as artificial intelligence, machine learning, robotics, and the Internet of Things) that leverage big data so manufacturers could react quickly to improve processes and create innovative new products.

Lean Six Sigma and Industry 4.0 are complementary. They both embrace constant improvement, innovation, high quality, and zero defects. Today's challenge is to meld the two philosophies into a single philosophy that delivers operational excellence as well as quality products and services – both physical and digital – to delight the customer.



Introduction: from Lean Sigma to Industry 4.0

Manufacturing companies worldwide have applied the Lean Six Sigma methodology (or Lean Sigma) for more than three decades, with the objective to improve performance by systematically removing waste and reducing variation.

Lean Sigma is a synergized managerial concept of Lean and Six Sigma. Lean traditionally focuses on the elimination of the seven kinds of waste, or Muda, classified as:

1. Defects
2. Overproduction
3. Waiting
4. Transportation
5. Inventory
6. Motion
7. Extra processing

Six Sigma (6σ) seeks to improve the quality of process outputs by identifying and removing the causes of defects and errors, and minimizing variability in manufacturing and business processes. It was introduced by American engineer Bill Smith while working at Motorola in 1986. A Six Sigma process is one in which 99.99966% of all opportunities to produce some feature of a part are statistically expected to be free of defects. Jack Welch made it central to his business strategy at General Electric in 1995[1].

1. Wikipedia, 'Six Sigma', available from: https://en.wikipedia.org/wiki/Six_Sigma

Lean Manufacturing traces its origins to the Toyota Production System (TPS) in 1930. However, the term Lean was first coined in 1988 by John Krafcik, CEO of Waymo, who in the 1980s worked for New United Motor Manufacturing, Inc., a Toyota-GM joint venture, and then at the International Motor Vehicle Program at MIT as a lean production researcher and consultant[2]. His research was made famous in the 1991 book The Machine That Changed the World by James Womack, Daniel Jones, and Daniel Roos[3].

Lean Manufacturing consists of five principles[4]:

1. Precisely specify value for each product
2. Identify the value stream for each product
3. Make value flow without interruptions
4. Let the customer pull value from the producer
5. Pursue perfection

Based on numerous examples collected over five years of research, Womack and Jones asserted that a manufacturing company that goes from batch-and-queue production to continuous flow production will:

1. Improve productivity by 100%
2. Reduce inventory and production times by 90%
3. Reduce process errors, waste, and time-to-market by 50%
4. Provide a wider variety of products at a modest additional cost
5. Get rid of plant and equipment with a modest, or even negative, investment

More recently, the fourth industrial revolution, or Industry 4.0, has paved the way for disruptive advancements in manufacturing processes. Introduced in 2011 by the German government, Industry 4.0 is a paradigm that includes a broad set of new technologies that hold enormous potential for manufacturing organizations. The application of these complementary technologies, when assembled, results in a transformation akin to a revolution.

Borrowing from Lean Sigma terminology, two philosophies capture the opportunity of Industry 4.0: Kaizen and Kaikaku. Kaizen means continuous change and improvement, which is central to the Lean Sigma philosophy. Kaikaku means radical change and innovation, which is embodied in Industry 4.0.

This paper shares insights and examples of how Industry 4.0 can augment Lean Sigma practices and contribute to the principles of operational excellence by elevating companies to a higher level of industrial performance.

2. Wikipedia, 'John Krafcik', available from: https://en.wikipedia.org/wiki/John_Krafcik

3. Wikipedia, 'The Machine that Changed the World', available from: https://en.wikipedia.org/wiki/The_Machine_That_Changed_the_World_(book)

4. Journal of the Operational Research Society, 'Lean Thinking: Banish Waste and Create Wealth in Your Corporation', 1996, available from: https://www.researchgate.net/publication/200657172_Lean_Thinking_Banish_Waste_and_Create_Wealth_in_Your_Corporation

The limits of Lean Sigma

For two decades, I worked in manufacturing operations optimization. First, as a continuous improvement leader in the automotive industry, then as a consultant, advising companies and implementing changes on the shop floor using Lean Sigma principles.

I received my Lean Manufacturing training from Shingijutsu, a small company of experienced professionals with impressive manufacturing operations expertise. The founding team at Shingijutsu were former pupils of Taiichi Ohno, the father or "Sensei" of TPS.

To improve processes on the shop floor, we used only paper, purposefully avoiding digital technology. We were taught that if production leaders spend too much time in front of a PC, they lose contact with the "Gemba", the place where value is created on the shop floor, where managers need to spend their time.

We implemented Lean transformations through the execution of Kaizen Week, which required concrete results in five-day workshops on the shop floor with a multidisciplinary team that included operators, supervisors, and indirect labor. We focused on process, people, and reorganization, following Lean principles and tools with no digital technology at all.

Later, when we began to combine Lean with Six Sigma, we used Minitab to take advantage of statistical software to detect trends and glean valuable insights from the data.

Lean Sigma principles and tools are still valid, but they have limitations. Here are a few examples:

- Implementing the Plan, Do, Check, Act (PDCA) methodology is still a best practice. However, taking a deep dive into a Root Cause Analysis (RCA), Gemba Genbutsu, and the Five Whys may not be enough to fully understand things that you cannot easily see, such as solving a complex issue in a pharmaceutical batch process

- The Define, Measure, Analyze, Improve, and Check (DMAIC) cycle is a very well-structured method, but chronicling the entire life cycle process from data collection through standardization takes a long time

- The Total Productive Maintenance (TPM) philosophy is excellent. Still, preventive issues using nothing but an operator's five senses and manual visual inspection is not enough to achieve zero breakdowns or defects

- Kanban pull with physical cards, visual management with printed paper boards, and Production Process Preparation (3P) with physical mockups all have room for improvement

- Poka-Yoke, a mistake-proofing process philosophy, can be inadequate for reaching zero defects without digital and advanced automation technology

The digital evolution and key enablers of Industry 4.0

The global industrial landscape has changed significantly in recent years. Significant gaps have appeared in Lean Sigma, and Industry 4.0 has gained steam as successive disruptive technologies transform fundamental manufacturing processes. To understand how the technology enablers of Industry 4.0 are changing the world, it is useful to categorize them into four clusters: connectivity, intelligence, human-machine interface (HMI), and automation and robotics. (See Figure 1)

Connectivity is about collecting, transporting, and storing data from the shop floor, including machines, people, and materials. It includes industrial information systems across all layers of the ISA-95 pyramid (PLC, SCADA, MES), ERP integration, smart sensors, Industrial Internet of Things (IIoT) platforms, cybersecurity, 5G, and blockchain.

Intelligence enables relevant insights from the data derived from big data technology, advanced analytics, artificial intelligence, advanced simulation, and machine learning, among others.

HMI enables the interaction of people and machines in real-time through mixed, augmented, and virtual reality (MR, AR, and VR) tools, voice recognition technology, mobile apps, wearables, touch screens, and keyboards.

Automation and robotics include mechanical design, electronic design, collaborative robots (cobots), robotic process automation (RPA), and 3D printing, also known as additive manufacturing.

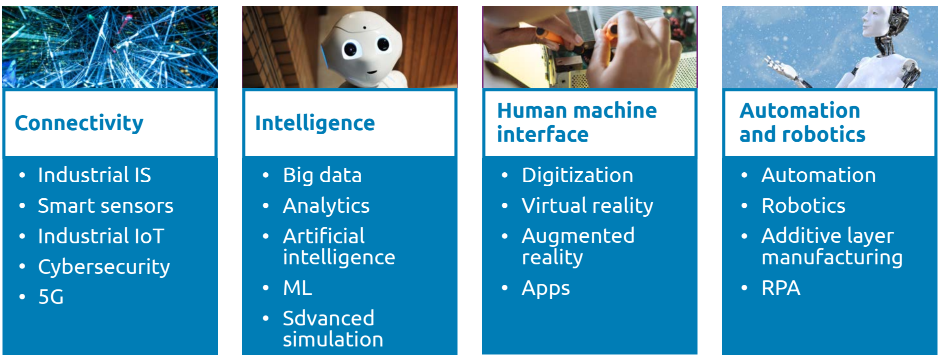


Figure 1: The four technology categories of Industry 4.0
Source: Capgemini Engineering

Industry 4.0 fills the gaps

The question manufacturing companies need to answer today is: how do we fill the gaps in the Lean Sigma methodology by integrating Industry 4.0 technologies?

While there are no easy answers, digital technologies can help overcome most of the limitations detailed above. The solution requires integrating different technologies with human ingenuity, multidisciplinary expertise, and innovative ways to perform the job.

Here are four ways Industry 4.0 can enhance Lean Sigma:

1. Improve the monitoring and control of the operating conditions of manufacturing systems by:

- Automating data collection and improving visibility through the connectivity of systems, people, and machines on the shop floor
- Allowing real-time information to be shared with stakeholders to anticipate problems and speed up the reaction time when issues arise
- Providing more visibility to reveal blind spots and complex processes such as those taking place in a biotech reactor or chemical vessel

2. Improve performance and predictability by:

- Simulating and testing faster, exploring different scenarios for potential changes on the shop floor, optimizing decision making, and improving OPEX and CAPEX utilization
- Detecting the root cause of issues in a few hours or days rather than a few weeks or months
- Using automation to predict possible failures before they occur

3. Digitally assist plant stakeholders by:

- Converging all the updated information they need to perform their jobs in a single interface to maximize productivity, quality, and safety
- Interactively guiding operators through the steps to ensure standardization
- Alerting operators when a mistake is about to be made
- Improving the effectiveness and efficiency of training

4. Automate processes by:

- Transferring the optimal workload from humans to machines in a collaborative way
- Relieving operators from tedious, non-ergonomic activities
- Ensuring precision and stabilizing processes

Digital transformation should be built on a firm foundation based on four criteria:

Technology-driven value creation

Understanding how operations contribute to value creation is critical to identifying opportunities to improve performance. Innovative ideas made possible by new technologies and their applications are essential for imagining and introducing new ways of working.

People-centric

Technology does not enhance performance; it is the people who use the technology that leverage its possibilities to improve efficiency, flexibility, and effectiveness. Humans must always be at the core of any transformation to ensure it aligns with the original Lean Sigma principles.

Innovation-enabled

Technology on its own is just a commodity. It is critical to figure out how to maximize the performance of new technologies to create value and deliver a competitive advantage.

Scale-oriented

Real transformation comes when changes are adopted at scale, transforming the organization and delivering results at the company level. Proof-of-concept projects are necessary to validate assumptions but the goal is the broad roll-out and adoption of new practices and technologies.

Case studies

Below are four real-world examples developed by manufacturing companies, with support from the Capgemini Engineering World Class Center for Advanced Manufacturing, that visualize the value of marrying digital evolution with Lean Sigma principles and tools to improve shop floor operations significantly.

Case #1: enhancing visual management, total productive maintenance, and andon through a smart connected virtual plant

A major aircraft manufacturer demonstrated the benefits of Industry 4.0 technologies that enable a generation of new use cases by creating a virtual replica or digital twin of its plant. The digital twin is connected to a smart IIoT platform that monitors equipment performance. It integrates laser-scanning drones, photogrammetry, CATIA conversion, and modeling. (See Figure 2)

The company digitalized its policy deployment visual management tool – the Safety, Quality, Cost, Delivery, People (SQCDP) panel – to create a real-time digital dashboard with visibility into its primary KPIs, distributed at both the plant and production-area levels. Visualization enables faster reaction times to address shop floor issues. It also improves transparency, data integrity, and communication among plant stakeholders.

It can also be considered an enhanced TPM approach, the way artificial intelligence is applied to sensor data, on top of the existing industrial information systems with an IoT platform. It predicts quality problems and maintenance needs of the Tricept robot before they occur, automatically sending signals via a digital andon. This frees human operators from performing surveillance and visual inspection tasks so they can focus on higher-value operations.

The company also uses digital twin to interactively train operators on repetitive maintenance tasks, one of the pillars of the TPM approach. This application includes an immersive VR solution that improves training effectiveness and saves time.

Case #2: assisting lab technicians through digital 5S, Poka-Yoke, standardization, and one-point lesson tools

A multinational pharmaceutical company implemented a customized digital-assistant interface focused on guiding and assisting lab technicians through their daily tasks. The initiative demonstrates how to reduce cycle time and achieve 100% right-first-time quality control in the quality control lab. (See Figure 3)

The interactive, virtual factory is a digital replica of the real factory. Using digital twin and VR technology, staff gain real-time access to production equipment and performance information to digitally monitor manufacturing lines and interact with systems. Other benefits include immersive high-end training and remote, virtual maintenance of equipment.

Figure 2: Digital twin used to evaluate Industry 4.0 benefits

Source: Capgemini Engineering

Using the digital assistant ensures the lab technician intuitively performs the full procedure, step by step, with direct access to the cross-referenced methods and regulations. Technicians are more efficient, data is secure, time is tracked, and the process complies with company procedures and applicable regulations.

This paperless solution is a digital or electronic standard operating procedure (E-SOP) and integrated the following technologies: augmented reality by projection, artificial vision, industrial information systems connectivity such as a laboratory information management system (LIMS), and laboratory asset tracking such as near-field communications (NFC) and quick response (QR) code.

Behind the foundation of this solution's success are Lean Sigma tools such as 5S, poka-yoke, one point lesson (OPL), and standardization.

Case #3: predicting performance with an augmentation of 3P, value stream mapping (VSM), and spaghetti charts

A composites plant owned by a major aircraft manufacturer needed to ensure that the operating conditions of the business case aligned with its committed rate of ramping up production for the next few years. Management defined and applied a reliable and realistic model of productive operations to identify the initiatives that needed to be put in place to reach the production target with optimal productivity.

The company improved the plant's throughput by applying a quantified decision-making process for the production system topology, including layout, investment, flows, shifts, staffing, etc., built on a simplified digital twin of site manufacturing operations. Advanced simulation leverages advanced stochastic modeling and simulation techniques.

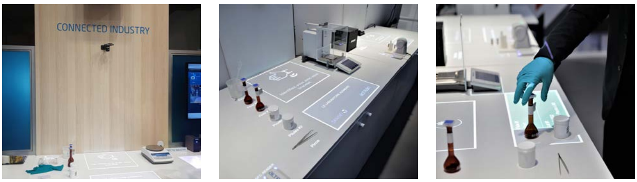
These efforts resulted in the plant saving between 30% and 50% of planned CAPEX and reduced recurrent costs by 20% due to the optimization of both labor and equipment utilization. The advanced simulation-based predictive performance solution is an example of the natural digital evolution of VSM, Toyota 3P methodologies, and spaghetti charts.

Case #4: predictive quality solution enhances the PDCA/DMAIC cycle and problem-solving techniques

An international pharmaceuticals manufacturer had significant manufacturing challenges due to the unpredictability of batch failures, which led to financial losses. To identify the root cause, it performed a multivariate analysis of the system's historical manufacturing data, such as bowl speed, flow rate, and pressure.

In a few weeks, the company identified the cause of the batch failures as system maintenance errors and took measures to correct the mistakes. The estimated financial benefit was approximately €1 million a year.

Identifying the root cause of the batch failures required advanced analytics. It is doubtful that it could have been solved with legacy Lean Sigma tools, such as PDCA, DMAIC, or the Five Whys.



The digital-assisted lab is a standard operating procedure (SOP) platform for creating customized lab setups to guide lab technicians through their daily tasks. Using AR by projection, artificial vision, and other technologies allows lab technicians to perform the SOPs correctly and consistently. Technicians are more efficient, data more secure, and performance is tracked to ensure compliance with procedures and regulations.

Figure 3: Digital-assisted lab reduces cycle time and improves quality

Source: Capgemini Engineering

Other case studies

A medical devices manufacturer was able to design and simulate a complete automated intralogistics process in a virtual greenfield environment that defined the most efficient solution to grow production, increase productivity, and create the technical specifications of the new equipment and its systems. One of the most significant innovations was the introduction of a new generation of intelligent autonomous vehicles (IAVs) that were used to optimize the milk run between the company's production areas.

An international pharmaceuticals manufacturer had assembly lines that it wanted to replicate in different countries. Its challenge was to manage the logistics of training staff and ensure maintenance support at all its facilities worldwide. Also, significant modifications on the assembly lines required a new qualification process. The company experimented with an AR framework for the automatic guidance of the operation and maintenance tasks, including the evolution of one-point lesson (OPL), standardization, and TPM. This ensured a safe, precise, and efficient realization of repetitive and complex operations within the manufacturing environment with relatively no adoption risk. The company enabled a remote assistance solution for experts worldwide, which lowered displacement costs and machine downtime.

A food products manufacturer developed a predictive maintenance solution that included a smart device that predicts potential HVAC problems and repairs them to ensure production could never be scrapped due to environmental issues.

A tier-one aerospace manufacturer implemented an evolution of its 5S system that tracked all assets and materials using location-based services. The solution reduced the time lost having the information in real-time to optimize production scheduling.

A pharmaceutical manufacturer implemented a real-time multivariate analysis (MVA) tool to enable advanced process control. The analysis resulted in significant yield improvements and batch cost savings of more than €1 million.

Augmented reality frameworks shared with pharmaceutical manufacturing plants around the world can ensure consistent training and application of complex, repetitive operations at all locations with virtually no adoption risk. Remote assistance from experts regardless of physical location reduces displacement costs and machine downtime.

Figure 4: Replicating a production line around the world

Source: Capgemini Engineering

Conclusion: the next level of industrial performance

The evolution of digital technology is expanding possibilities. Manufacturers have access to the tools they need to transform their operations and reach the next industrial performance level. Targets such as zero defects, zero unplanned breakdowns, zero accidents, and 100% on-time deliveries are closer than ever before. On top of what Lean Sigma transformation can deliver, new technologies have created the space to double productivity and efficiency, halve the space required for inventory and WIP, halve maintenance costs, increase flexibility, and reach full quality compliance.

Manufacturers that step up to the challenge have the potential to achieve sustainable results and establish a competitive advantage. The Capgemini Engineering World Class Center for Advanced Manufacturing is committed to designing and implementing technology transformations that help meet the challenge.

Appendix: Lean Sigma and technology acronyms and definitions

Lean Sigma

- **Kaikaku –** Radical improvement of an activity to eliminate waste (or Muda), e.g., by reorganizing processing operations for a product. Instead of traveling to and from isolated process villages, the product proceeds through the operations in a single-piece flow in one short space. Kaikaku is also called breakthrough kaizen, flow kaizen, and system kaizen

- **Andon board –** A visual control device in a production area, typically a lighted overhead display, giving the current status of the production system and alerting team members to emerging problems

- **Batch-and-queue –** The mass-production practice of making large lots of a part, then sending the batch to wait in the queue before the next operation in the production process. This process is in contrast to single-piece flow

- **Cycle time –** The time required to complete one cycle of an operation. If cycle time for every operation in a complete process can be reduced to equal takt time, products can be made in single-piece flow

- **Define, measure, analyze, improve, and control (DMAIC) –** A data-driven improvement cycle used to improve, optimize, and stabilize business processes and designs. The DMAIC improvement cycle is the core tool used to drive Six Sigma projects

- **Five Ss (5S) –** Five words beginning with S utilized to create a workplace suited for visual control and lean production. Seiri means to separate needed tools, parts, and instructions from unneeded materials and to remove the latter. Seiton means to neatly arrange and identify parts and tools for ease of use. Seiso means to conduct a clean-up campaign. Seiketsu means to conduct seiri, seiton, and seiso at frequent, indeed daily, intervals to maintain the workplace in perfect condition. And shitsuke means to form the habit of always following the first four Ss

- **Five whys –** Taiichi Ohno's practice of asking "why" five times whenever a problem was encountered to identify the root cause of the problem so that effective countermeasures could be developed and implemented

- **Gemba genbutsu/Genchi genbutsu –** Literally translates to "real location, real thing" and is an important element of the Toyota Production System. The principle is sometimes referred to as "go and see."

It suggests that to truly understand a situation, one needs to observe what is happening at the site where the work actually takes place: the Genba. One definition is collecting facts and data at the actual site of the work or problem

- **Hoshin kanri/policy deployment –** A strategic decision-making tool for a firm's executive team that focuses resources on the critical initiatives necessary to accomplish the firm's business objectives. Using visual matrix diagrams similar to those employed for quality function deployment, three to five key objectives are selected while all others are deselected. The selected objectives are translated into specific projects and deployed down to the implementation level in the firm. Hoshin kanri unifies and aligns resources and establishes clearly measurable targets against which progress toward the key objectives is measured regularly

- **Kaizen –** Continuous, incremental improvement of an activity to create more value with less muda. Other names include point kaizen and process kaizen

- **Kanban –** A small card attached to boxes of parts that regulates pull in the Toyota Production System by signaling upstream production and delivery

- **Milk run –** A routing of a supply or delivery vehicle to make multiple pickups or drop-offs at different locations

- **Muda –** Any activity that consumes resources but creates no value. In Japanese, it translates to futility, uselessness, and wastefulness

- **One-piece flow –** A situation in which products proceed, one complete product at a time, through various operations in design, order-taking, and production, without interruptions, backflows, or scrap, contrasting with batch-and-queue

- **One-point lesson (OPL) –** A simple, visual, and often pointwise description of a task

- **Plan-do-check-act (PDCA) –** An iterative four-step management method used in business to control and continuously improve processes and products

- **Poka-yoke –** A mistake-proofing device or procedure to prevent a defect during order-taking or manufacturing. An order-taking example is a screen for order input developed from traditional ordering patterns that question orders falling outside the pattern. The suspect orders are then examined, often leading to discovering inputting errors or buying based on misinformation. A manufacturing example is a set of photocells in parts containers along an assembly line that prevent components from progressing to the next stage with missing parts. In this case, the poka-yoke is designed to stop the movement of the component to the next station if the light beam has not been broken by the operator's hand in each bin containing a part for the product under assembly at that moment. A poka-yoke is sometimes called a baka-yoke

- **Production preparation process (3P) –** A tool focused on eliminating waste through product and process design

- **Pull –** A system of cascading production and delivery instructions from downstream to upstream activities. The upstream supplier produces nothing until the downstream customer signals a need; the opposite of push. See also Kanban

- **Sensei –** A personal teacher with a mastery of a body of knowledge, in this case, mastery of lean thinking and techniques

- **Spaghetti chart –** A diagram defined as a visual representation using a continuous flow line tracing an item's path or activity through a process

- **Standard work/standardization –** A precise description of each work activity specifying cycle time, takt time, the work sequence of specific tasks, and the minimum inventory of parts on hand needed to conduct the activity

- **Total productive maintenance (TPM) –** A series of methods, originally pioneered by Nippon Denso (now Denso), a member of the Toyota Group, to ensure that every machine in a production process can always perform its required tasks so that production is never interrupted

- **Visual management –** A way to visually communicate expectations, performance, standards, or warnings. An example is an SQCDP board, which stands for Safety, Quality, Costs, Delivery, and People. The board supports periodic meetings to monitor the process and detect emerging problems

- **Value-stream mapping (VSM), also known as material and information-flow mapping –** A method for analyzing the current state and designing a future state for a series of events that take a product or service from the beginning of the specific process until it reaches the customer

Technology

- **Advanced analytics –** The autonomous or semi-autonomous examination of data or content using sophisticated techniques and tools, typically beyond those of traditional business intelligence (BI), to discover deeper insights, make predictions, and generate recommendations

- **Advanced process control (APC) –** Refers to a broad range of techniques and technologies implemented within industrial process control systems. Advanced process controls are usually deployed optionally and in addition to basic process controls, which are designed and built with the process itself to facilitate basic operation, control, and automation requirements. Advanced process controls are typically added subsequently, often over many years, to address particular performance or improvement opportunities in the process

- **Advanced simulation –** The process of modeling a real phenomenon with a set of mathematical formulas. It is essentially a program that allows the user to observe an operation through simulation without performing the operation

- **Artificial intelligence (AI) –** Intelligence demonstrated by machines, unlike the natural intelligence displayed by humans. Any device that perceives its environment and takes actions that maximize its chance of successfully achieving its goals. Colloquially, AI is often used to describe machines or computers that mimic cognitive functions that humans associate with the human mind, such as learning and problem-solving

- **Artificial vision or computer vision –** An interdisciplinary scientific field that deals with how computers can gain high-level understanding from digital images or videos. From the engineering perspective, it seeks to understand and automate tasks that human visual systems can do

- **Augmented reality (AR) –** An interactive experience of a real-world environment where objects in the real world are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory, and olfactory

- **Big data –** A field that develops ways to analyze and systematically extract information from, or otherwise deals with, datasets that are too large or complex to be dealt with by traditional data-processing application software

- **Blockchain –** A system for managing a record of transactions, called blocks, that are linked using cryptography. By design, a blockchain is resistant to modification of its data

- **Collaborative robots (Cobots) –** Robots intended for direct human-robot interaction within a shared space or where humans and robots are in close proximity. Cobot applications contrast with traditional industrial robot applications in which robots are isolated from human contact

- **Cybersecurity –** Protects computer systems and networks from the theft of or damage to hardware, software, and electronic data, as well as from the disruption or misdirection of the services they provide

- **Digital or electronic standard operating procedure (E-SOP) –** A simplified solution for managing and developing workflows

- **5G –** The fifth-generation cellular network technology

- **Human machine interface (HMI) –** An interface that allows humans to interact with machines

- **Intelligent automatic vehicle (IAV) and automated guided vehicle (AGV) –** Portable robots that move along marked lines or wires on the floor or use radio waves, vision cameras, magnets, lasers, etc., for navigation. They are most often used in industrial applications to transport heavy materials around a large industrial building, such as a factory or warehouse

- **ISA-95 –** An international standard of the International Society of Automation for developing an automated interface between enterprise and control systems. This standard has been developed for global manufacturers to be applied in all industries and all sorts of processes, including batch, continuous, and repetitive processes

- **Laboratory information management system (LIMS), also called laboratory information system (LIS) or laboratory management system (LMS) –** A software-based solution with features that support a modern laboratory's operations. Key features include, but are not limited to, workflow and data tracking support, flexible architecture, and data exchange interfaces, which fully support its use in regulated environments

- **Manufacturing execution systems (MES) –** Computerized systems used in manufacturing to track and document the transformation of raw materials to finished goods. MES provides information that helps manufacturing decision makers understand how current conditions on the plant floor can be optimized to improve production output. MES works in real-time to enable the control of multiple production process elements, e.g., inputs, personnel, machines, and support services

- **Minitab –** A statistics package software that automates calculations and the creation of graphs, allowing the user to focus more on the analysis of data and the interpretation of results

- **Multivariate analysis (MVA) –** Based on the principles of multivariate statistics, which involves observation and analysis of more than one statistical outcome variable at a time. Typically, MVA is used to address the situations where multiple measurements are made on each experimental unit, and the relations among these measurements and their structures are important

- **Near-field-communications (NFC) –** A set of communication protocols for communication between two electronic devices over a distance of 4 cm (1.5 in) or less. NFC offers a low-speed connection with a simple setup that can bootstrap more capable wireless connections. NFC devices can act as electronic identity documents and keycards

- **Programmable logic controller (PLC) –** An industrial digital computer that has been ruggedized and adapted to control manufacturing processes, such as assembly lines, robotic devices, or any activity that requires high reliability, ease of programming, and process fault diagnosis

- **Quick response (QR) code –** A type of matrix barcode (or two-dimensional barcode). A barcode is a machine-readable optical label that contains information about the item to which it is attached. In practice, QR codes often contain data for a locator, identifier, or tracker that points to a website or application

- **Robotic process automation (RPA) –** A form of business process automation technology based on metaphorical software robots, artificial intelligence, or digital workers. It is sometimes referred to as software robotics

- **Supervisory control and data acquisition (SCADA) –** A control system architecture comprising computers, networked data communications, and graphical user interfaces (GUIs) for high-level process supervisory management, while also comprising other peripheral devices such as programmable logic controllers (PLCs) and discrete proportional-integral-derivative (PID) controllers to interface with the process, plant, or machinery

- **Smart sensors –** Sensors that collect, process, transfer, and analyze valuable information in different environments

- **3D printing or additive layer manufacturing (ALM) –** The construction of a three-dimensional object from a CAD model or a digital 3D model. It can refer to various processes in which material is deposited, joined, or solidified under computer control to create a three-dimensional object, with materials being added together such as liquid molecules or powder grains being fused, typically layer by layer

- **Virtual reality (VR) –** A simulated experience that can be similar to or completely different from the real world

- **Wearables –** Smart electronic devices such as electronic devices with microcontrollers that are worn close to or on the skin's surface that detect, analyze, and transmit information

About Capgemini Engineering

Capgemini Engineering combines, under one brand, a unique set of strengths from across the Capgemini Group: the world leading engineering and R&D services of Altran – acquired by Capgemini in 2020 – and Capgemini's digital manufacturing expertise. With broad industry knowledge and cutting-edge technologies in digital and software, Capgemini Engineering supports the convergence of the physical and digital worlds. Combined with the capabilities of the rest of the Group, it helps clients to accelerate their journey towards Intelligent Industry. Capgemini Engineering has more than 52,000 engineer and scientist team members in over 30 countries across sectors including aeronautics, automotive, railways, communications, energy, life sciences, semiconductors, software & internet, space & defence, and consumer products.

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