Introduction to Quality 4.0

Course notes

Mihai Dragomir

Diana Alina Blagu

Diana Cristina Dragomir

Denisa Adela Szabo

UTPRESS

Cluj-Napoca, 2022

ISBN 978-606-737-613-5

Mihai DRAGOMIR

Diana Cristina DRAGOMIR

Diana Alina BLAGU

Denisa Adela SZABO

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ISBN 978-606-737-613-5

Editura UTPRESS
Str. Observatorului nr. 34
400775 Cluj-Napoca
Tel.:0264-401.999
e-mail: utpress@biblio.utcluj.ro
http://biblioteca.utcluj.ro/editura

Director: Ing. Dan Colțea

Recenzia: Prof.dr.ing. Călin Neamțu
Conf.dr.ing. Emilia Câmpean

Pregătire format electronic: Gabriela Groza

ISBN 978-606-737-613-5

Foreword

- The e-book **“Introduction to Quality 4.0. Course notes”** is intended for the students at the Technical University of Cluj-Napoca that study topics related to quality engineering and management within study programs in the scientific domains Industrial Engineering, Engineering and Management & Mechatronics and Robotics
- The authors have included in this training material some of the know-how they developed within an Erasmus+ project (“A Customized Education Plan Based on Industry 4.0 Competency Gaps - CEPI 4.0”, project ID: 2019-1-TR01-KA202-077366), factory experiences, consultancy projects, and other practical achievements
- The goal is to present the latest developments in the field of quality as it integrates technologies specific to Industry 4.0 and beyond
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OUTLINE OF ROBOTICS IN INSPECTION

- Introduction
- Robotization in manufacturing
- Digital transformation for robotics
- Robotic inspection systems
  - Machine vision
  - Robots and CMM
  - Collaborative inspection
- Outlook

INTRODUCTION

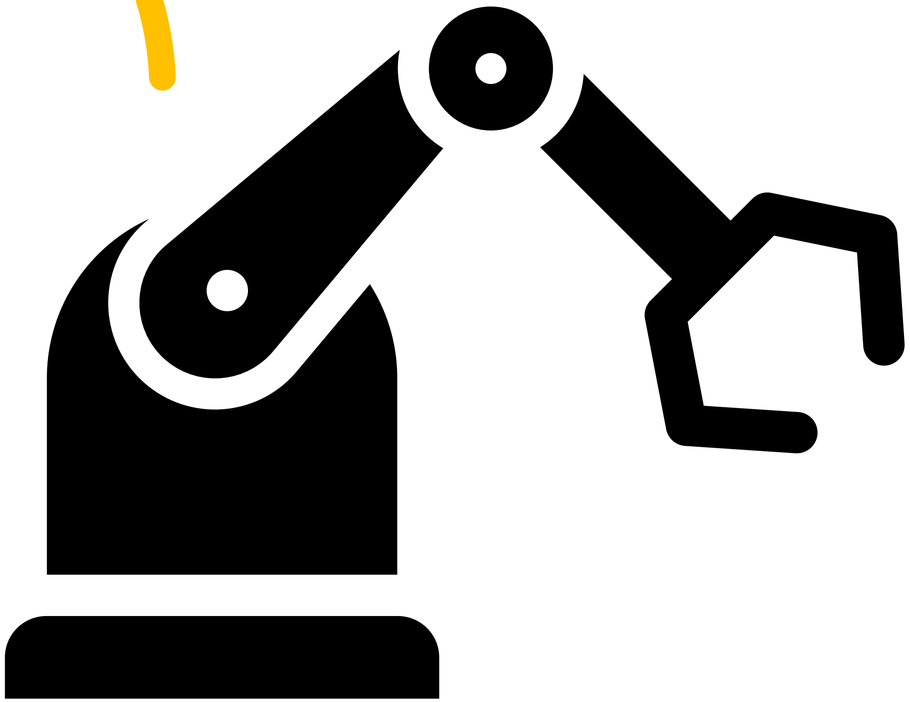
- Robots have been part of the manufacturing industry for over 60 years (since GM's Unimate)
- Robotics, together with IoT and AI are key enabling technologies for Industry 4.0
- Integration of robots into manufacturing processes requires technological transformation & new skills, but also process re-engineering
- Currently, advanced robots are economically viable and have advanced capabilities for decision making and interaction with humans

Introduction

- Developing STEM skills, including building and competing with robots, coding and AI programming is becoming a critical for young people
- Robotics research is focused on optimized manufacturing, besides service and social robots
- Robots are also important for the Quality 4.0 modern approach to QM
- Advances in machine vision, additive manufacturing and metrology can be correlated with robotic quality control

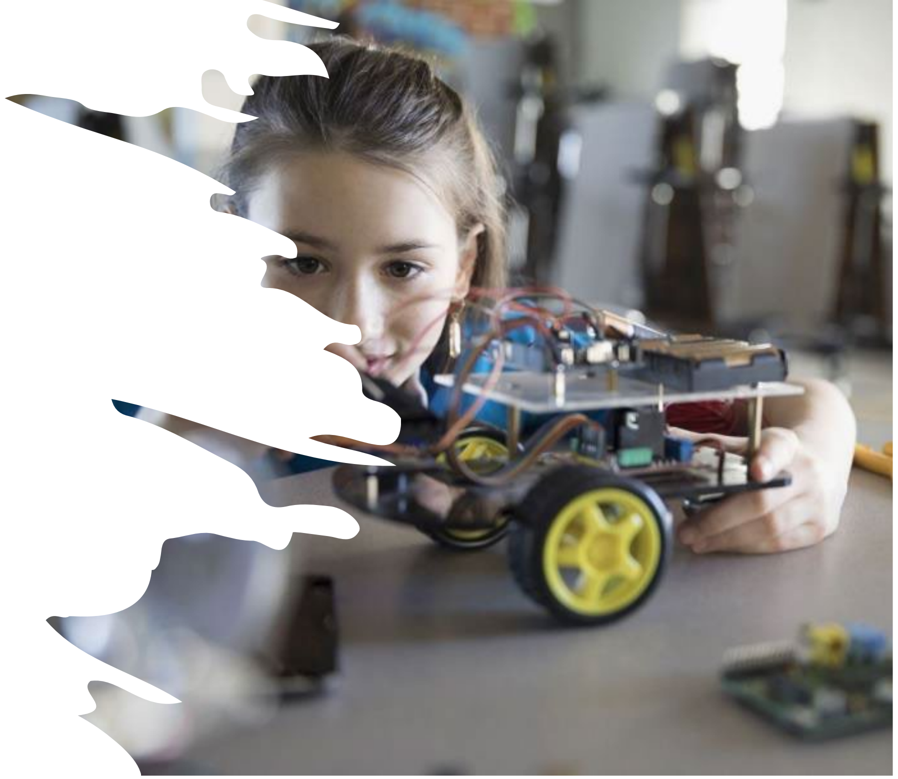
Robotization in manufacturing

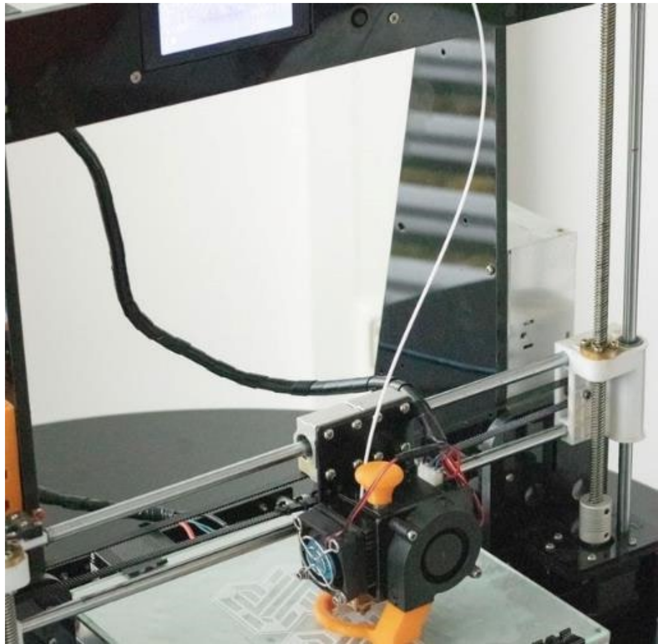
- Processes most adequate for robotization:
  - Machine loading and unloading
  - Palletizing and depalletizing
  - Spot welding (especially in automotive)
  - Spray painting (especially in automotive)
  - Automated storage and retrieval
  - Transport within the facility
  - Quality control (especially video inspection)
- Collaborative robots are becoming common place
- Versatile robots (“dogs”) can also be used



Robotization in manufacturing

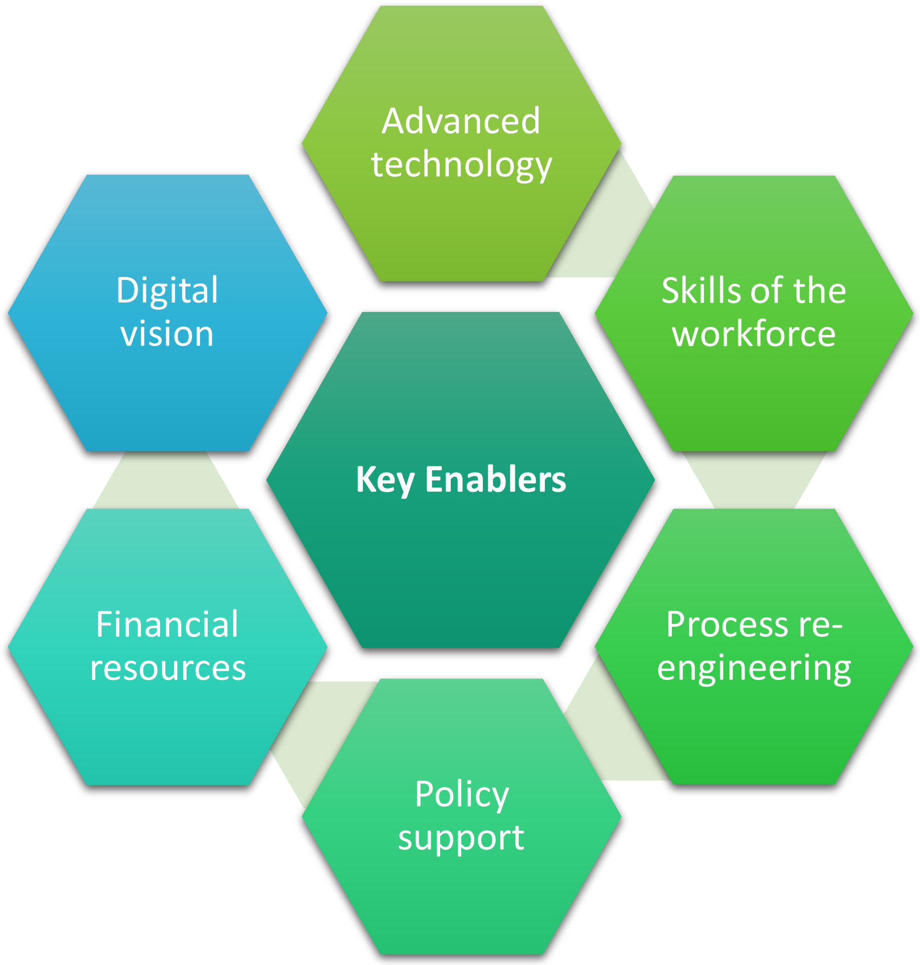
- Most common types of robots in manufacturing
- Serial (articulated arm) robots – working with machines or independently
- SCARA robots (with parallel axes) – for precise operations
- Cartesian robots – for enhanced accessibility in certain spaces
- Autonomous robots – for the ability to move around the facility



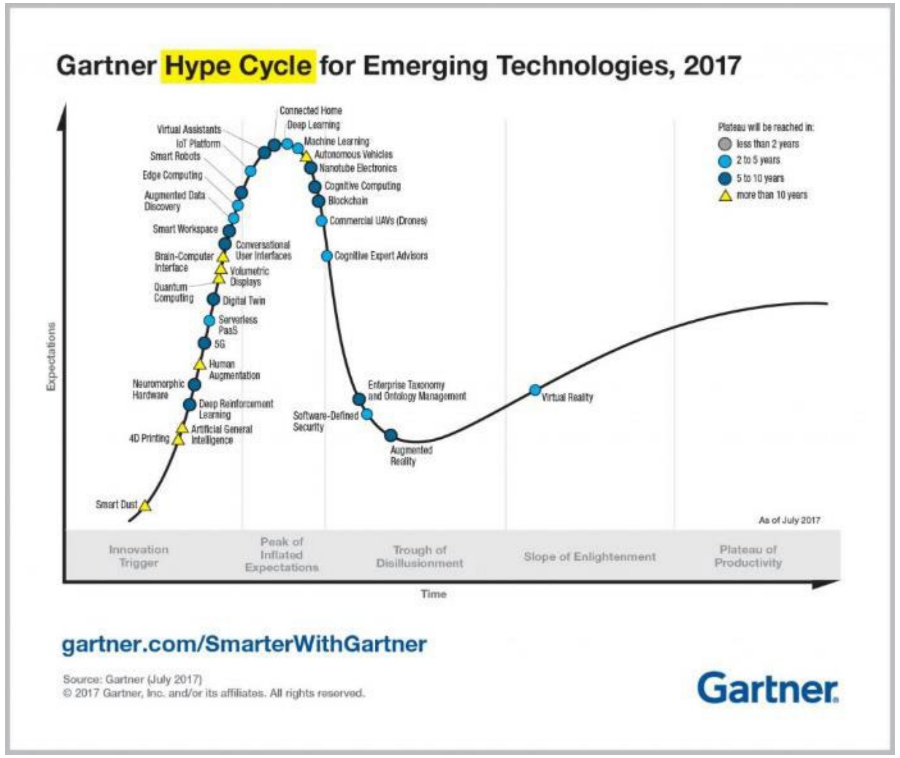


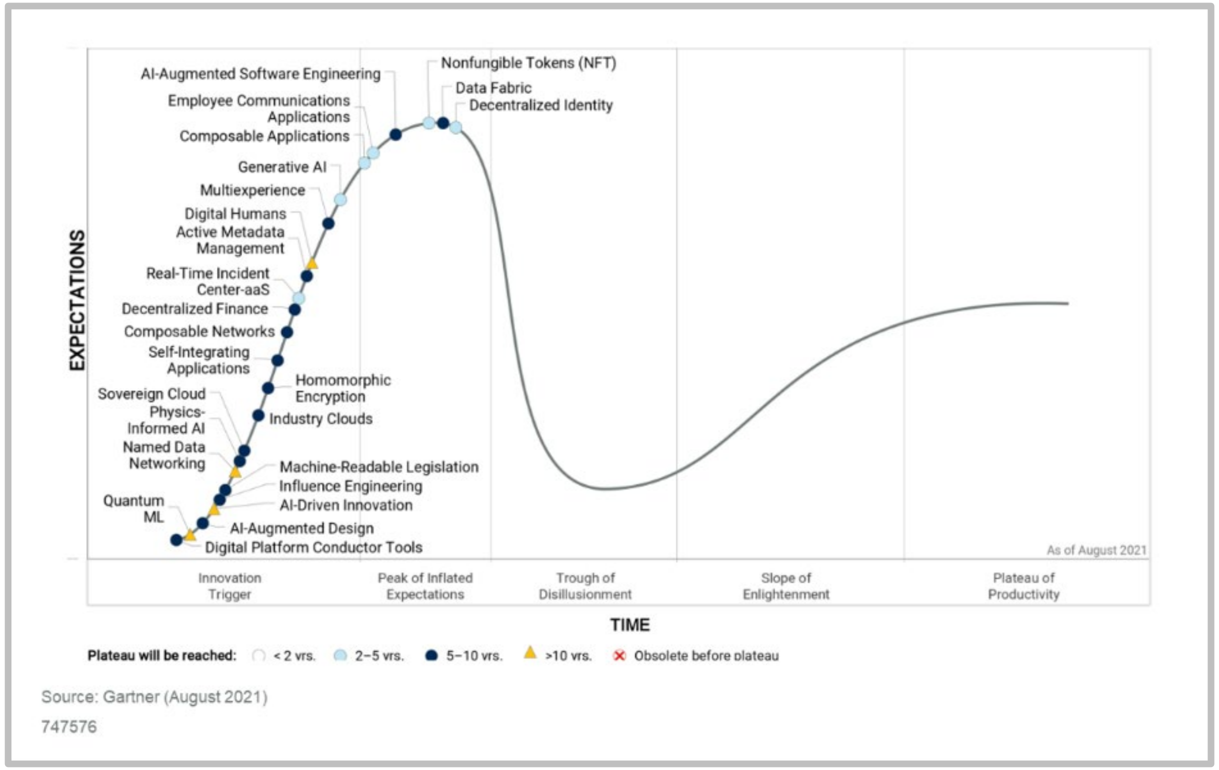
Digital transformation for robotics

- Digital transformation of manufacturing takes place inside Industry 4.0 (cyber-physical-systems - CPS - that incorporate Industrial Internet of Things, Artificial Intelligence, Robotics and other technologies)
- The end goal is to obtain quasi-autonomous factories that can respond instantly to changes in customer and market requirements, delivering mass-customized products that are smart, green and responsible



Digital transformation for robotics





- Digitalization is NOT a trend; it is here to stay and change everything in life/industry
- The GARTNER Hype Cycle (https://www.gartner.com/) shows the pace/risks of technology
- Robotics MUST work in unison with other equipment & humans to deliver competitiveness

Robotic inspection systems

Robotic inspection systems combine one type of robot used for manufacturing processes with a measurement and/or inspection technology, to deliver in-process quality control

Some systems perform simple data collection that is then supplemented by a human operator, while other employ image (or other sensor data) processing and decision-making support options, ranging from process parameters calculation (e.g., capability, stability, variability) to full artificial intelligence and CPS that can make changes in the on-going process

The robot part is usually in charge of position control and precision, while the measurement apparatus is in charge of determining the value of the targeted quality characteristics

Robotic inspection systems

Machine vision systems use serial or autonomous robots together with visible or infrared cameras to capture product (or process) data and compare it to an established baseline in order to determine conformity status

Typical quality characteristics: product geometry, presence/absence of features (e.g., an on/off switch), aesthetic aspects (color, texture, polish, etc.) and functional characteristics (e.g., normal or abnormal heat picked up by an infrared camera)

Can be connected to a simple display for operators, a software for determining and displaying parameters or a decision-support system capable of machine learning (e.g., determining trends, anticipating errors and failures, sending commands to modify process inputs, recommending product design changes, etc.)

Robotic inspection systems

Machine vision systems **are already very popular**

Price decrease and the variety of solutions has made them useful for many industries

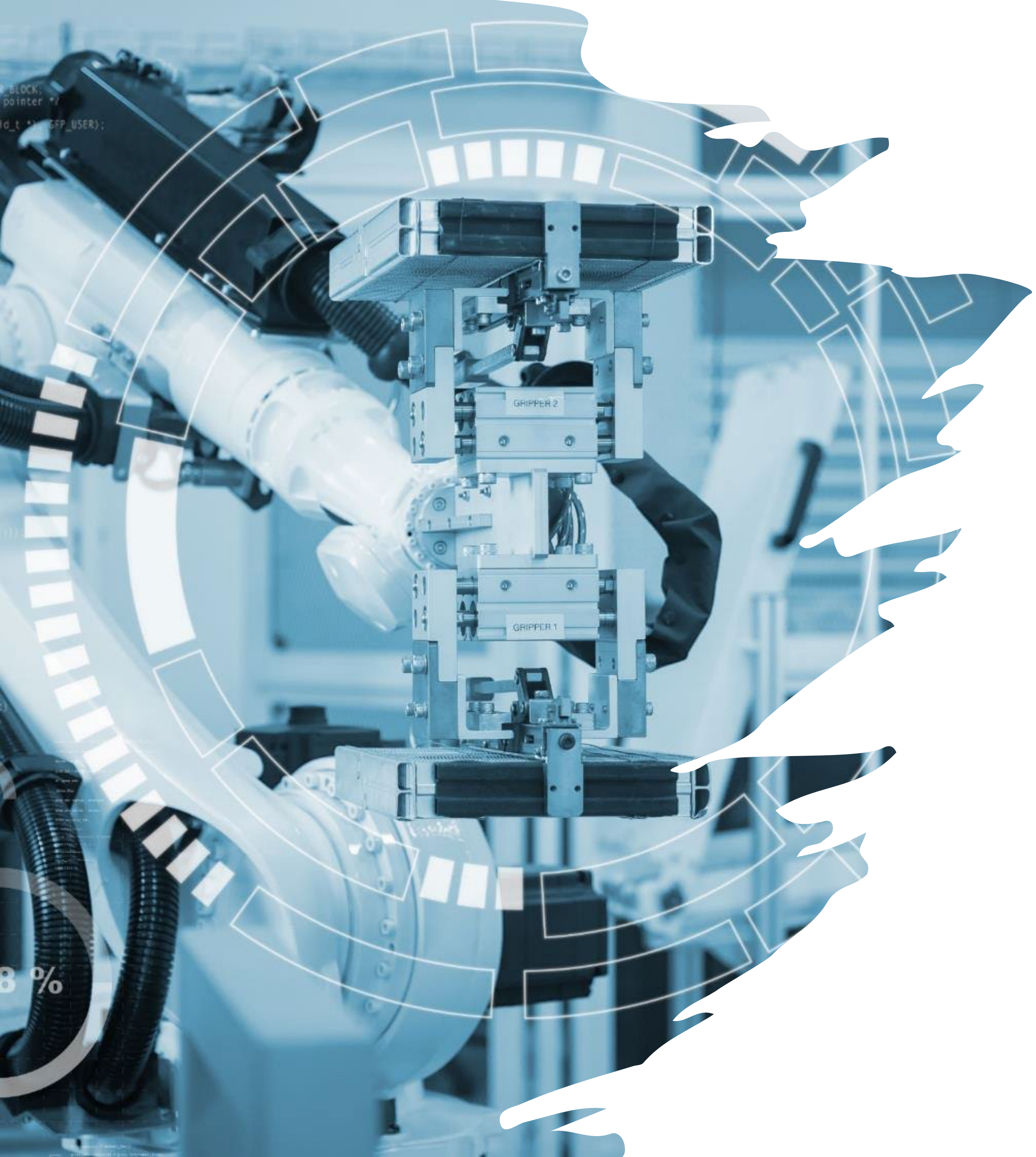
Manufacturing is one of them, but also food production, cosmetics, building materials, etc.

Among the downsides, one can count:

- inflexibility of the fixed image processing systems
- cost of machine learning based system
- difficulties in integrating the systems with the other equipment and robots

Example applications:

- full bottle inspector (beverage industry)
- seam continuity detection (textile industry)
- assembly process validation (automotive, aerospace)



Robotic inspection systems

- Robots, especially serial robots, can work in tandem with coordinate measuring machines (CMM) that are automated by CNC
- Tactile, optical, laser and CT probe sensors can be used to determine dimensional, roughness or structural product characteristics
- The robots can serve to load/unload the machine, cand be used for precise positioning or for transporting the parts on the factory floor
- Integrating the software of the robots and that of the CMM, possibly also with the ERP and other manufacturing support systems in Industry 4.0 facilities, is a challenging task
- Robotic arms can also work in conjunction with testing rigs (e.g., furniture testing, sealing, etc.)

Robotic inspection systems

Robot and fixed/mobile CMM

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Robotic inspection systems

Mobile CMM robot and mobile inspection robot

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Robotic inspection systems

Advantages

- Easy operation
- Increased repeatability
- High precision

Challenges

- Compatibility of systems
- Human supervision
- Low versatility

Robotic inspection systems

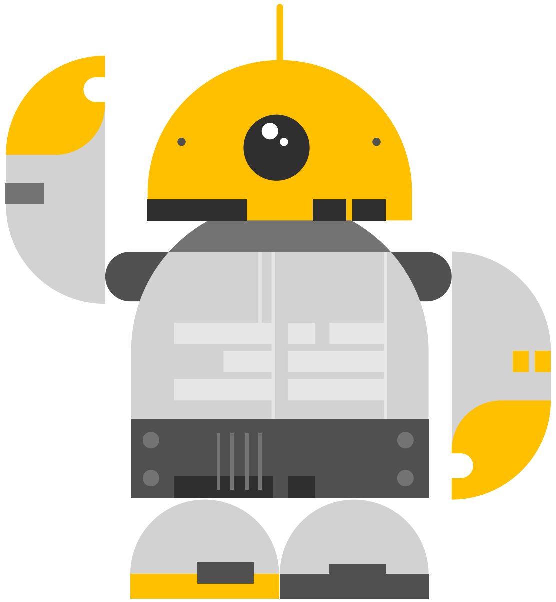
- Quality control, with a high degree of adaptability, can be achieved by collaborative inspection and testing
- The separation of tasks usually has the robot doing the positioning and loading (especially for heavy parts, e.g., the automotive industry) and the human operator do the reading, data capturing and assessment of the state of the quality characteristics
- This approach can be very flexible, according to the needs of the production system and process, the robot can learn from and follow the human to anticipate and match their movements
- Productivity is also increased significantly in the process

Robotic inspection systems

- Collaborative robots are usually user friendly and have humanoid shapes
- Safety of the operator is one of the main concerns to be addressed
- Quality control and inspection operations require low speeds and precise positioning, lowering risks
- Inspection results are delivered digitally through the manufacturing process

Outlook

- This chapter discusses the introduction of robots in all areas of manufacturing and, especially, in quality control
- Each application must be considered and customized individually, from the point of view of factory positioning, system structure, process steps and results usability and impact
- Cost considerations should also be observed, and cost-benefit analyses should be performed in due time
- Robotization of quality control can be done standalone but full Industry 4.0 solutions should be favored for effectiveness



OUTLINE OF DATA ANALYTICS 1

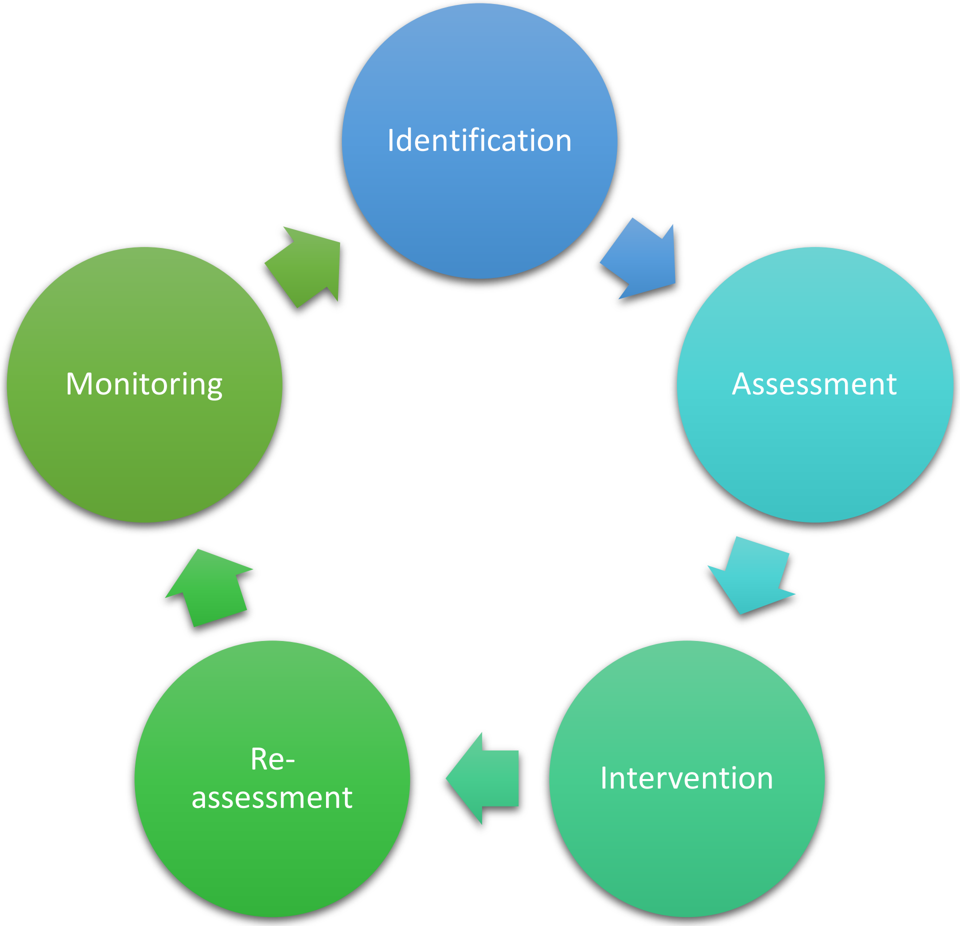
- Process management
- Risk management process
- Variability, capability, reliability
- Terms used in reliability analysis
- Methods to ensure reliability
- How to use Lean Six Sigma
- Sensors and data collection
- Data processing and decisions

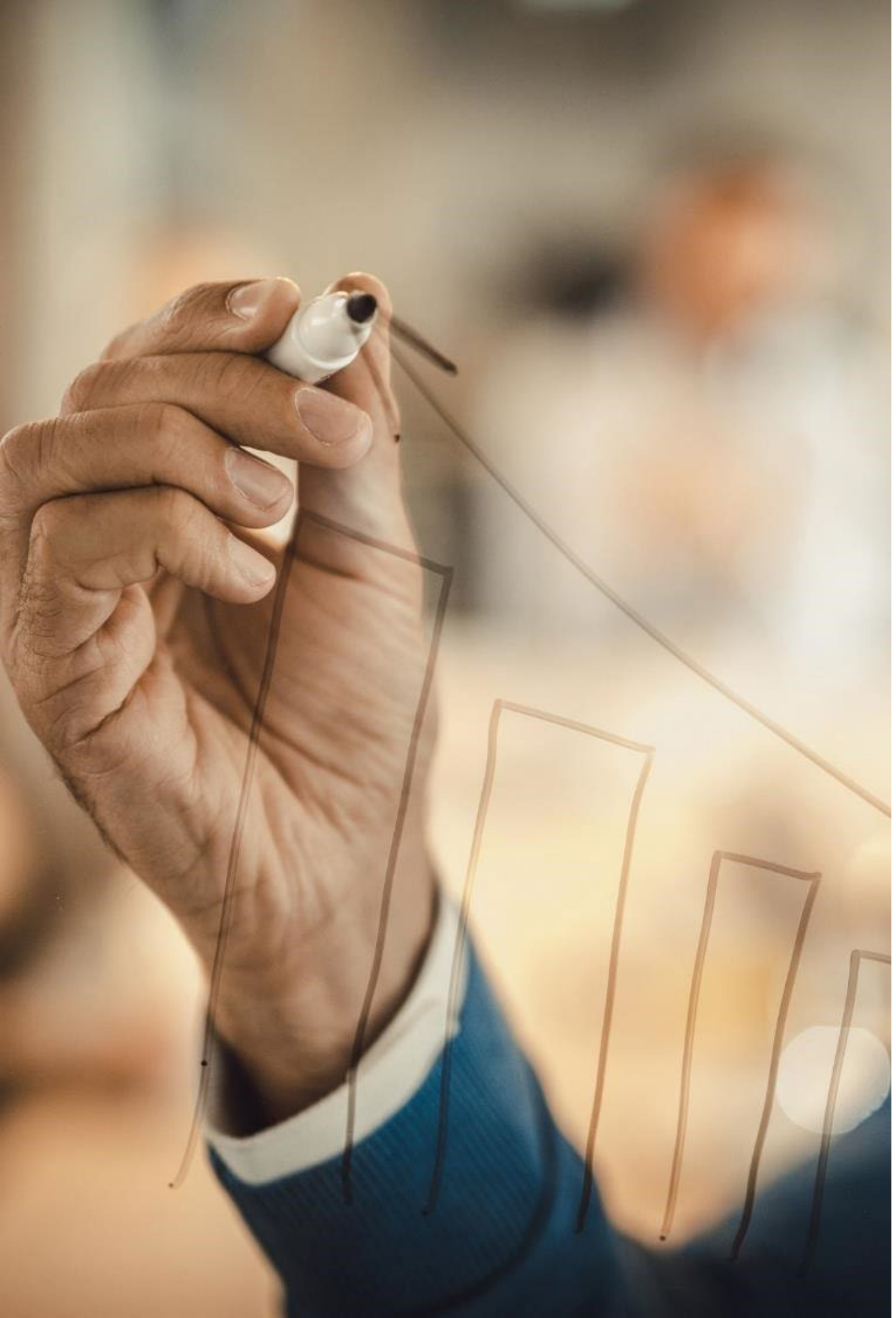
Process management

- Since the publication of ISO 9001:2015, the process approach and the risk approach form a complementary pair of logical frameworks that help companies create a functional and robust quality management system, that can respond to changes and challenges
- Modern process management must include digitalization and data management, to ensure the inputs and outputs of the process are properly managed and controlled
- In-process transformations in manufacturing also require product management and a lifecycle approach, as well as the mastering of Industry 4.0 technologies

Risk management process

- Risk management is required to prepare companies and processes to deal with complex changes in their internal and external environment
- According to ISO 9001, risks and opportunities represent the two sides of the same issues, possible future events that can impact the functioning of a company
- Process should be managed, avoided, mitigated or accepted as such



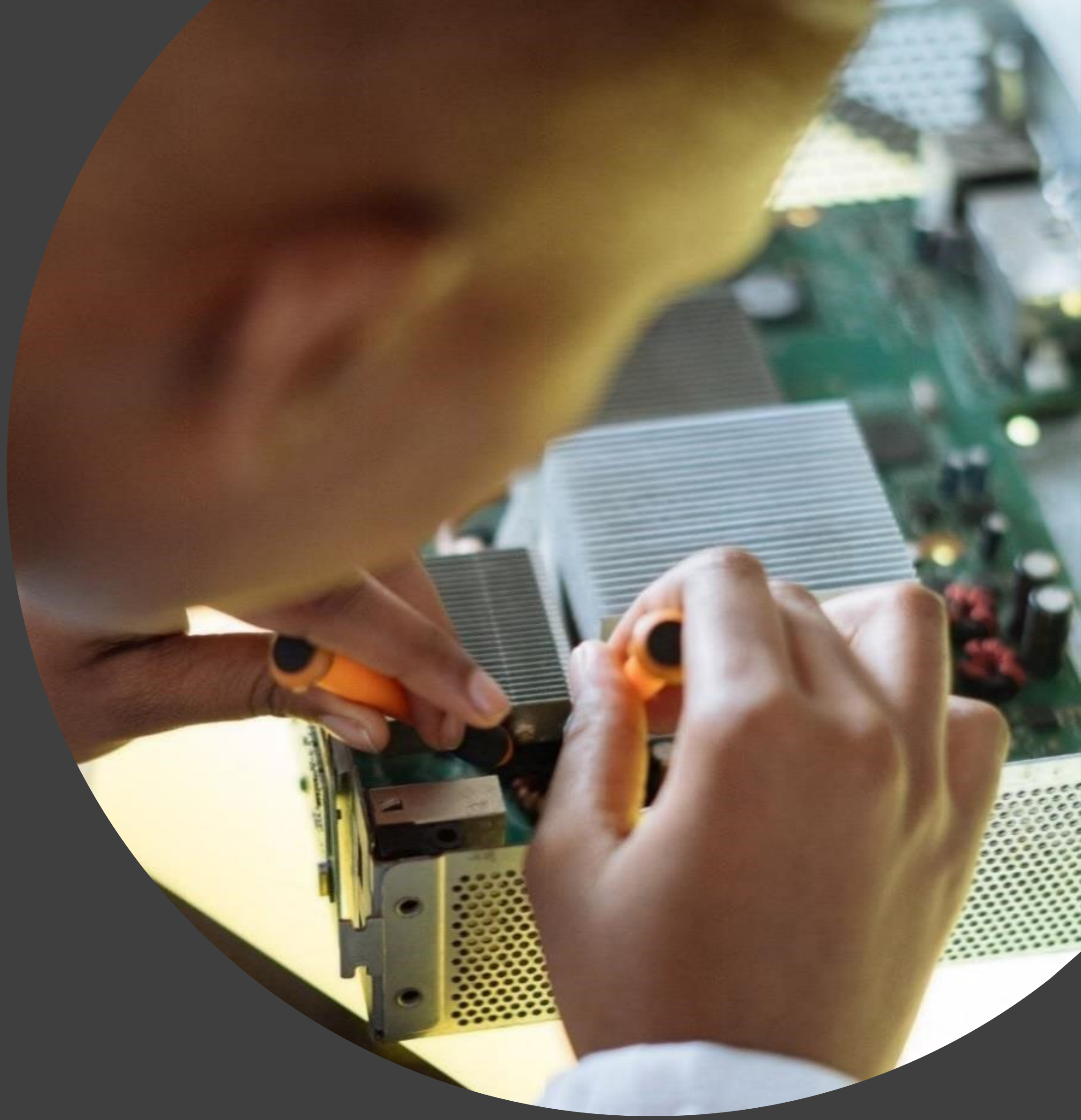


Process assessment

- Variability is the natural tendency of any process to display a range of results because of the complex interactions during its tasks between humans, equipment, resources, materials and environmental factors
- Capability is defined as the process ability to meet current and future demands of the internal and external customers formalized as specification limits within which variability should conform
- Reliability measures the dependability and availability of a system to perform its allocated tasks
- All these assessment measures can be supported by the collection of process data and its statistical processing

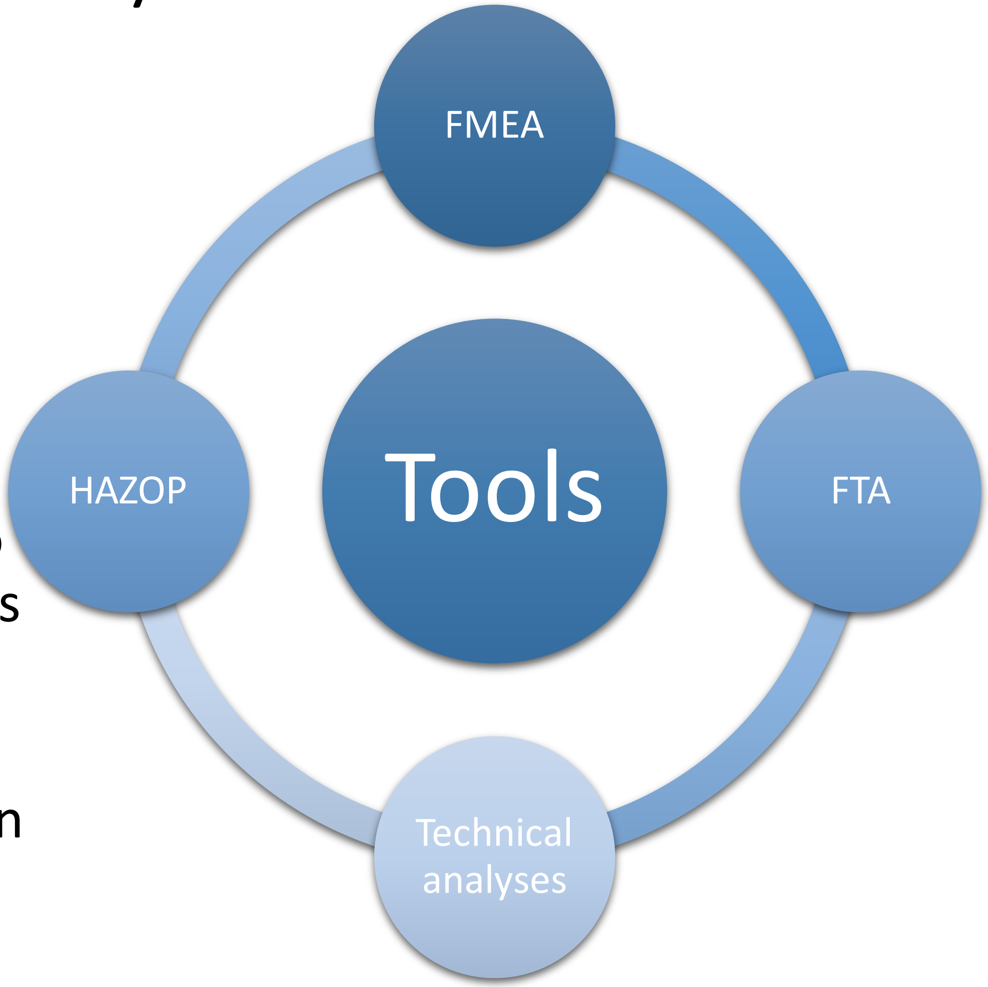
Terms used in reliability analysis

- Hazard / risk: the existence of a possible negative interaction among the analyzed system and an internal or external uncontrolled factor (hazard) combined with the probability of occurrence (risk)
- Fault / failure: the actual manifestation of a risk influencing negatively the ongoing process (fault) or leading to it completely missing its expected function or result (failure)
- Uptime / downtime: the total time when a device is able and ready to perform its function and its distribution (uptime) and vice versa (downtime)
- Corrective / preventive maintenance: maintenance activities performed after a fault or failure to remove consequences and restore availability (corrective) or before a fault or failure to prevent its occurrence, based on best practices (preventive) or data processing (predictive)



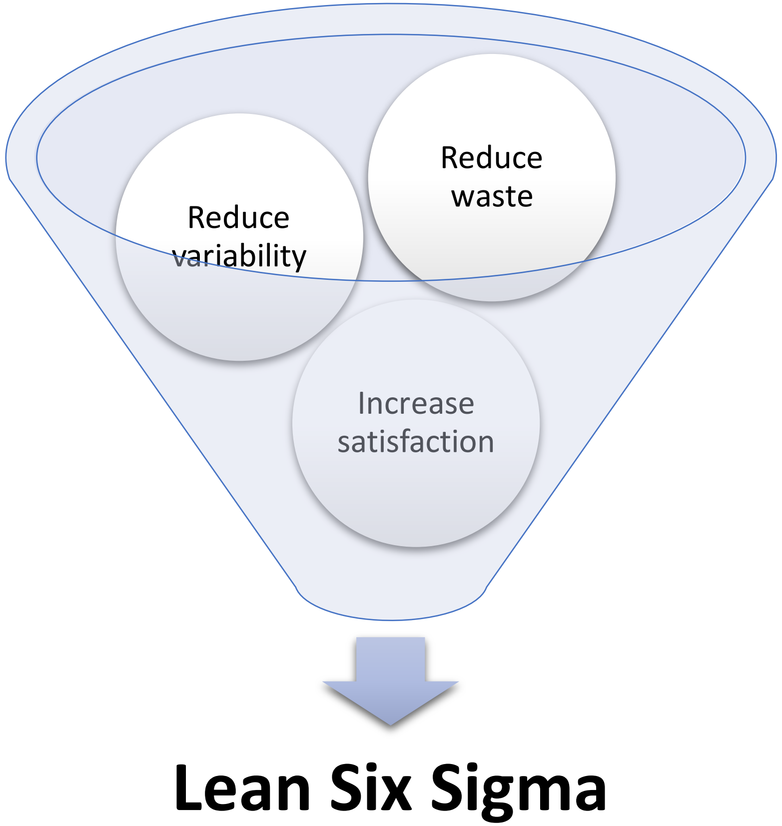
Methods used to ensure reliability

- Reliability engineering is a field of practice closely related to quality engineering, that can benefit significantly from Industry 4.0 technologies such as big data processing, simulation and augmented reality
- The classic approach to reliability employs maintenance activities (corrective and preventive) to ensure functional production equipment and systems for the needs of production
- When applying digital transformation, maintenance can be optimized with real-time data, trend detection and machine learning that correlates with the customized processes via CPS



How to use Lean Six Sigma

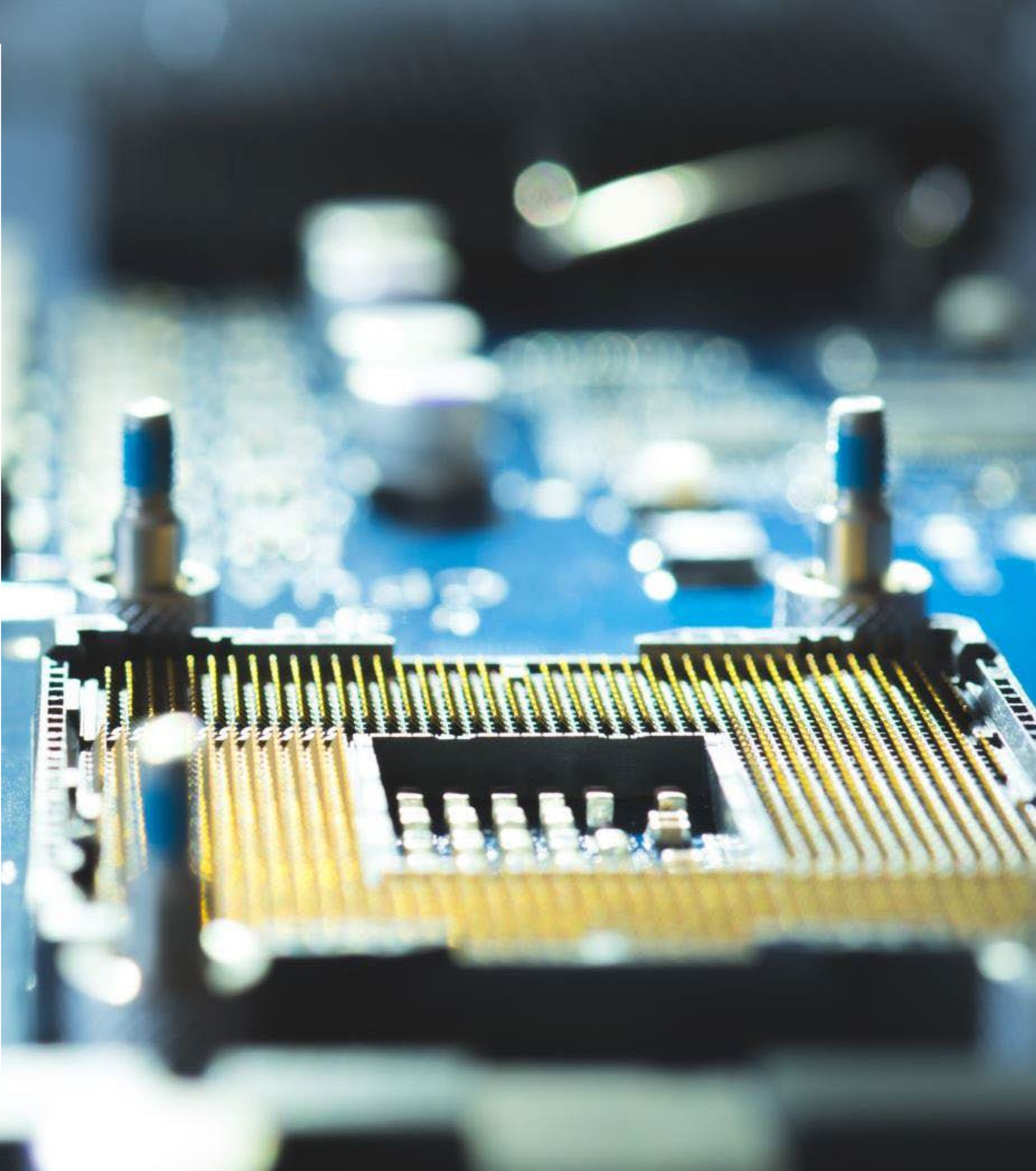
- The Six Sigma process of DMAIC (Define – Measure – Analyze – Improve – Control) and the DPMO metric (Defects per million of opportunities) can be used in conjunction with reliability assessment and maintenance processes
- Lean manufacturing tools such as Kaizen events, 5S approach, Poka Yoke and Total Preventive Maintenance contribute to more effective availability of the production equipment
- Data analytics has the capability enhance all these managerial approaches and make them take place in real time with associated decision-making processes made by personnel or software decision support systems (DSS)



Sensors and data collection

- In Quality 4.0, data collection is performed inline using cyber-physical-systems and broad-band data transmission, as well as cloud storage and curation

- Sensor types useful for reliability include:
  - Temperature and humidity probes
  - Noise and vibration sensors
  - Force and pressure sensors
  - Smoke and gas sensors
  - Thermal imaging
  - Ultrasonic detection
  - Complex sensors



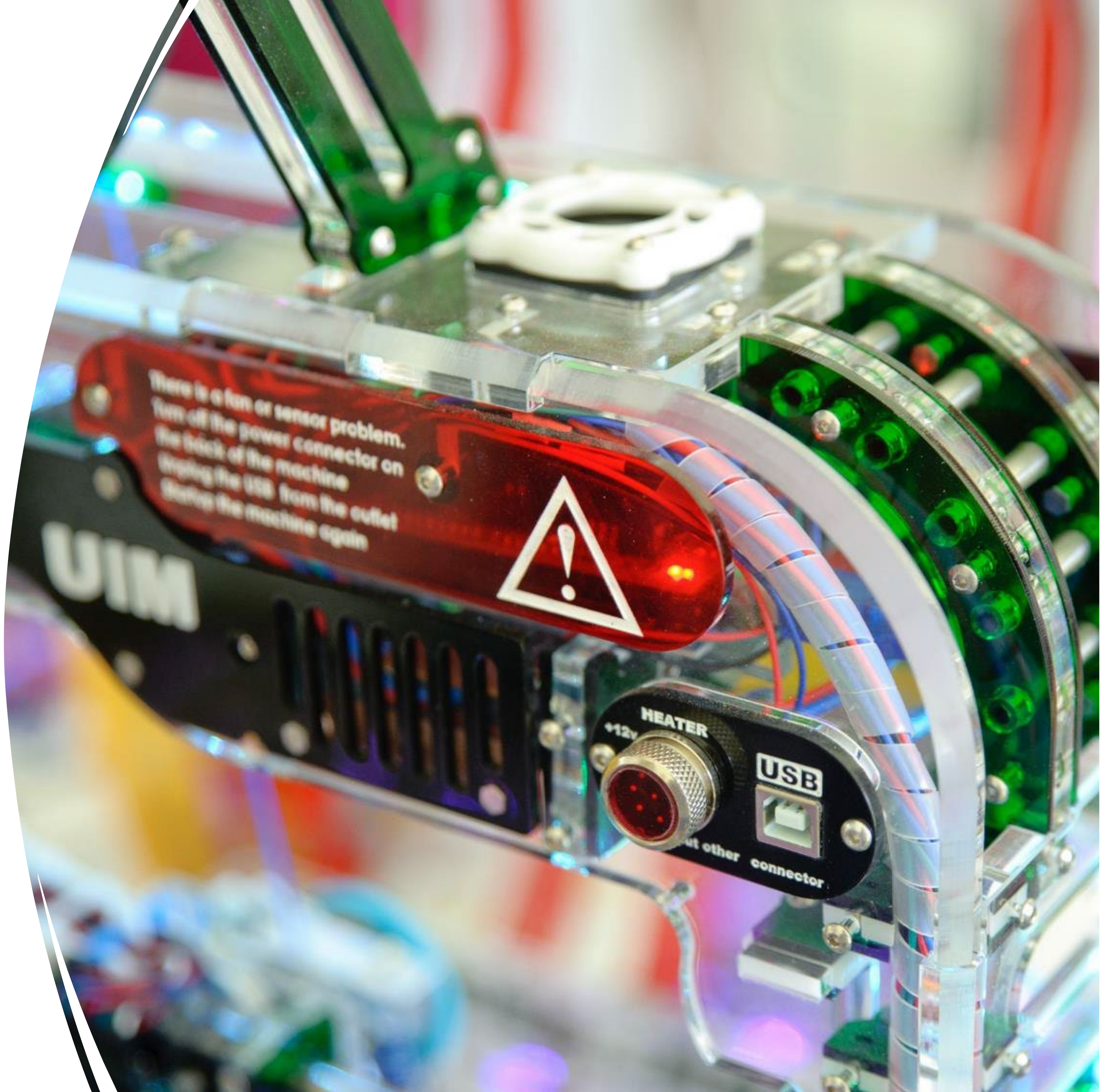
Data processing and decisions

- In manufacturing companies, data analytics is used to enable the predictive maintenance process by making use of dedicated sensors, deep learning and decision-making systems
- This approach is usually integrated into a Manufacturing Execution System or other software, but can also be performed by human operators
- The quality of the decisions depends significantly on the precision of the data collected and the robustness of the algorithms used

OUTLINE OF DATA ANALYTICS 2

- Main sources of process data
- Types of data & processing used
- Customization frameworks
- Discrete process customization
- Real-time process customization
- Managing in-process change
- Responsiveness and adaptability
- Measuring process performance

Main sources of process data



- Data is continuously generated in large quantities (i.e., Big data) by the production equipment, the product and its components, the housing facility, the personnel and the relationships with the outside environment (e.g., customers, distributors, etc.)
- Data is being processed locally by the CPS or centrally by complex systems such as ERP - Enterprise Resources Planning, MES - Manufacturing Execution Systems, PLM - Product Lifecycle platforms, etc.
- Process data in Industry 4.0 is usually collected with embedded sensors and used to adjust the operations in real time to respond to the requirements (using IoT)

Types of data & processing used

- The control of manufacturing processes requires the processing of data related to:
  - Productivity of the system
  - Process capability and variability
  - Equipment downtime and errors
  - Material and resource consumption
  - Quality control and inspection
  - Nonconformities and their solutions
  - Output, yield and acceptance tests
  - Logistics information (inside/outside)
- For these results to be available to the personnel or the automated / AI systems, the primary data should be provided by:
  - counters/presence sensors
  - inspection/measuring equipment
  - distance/travel sensors
  - weight/volume sensors
  - fault detection systems
  - human operator input

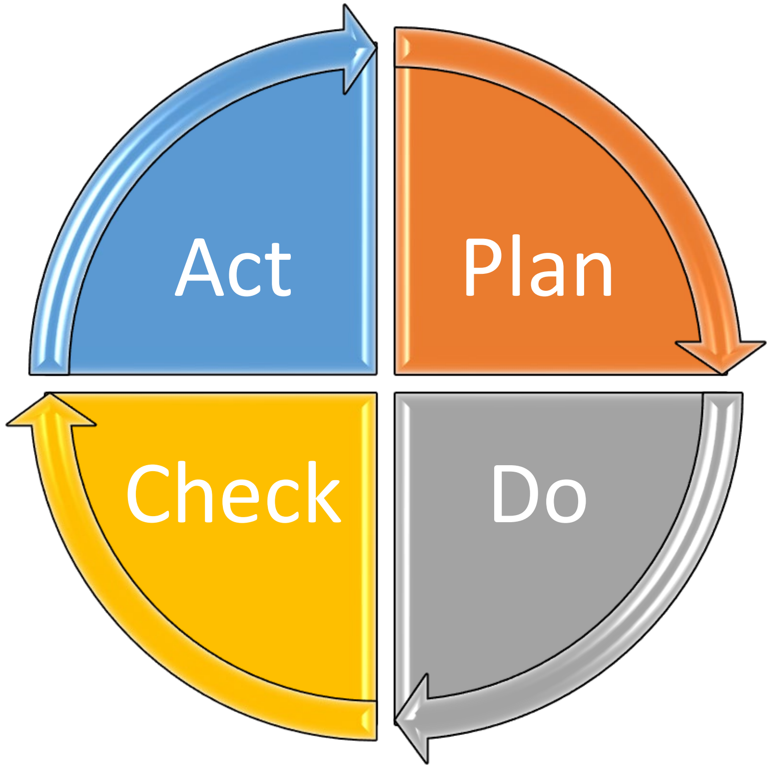
Process customization

- Process management is one of the key tasks in quality assurance for manufacturing and other industries, as it allows for performance improvement, cost reduction and customer satisfaction enhancement

- The most commonly used process customization frameworks include:
  - The PDCA cycle (Plan-Do-Check-Act) promoted by ISO through the Annex SL guidelines
  - Business Process Management / Business Process Re-engineering good practices
  - Agile process / project management in accordance with the Agile Manifesto
  - The Capability Maturity Model Integration (CMMI) from SEI-Carnegie Mellon University
  - Value Stream Mapping that is used in Lean Manufacturing / Management
  - ISO/IEC/IEEE 15288:2015 - System life cycle processes (from Systems engineering)

Discrete process customization

- Process approach forms one of the pillars of the ISO 9001 family of standards aimed at helping companies create a functional quality management system
- Process approach mechanisms (i.e., the PDCA cycle) can be applied in a fractal manner to the company (as a network of processes), to the principal/support/managerial processes, and to the manufacturing sub-processes (operations) included in the meta-process of Production
- Stages of implementation under ISO 9001 include: determining processes and their interactions, defining or describing processes, providing resources and implementation, measurement and monitoring of results and implementation of improvements
- Usually, problem solving tools are used for customization among cycles (8D, APQP/PPAP, DMAIC), detailed analyses are performed, new solutions are proposed and implemented, validation occurs during the next cycles

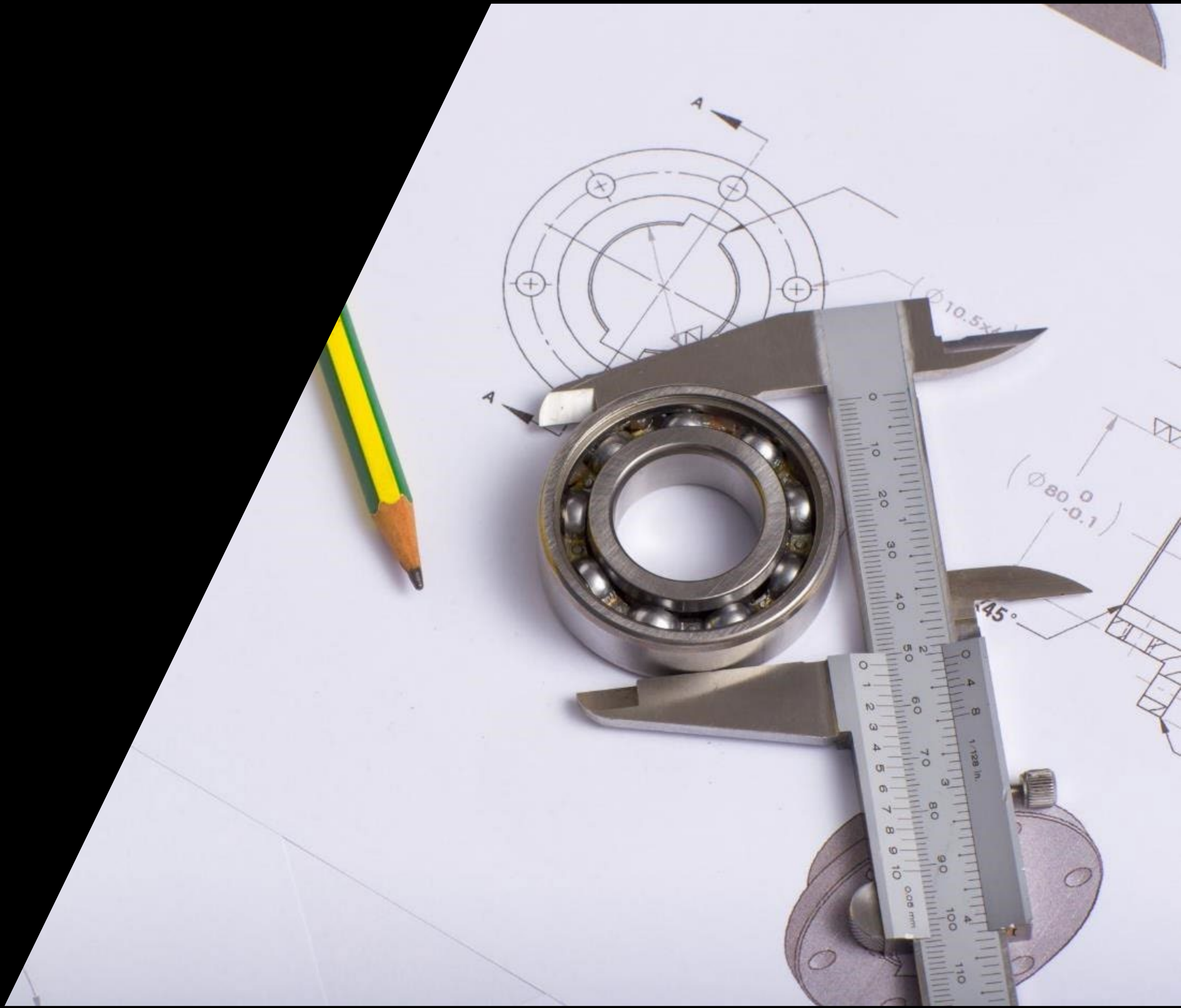


Real-time process customization

- Real-time process customization is a consequence of:
  - Industry 4.0 cyber-physical-systems based on sensors&actuators
  - Agile management implemented on the factory floor
  - VUCA conditions: volatility, uncertainty, complexity and ambiguity
  - Mass customization required by customers and competitivity
- This type of customization is limited in scope, usually to process parameters adjustment and manufacturing equipment reconfiguration
- The focus of the companies is on speed of change, accuracy of modifications, cost reduction across the Production process and traceability along the product life-cycle
- AI systems could soon replace human change makers

Managing in-process change

- Process change should be addressed using change management approaches and information control mechanisms
- Stages of in-process implementation of validated changes include:
  - Process interruption, product safeguarding and customer notification (optional)
  - Modifications to equipment, operations and/or conditions
  - Test-runs and ramping-up of production under the new model
  - Training of personnel and modification of documentations
- Technical and technological changes (e.g., data processing) are influenced primarily by the investment effort, while the changes to operator behavior is influenced by cultural factors (e.g., Juran's chronic waste)



Responsiveness and adaptability

- Responsiveness is the primary measure of agility in approaching customization as a function of data analytics
- It can be defined as the time interval between the appearance of the change necessity in the external or internal environment and the final implementation of the change in the interested processes
- Adaptability is the primary measure of proficiency in approaching customization as a function of data management
- It can be defined as the percentage of changes to the processes that is successfully implemented to deliver effective results into the environment

Measuring process performance

- The most common indicators when measuring manufacturing process performance in a data rich environment specific to Quality 4.0 are:
  - Productivity of the production system
  - Capability of the processes/sub-processes
  - OEE - overall equipment effectiveness
  - MTBF - mean time between failures
  - Defect/scrap rate
  - Amount of waste/loss
  - Wait times/bottlenecks

OUTLINE OF SMART FACTORY

- Production process fundamentals
- Process features and models
- Equipment conditions and status
- Advanced sensors for production
- Smart factory production processes

Production process fundamentals

- Production is the main process of any company in the manufacturing industry and beyond (e.g., foodstuff production, water treatment, etc.)
- Usually, production is a macro-process made up of components that act themselves as processes, in a fractal approach (cutting, drilling, turning, finishing, painting, assembling, etc.)
- There are specific support processes that are intimately connected with production, such as maintenance and procurement, as well as delivery, installation and commissioning
- As technology matured and outsourcing became commonplace, the value added from production has diminished, but the potential for non-conformities is still very significant

Production process fundamentals

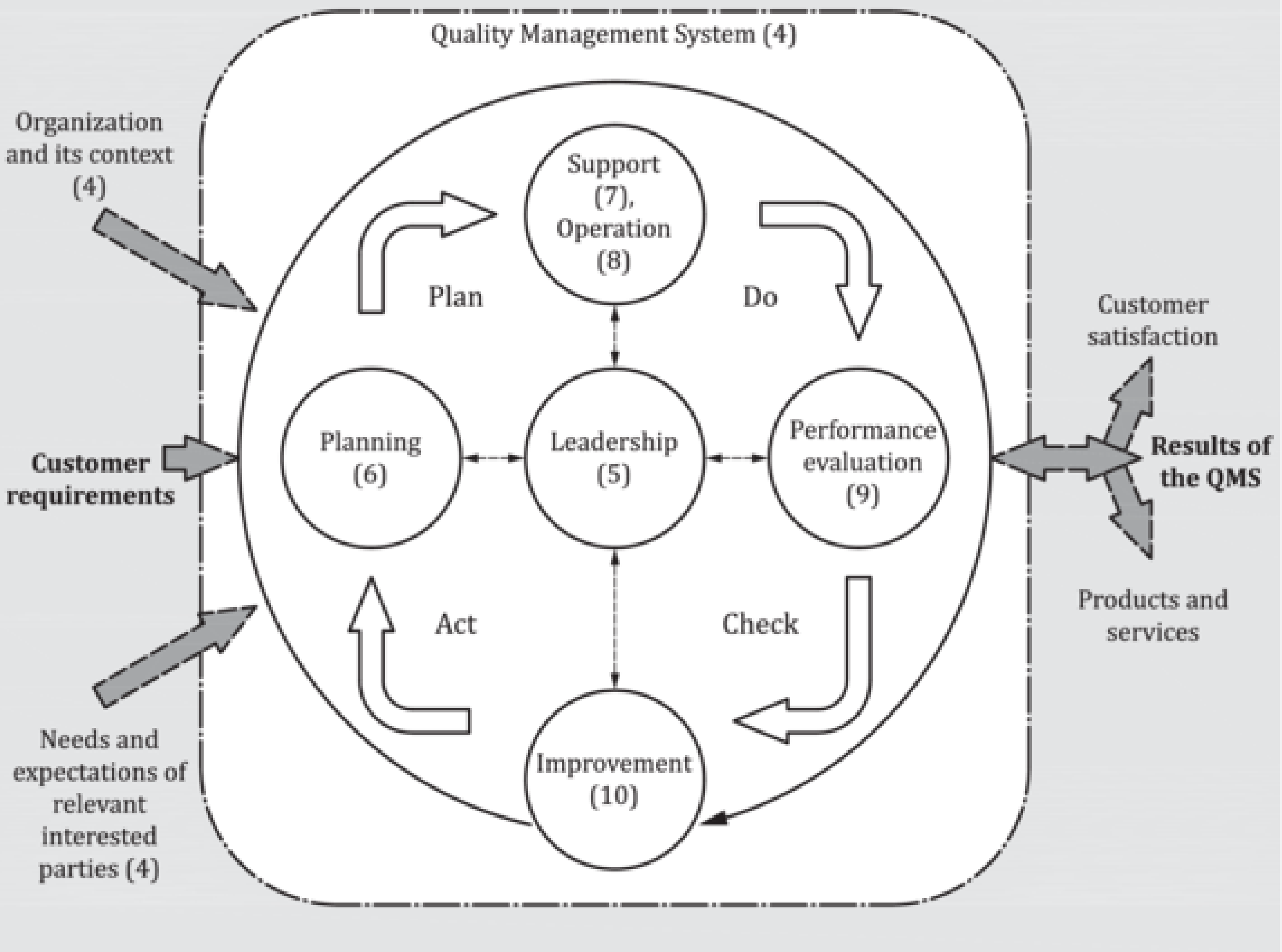
- Production process are inherently deterministic, with errors, delays and non-conformities easily propagating and amplifying from one operation to the next
- Usually, in most companies there is an uneven level of digitalization and wide range of ages and features of the production equipment
- Production is connected most of the times with outsourced and sub-contracted processes, that take the partial outputs and provide partial inputs in one or more specialized areas (e.g., painting, chemical treatment, etc.)
- SMEs are more prone to employing non-standardized automation solutions that solve some difficulties while creating others

Process features and models

The process approach of ISO 9001 frames Production as an operational process included in the PDCA cycle

Production is responsible for transforming customer requirements and internal and external resources into products and/or services

This is valid for any company, but when implementing a structured QMS, production variability can be reduced, and its effectiveness increased



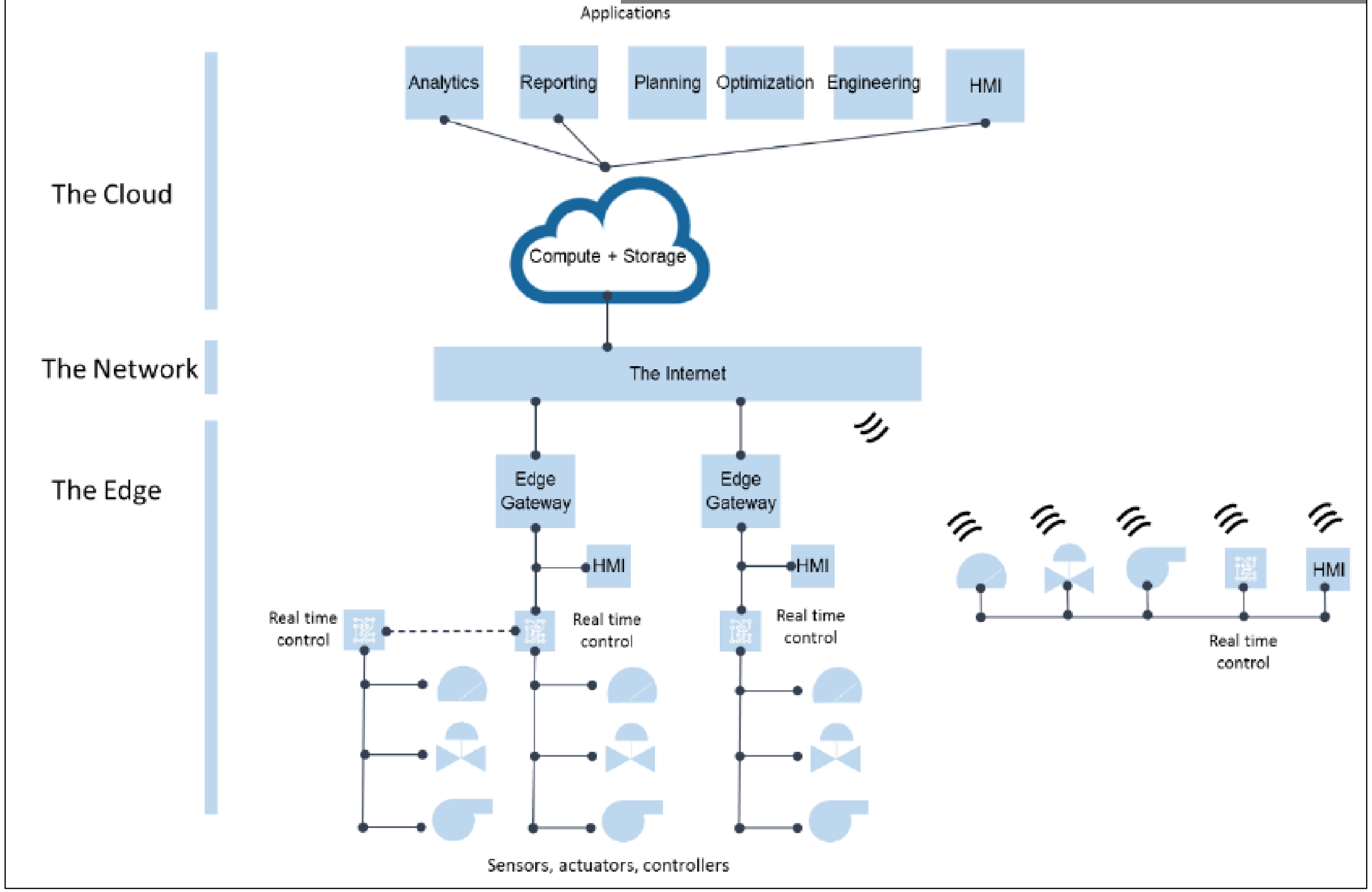
Process features and models

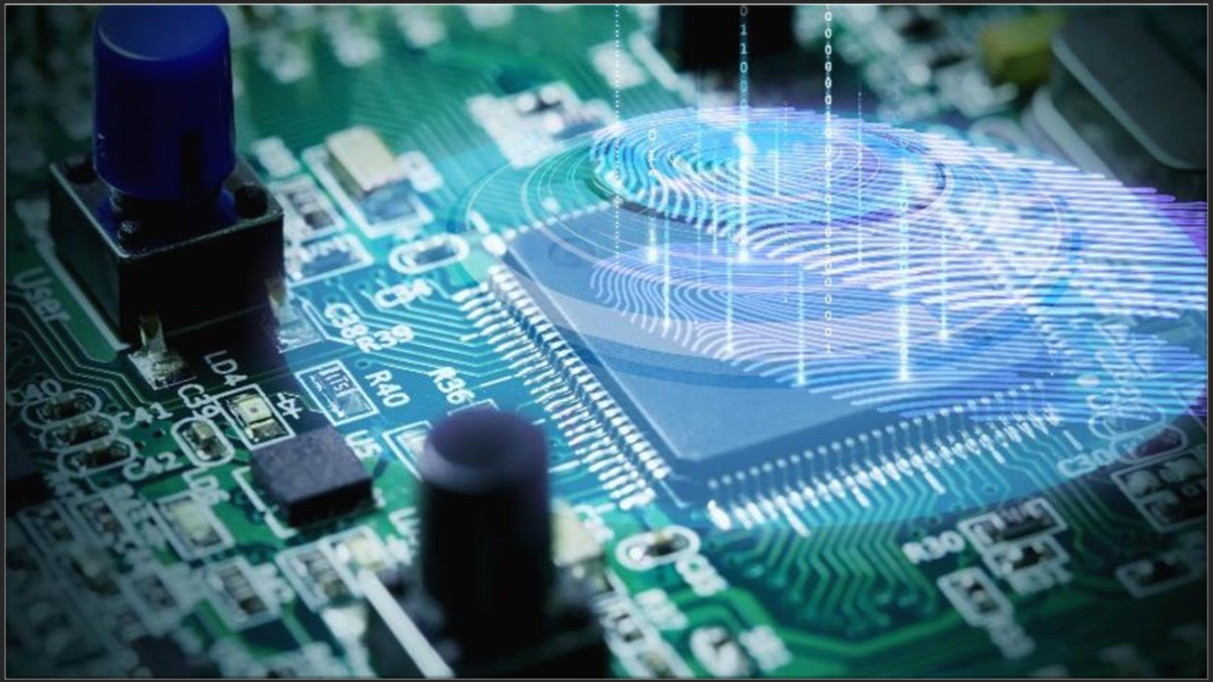
- There are many instruments to visualize, control and improve production processes and to monitor their results and achievements
- The most common tools used include:
  - Flowcharting (inline or ASME notation)
  - IDEF standards (Icam DEFinition for Function Modeling)
  - Process Flow Diagrams (includes equipment)
  - Piping and Instrumentation Diagrams (includes equipment)
  - BPMN (Business Process Model and Notation)
  - Value Stream Map (from Lean Manufacturing)
  - PERT diagram (Program Evaluation and Review Technique)
  - CAD - VR immersive simulations

Equipment conditions and status

- Equipment monitoring is performed using Industrial Internet of Things approaches

- The technology can involve smart sensors, RFID tags for equipment, laser and camera tracking, human-machine interfaces, cloud storage and processing, big data analytics, cybersecurity for the involved networks, decision support systems, etc.



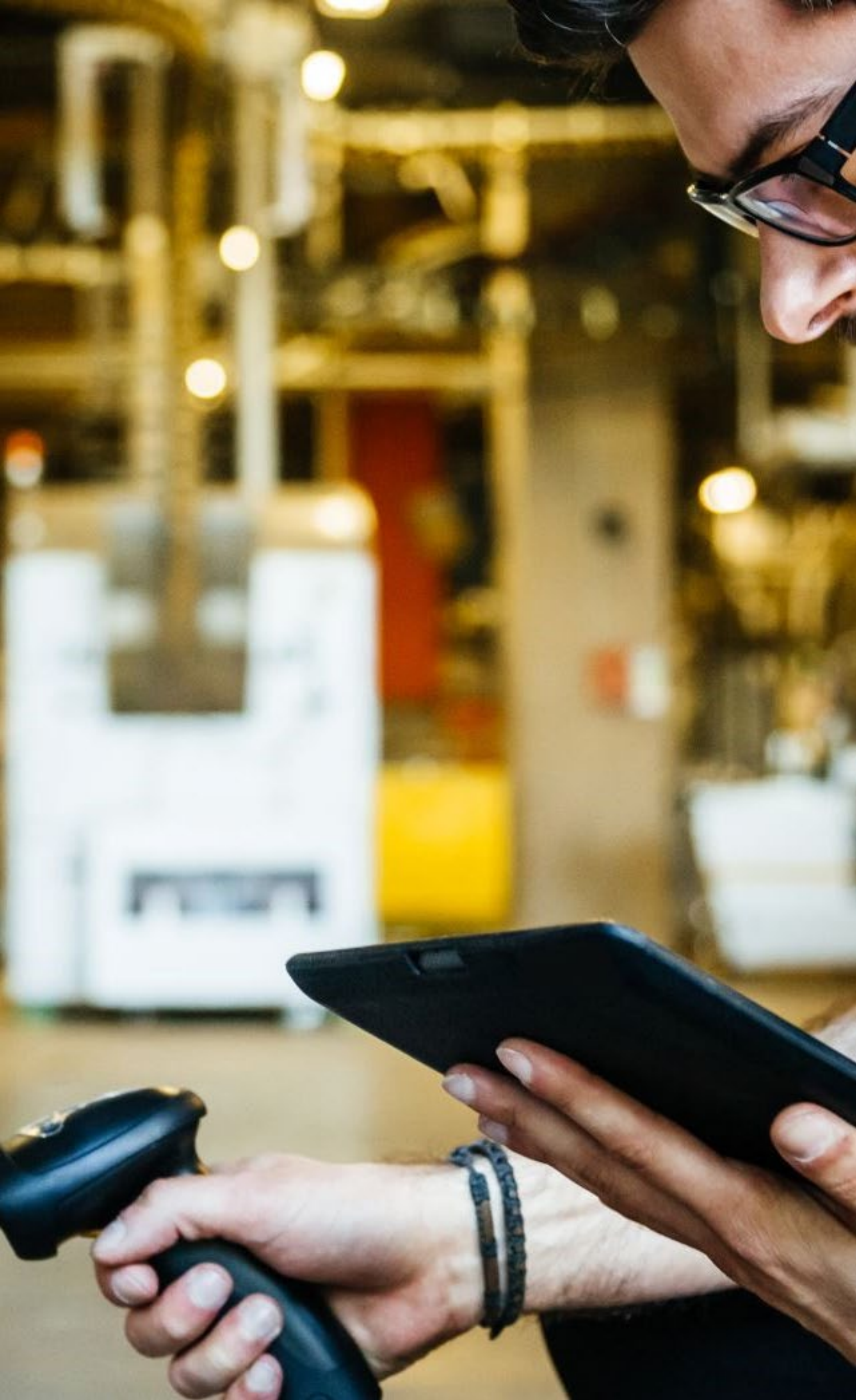


Advanced sensors for production

Full digitalization can lead to the creation of digital versions of the equipment and/or the production process

This enables advanced virtual studies upon the condition and status of the equipment and running of what-if scenarios

Complex sensors transmit data on a multitude of parameters (physical, functional, ergonomic, etc.) and the monitoring system interprets it based on pre-established rules



Smart factory production processes

- Smart factories achieve integration of all the technologies and instruments presented above into a functional unit
- The main characteristic of a smart factory is its extreme adaptability to any customer and market fluctuations, which is achieve through equipment and process flexibility, in relation with product development and distribution processes
- Secondarily, smart factories reserve a creative role for the human personnel and have the ability to decrease resource consumption and to reduce the impact of production upon the environment
- Smart production requires smart equipment, logistics, maintenance and other support processes, as well as Quality 4.0

Smart factory production processes

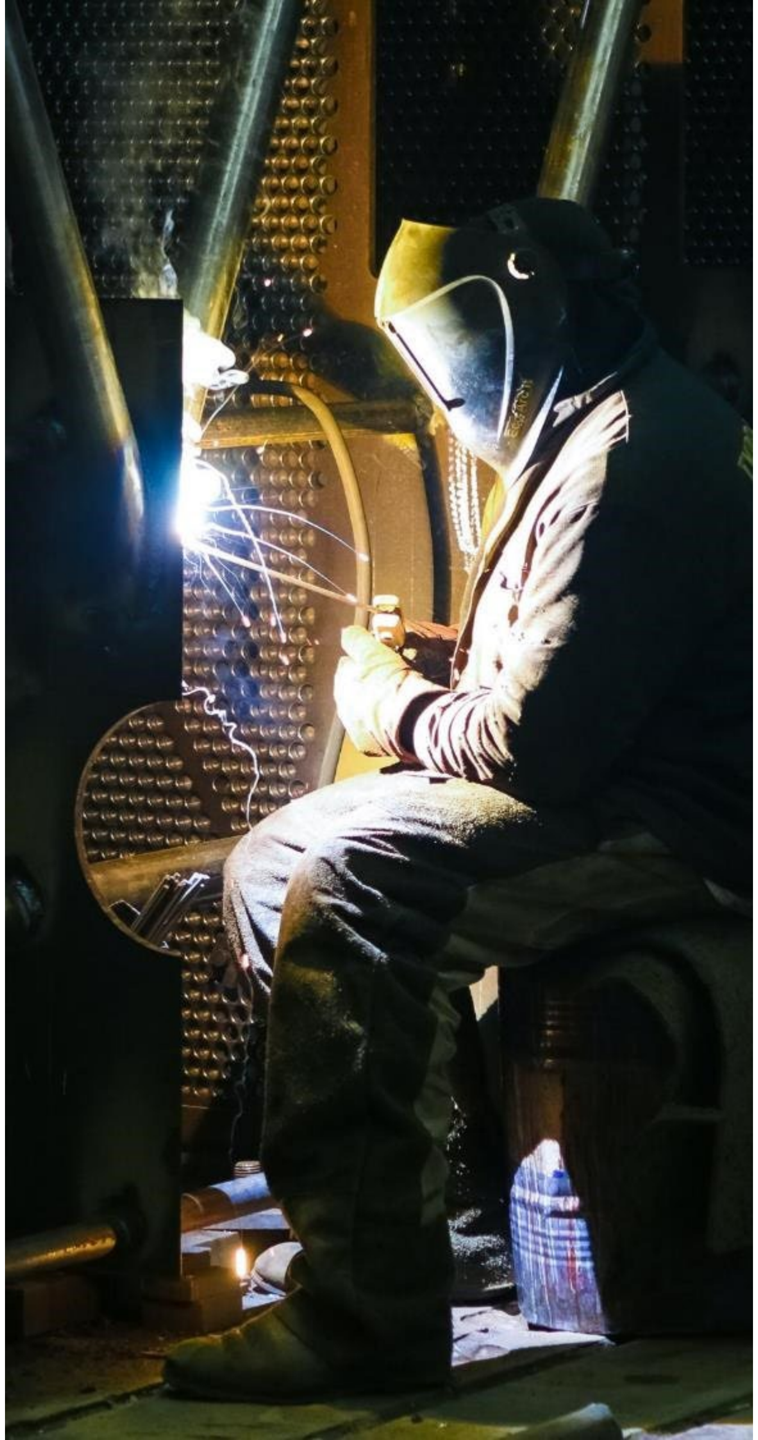
- The humans in a smart factory are responsible for designing and planning the processes, for advanced problem solving and for representing the production unit in relation with other humans
- Technologies that put humans and smart equipment in the same work teams include collaborative robots, head mounted displays and augmented reality collocation
- Artificial intelligence / deep learning, autonomous robots and robotic process automation (for red tape) are decreasing costs, ensuring human safety and responding to customer need in a timely manner
- Completely autonomous factories are foreseen for Industry 5.0

OUTLINE OF IOT FOR MAINTENANCE

- Types of approaches to maintenance
- Total Productive Maintenance (TPM)
- Maintenance specific activities
- Standards related to maintenance
- Typical maintenance documents/results
- Software solutions for predictive maintenance

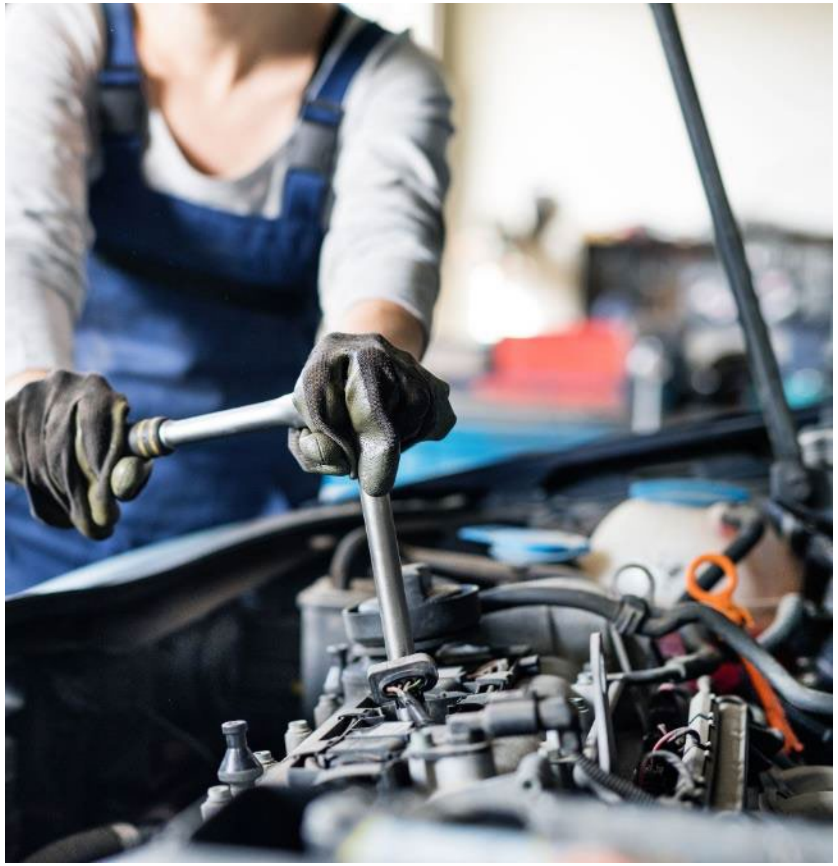
Types of approaches to maintenance

- Corrective maintenance (a.k.a repairs) is necessary to restore the functional parameters and the availability of equipment within the operational factory by removing the elements that cause impairment and defects and replacing the affected components
- Preventive maintenance is performed periodically ahead of time, before any impairment or other effects are detected, using good practices, the history of the equipment and measurements/analysis of trends in equipment parameters
- Predictive maintenance is performed in an optimized manner, by anticipating with precision the moment of failure and enabling the implementation of the needed operations with minimal disruptions and costs



Types of approaches to maintenance

- The **drawbacks** of corrective maintenance are:
  - Failure can have disastrous consequences for the process or personnel
  - Repairs must be performed at the place of failure
  - Usually involves the replacement of components, recalibration of equipment, reprogramming of operations sequence or all three
  - It creates significant downtime on the production line
  - It can create defective parts, before or after repairs, due to misalignment of requirements and attributes
  - Requires a buffer stock of parts that produce costs or/and can become defective themselves
- The **advantages** of corrective maintenance are:
  - The repairs are precise and usually directed to a singular component that has failed, not involving any guess-work
  - “Luck” helps to avoid doing the work for a long time before a failure occurs
  - Waste from replaced components and consumables is minimized



Types of approaches to maintenance

- The **drawbacks** of preventive maintenance are:
  - The necessity for dedicated processes and resources, and, sometimes, exclusive personnel and departments
  - Does not work very well for newly ramped-up production systems and even worse for completely new technologies
  - Requires a considerable organizational culture leap from ‘throwing away good parts” to “replacing a component before failure prevents costs and accidents”
- The **advantages** of preventive maintenance are:
  - Significantly less downtime that in the case of corrective maintenance (a.k.a. waiting to fail)
  - Clearly predictable costs and activity planning over long periods of time, suitable for being addressed in business plans
  - Easy to integrate within Lean or Agile Manufacturing, as well as other modern trends in the field
  - Considerable know-how and literature is available for the topics covered

Types of approaches to maintenance

- The **advantages** of predictive maintenance are:
  - It provides the best balance between intervention time and effort on one hand, and equipment uptime and lack of failures on the other hand
  - Maintenance costs are optimized to a high degree, with the deployed systems paying for themselves through savings in staff, spare parts, consumables and continued productivity
  - Downtime and failures of equipment are anticipated through trend detection and sophisticated models that reflect reality considerably better than shop-floor best practices collected by workers
- The **drawbacks** of predictive maintenance are:
  - It involves considerable costs for investment and preparation time to train the deep learning algorithms
  - Highly qualified personnel is needed, albeit in a far reduced number than other approaches
  - The company must have a long term and well-developed relationship with the software and systems providers that enable the running of the process

Types of approaches to maintenance

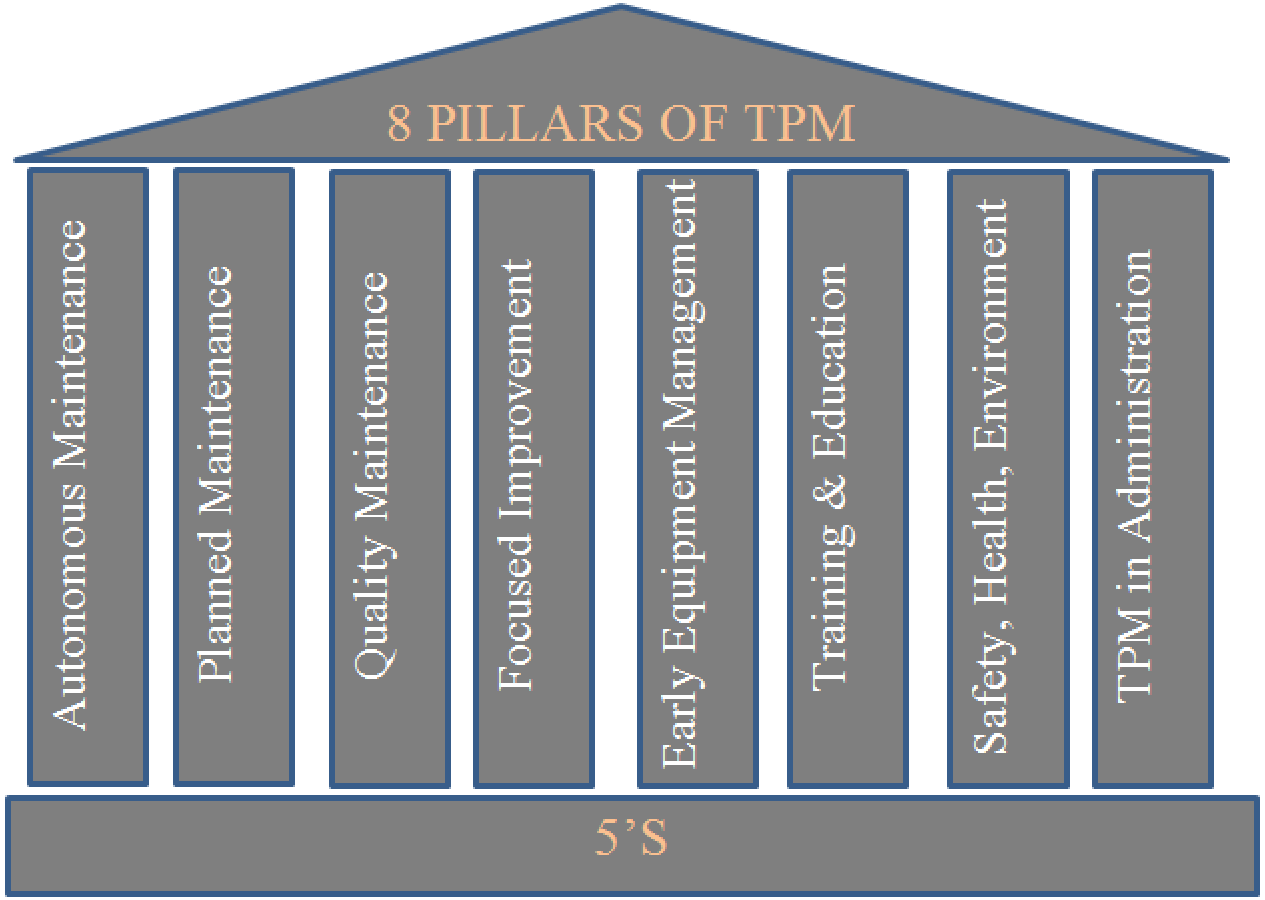
- Other ways to undertake maintenance activities are:
  - Reliability centered maintenance that requires complex mathematical and 3D modelling of the manufacturing processes and production systems to enable predictive maintenance to get close to the results of predictive maintenance
  - Condition based maintenance that sits between corrective and preventive approaches, by tracking certain parameters that indicate the future failure of an equipment, before it happens
  - Prescriptive maintenance and self-maintenance involve the use of smart-equipment that can prompt for or even perform by itself the necessary activities

Total Productive Maintenance

- Total Productive Maintenance (TPM) is a holistic approach to the maintenance process in manufacturing systems that is part of the Lean paradigm of organizing production
- TPM can also be understood by relating it with the TQM (Total Quality Management) approach used for involving all the resources of an organization in the quality management drive towards satisfied customers
- TPM is less concerned with the formal structure of the activities performed, and more focused on involving the adequate personnel, methods and tools at the proper moment to ensure the manufacturing system delivers maximum productivity (measured by OEE - Overall Equipment Effectiveness)

Total Productive Maintenance

- TPM is based on the elementary lean practices of 5S in every process:
  - Sort (Seiri, orig. 整理)
  - Set in order (Seiton, orig. 整頓)
  - Shine (Seiso, orig. 清掃)
  - Standardize (Seiketsu, orig. 清潔)
  - Sustain (Shitsuke, orig. しつけ)
- Results are driven by working in 8 main areas of the company, including equipment, management systems, human factors and support processes



Source: Mechanical matters, 2019

Total Productive Maintenance

- Overall Equipment Effectiveness is calculated as the product of Availability, Quality & Performance, in the form of a percentage that shows the global impact the production system has on delivering towards the customer expectations
- The 8 pillars can be mapped out on this directions to increase the chances of a successful deployment of the methodology in a company
- Availability - pillars 1 & 2; Quality - pillars 3, 4 & 5; Performance - pillars 6, 7 & 8.
- The implementation of TPM requires a mandatory change in the organizational culture to be successful

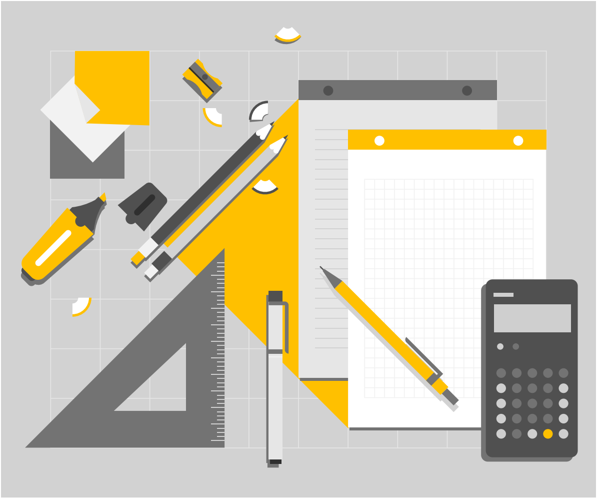
Maintenance specific activities

- Mechanical devices: measuring parameters and wear&tear, adjustments of parts&systems, component replacement, replacing/completing consumables, cleaning residues

- Electrical devices: measuring parameters and calibration, adjustments and blockage clearance, component replacement, testing of sensors and triggers, verifying insulations

- IT&C devices: software update and security checks, speed and accuracy tests of hardware and connections&networks, checking interfaces and information transfer, performing backups

- Scheduling and documenting maintenance activities and decisions
- Participating in interdepartmental problem-solving teams
- Participating in investment planning and capacity development
- Training of production staff for proper use and condition identification



Maintenance specific activities

- The general principles of maintenance (planning, checking, overhaul, replenishing, testing, recording) can be applied to other resources of an enterprise beside the manufacturing equipment
- Buildings and infrastructure require specific (and costly) maintenance, having time intervals far longer than machinery
- The personnel and their skills should be continuously trained and developed along with proper motivation approaches
- Customer relationships (as well as other corporate relations) should be maintained through technical support, customer care and customer service

Standards related to maintenance

- A multitude of ISO standards (e.g., the ISO 55000 family or the ISO 13370 family) cand be used to set up or improve the preventive maintenance process within a company
- Similarly, there are specific standards for certain industries (e.g., automotive, aerospace, military equipment) that can be employed for sensitive production equipment
- A coherent process structure in the field is better suited for the automation of tasks within Quality 4.0 approaches

Typical maintenance documents/results

- Maintenance documents have been used since the advent of mass production
- They can come in the form of templates, standalone software or online platforms
- Preventive maintenance is based upon the timely scheduling of adequate actions (see example ➲)

Insert Facility Name

Preventive Maintenance Work Plan

Frequency Key
W – Weekly **M** - Monthly **Q** - Quarterly **SA**- Semi-Annually **A**- Annually **SST** - Seasonal Start-Up **SSH** - Season Shut Down

Fans (Supply, Exhaust, Return)(Belt or Shaft Driven)

Critical Tasks	Frequency	Status	Date Completed	Initials
Inspect unit for unusual noise and/or vibration, ensure that it is in good working order.	Q			
If unit is not running or an identified problem requires the unit to be serviced, perform ALL **Non-Critical Tasks** listed below.	Q			
If present, inspect belts for proper tension and wear (if belts are replaced, record belt type and replacement date on unit)	Q			
Inspect fan and motor assemble for proper alignment.				
Provide lubrication, if necessary.	Q			
Clean entire unit, motor and fan assembly with a damp cloth.	Q			
Check exhaust fan intake grills for dirt/debris.	Q			
Other recommended tasks				
For fans 2HP or more, check load amps.	A			
Inspect fan and motor pulleys for proper alignment.	A			
Inspect fan blades and moving parts for excessive wear.	A			
Inspect all fan wiring for deterioration.	A			
Ensure tightness of all electrical connections.	A			
Inspect motor starter/control center.	A			
Ensure that overload settings are proper	A			
Verify correct operation of starter.	A			
Inspect electrical contact surfaces.	A			
Inspect fan assembly.	A			
Verify tightness of balance weights.	A			

Source: https://www.templateroller.com/template/608812/preventive-maintenance-work-plan-template.html

Typical maintenance documents/results

- Once an intervention is performed on the production line (preventive or corrective in nature) proper documentation of the activity and its results is critical

- Reports are also needed to document inventory changes for spare parts and consumables used

- This information can also contribute to the future modification of the preventive maintenance scheduling (see example ➲)

Equipment Maintenance Log Sheet

Date	Machine Name	Serial Number	Maintenance performed

Notes after Check up

Source: https://templatearchive.com/equipment-maintenance-log/

Typical maintenance docs

- In TPM, maintenance activities become less frequent and the failures less severe due to the continuous application of the 5S approach
- Audit forms can be customized for various manufacturing lines depending on their configuration
- Monitoring can be performed using scores or graphs (see example ➲)

5S Checklist - Manufacturing

Area:
Auditor:
Date:

Checklist item	Criteria	Exist? (Y / N)	Rating (0,1,2,3 or 4)	Comments
Sort - SEIRI				
Cabinets and shelves	No irrelevant reference materials, documents, drawings, etc.			
Desks and tables	No irrelevant reference materials, documents, etc.			
Drawers	No excess pieces of equipment, documents, etc.			
Other storage area	Storage area is defined to store unneeded items and out-dated documents			
Standards for disposal	Standards for eliminating unnecessary items exist and are being followed			
Set in order - SEITON				
Tools and equipment	Locations of tools and equipment are clear and well organized			
Materials and products	Locations of materials and products are clear and well organized			
Labeling	Labels exist to indicate locations, containers, boxes, shelves & stored items			
Inventory control	Evidence of inventory control exists (i.e. Kanban cards, FIFO, min & max)			
Outlining / dividing lines	Dividing lines are clearly identified and clean as per standard			
Safety	Safety equipment and supplies are clear and in good condition			
Shine - SEISO				
Building structure	Floors, walls, ceilings & pipework are in good condition & free from dirt/dust			
Racks and cabinets	Racks, cabinets and shelves are kept clean			
Machines and tools	Machines, equipment and tools are kept clean			
Stored items	Stored items, materials and products are kept clean			
Lighting	Lighting is enough and all lighting is free from dust			
Ventilation	Good movement of air exists through the room (limits the spread of viruses)			
Pest control	Pest control exists and effective			
Cleaning tools	Cleaning tools and materials are easily accessible			
Cleaning responsibilities	Cleaning assignments are defined and are being followed			
Standardize - SEIKETSU				
Visual controls	Information displays, signs, color coding & other markings are established			
Procedures	Procedures for maintaining the first three S's are being displayed			
5S documentation	5S checklists, schedules and routines are defined and being used			
Responsibilities	Everyone knows his responsibilities, when and how			
Regular Audits	Regular audits are carried out using checklists and measures			
Sustain - SHITSUKE				
5S System	5S seems to be the way of life rather than just a routine			
Success stories	Success stories are being displayed (i.e. before and after pictures)			
Rewards and recognition	Rewards and recognition is part of the 5S system			

Comments

		0		
		Score: 0.0%		

Continuous Improvement Toolkit . www.citoolkit.com

Guide:
Use either the checklist or the rating system to ensure that 5S standards and workplace organization are being met.
In the rating column, use the following rating criteria: 0 for 'very poor', 1 for 'poor', 2 for 'good', 3 for 'very good' and 4 for 'excellent'.
You need only to fill the white cells.

Software solutions for predictive maintenance

- If preventive maintenance can be approached inhouse, for predictive maintenance most companies must rely on technology providers

- The market for software (and hardware) solutions to automate and support the predictive maintenance process is very diverse

- Companies with experience in manufacturing or technology are striving to develop integrated solutions/platforms

- Some examples (for illustration purposes) are:
  - https://global.abb/topic/ability/en
  - https://siemens.mindsphere.io/en
  - https://www.ge.com/digital/iiot-platform

ABB

ABB Ability™

SIEMENS

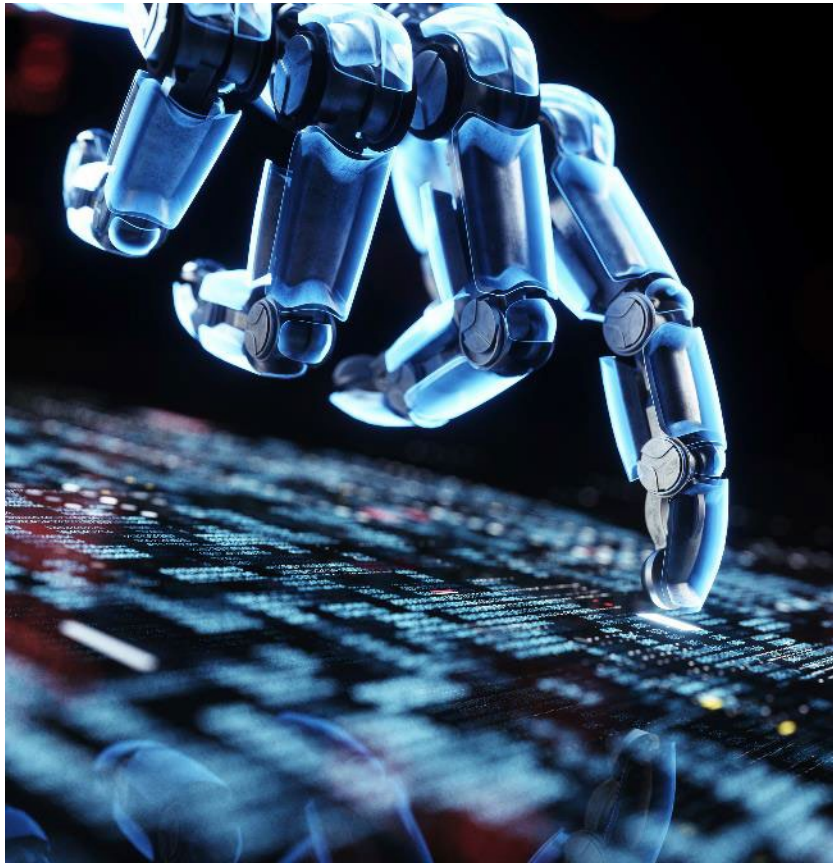
Ingenuity for life

GE Digital

PREDIX

Software solutions for predictive maintenance

- Software solutions for predictive maintenance are usually part of larger IoT approaches deployed as SaaS by big tech companies
- They can be used as cloud solutions by SME, with the possibility to tailor them to the specific needs of the company
- Payment is in the form of subscription fees that depend on number of devices, number of transactions and/or the time the platform is used
- Due to its nature, based on quantifiable physical processes (e.g., wear, environmental interaction, signal degradation etc.), predictive maintenance is well suited to the implementation of machine learning and artificial intelligence solutions



OUTLINE OF SIMULATION FOR QUALITY

- Role of simulation in manufacturing
- Design for Excellence (DfX)
- BPM (business process modeling)
- BPMN (business process modeling notation)
- Value Stream Mapping (VSM)
- Organizational simulation of ISO 9001 quality systems

Role of simulation in manufacturing

- Using a computer to model and analyze a product or a process in a virtual environment enables better results, reduced costs and faster turnover times
- The simulation tools assist manufacturing businesses in determining whether a product will meet customer needs, whether changing features might help cut operational expenses, or how the product will function in various circumstances, and in other quality related analyses
- Simulation is an important part of achieving and fulfilling Industry 4.0/Quality 4.0 principles, and almost all manufacturing companies use it before beginning to produce a product or develop a process
- CAD-CAM-CAE solutions have been used for over 30 years, PLM (product lifecycle management) and LCA (lifecycle analysis) are already vital for green manufacturing, while collaborative design and servitization are becoming common place with the assistance of simulation

Design for X

Design for Excellence is a framework for product design and development that can be used to guide simulation efforts in the manufacturing industry

The method is also known as Design for X, where X represents the target/ objective of the company

This method incorporates DFSS (Design for Six Sigma)

Types of Design for X (DFX) used for quality topics:

Design for Manufacturability

Design to Cost

Design for Inspection

Design for Testability

Design for Maintainability

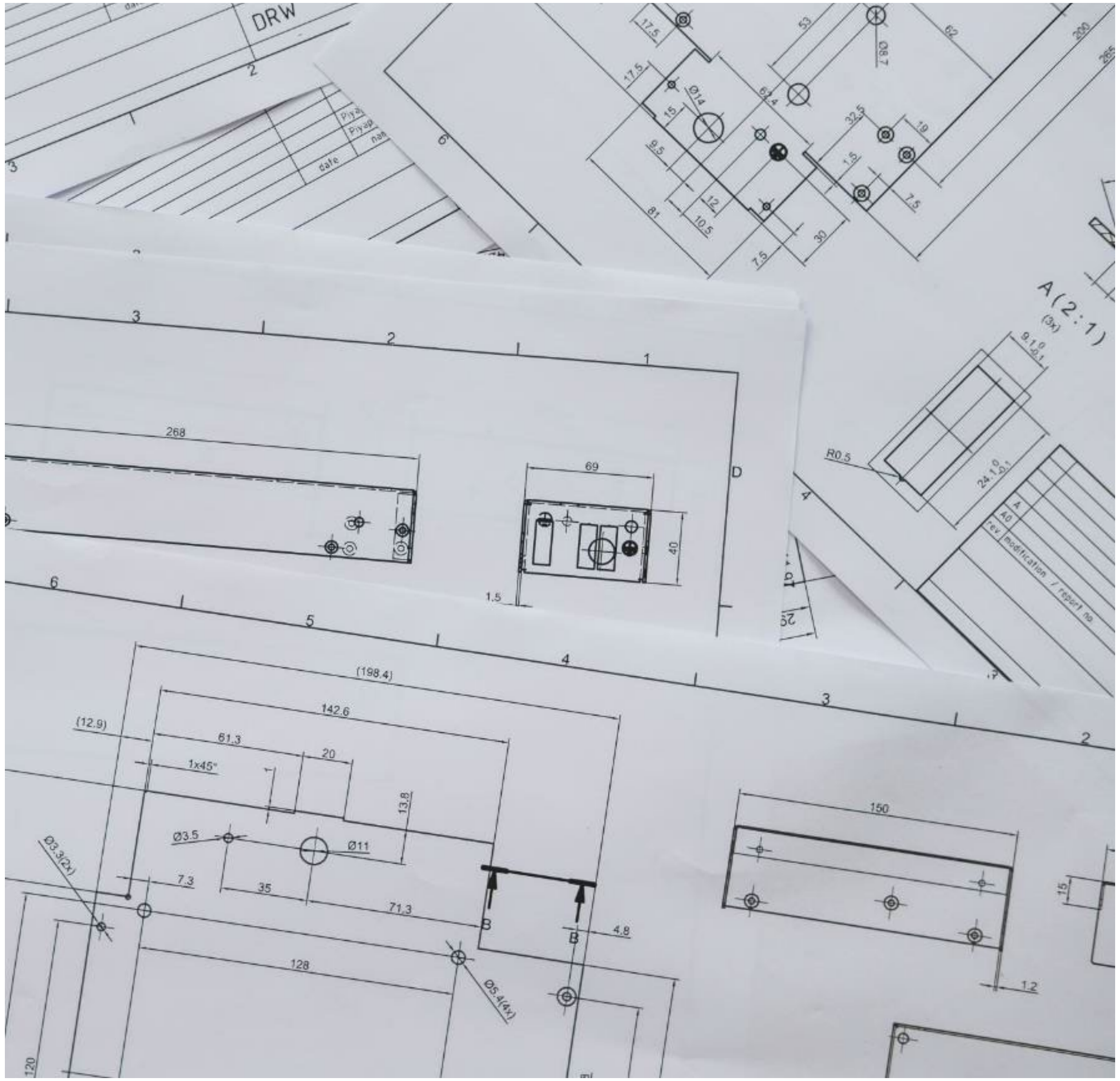
Design for Usability

Design for Robustness

Design for Safety

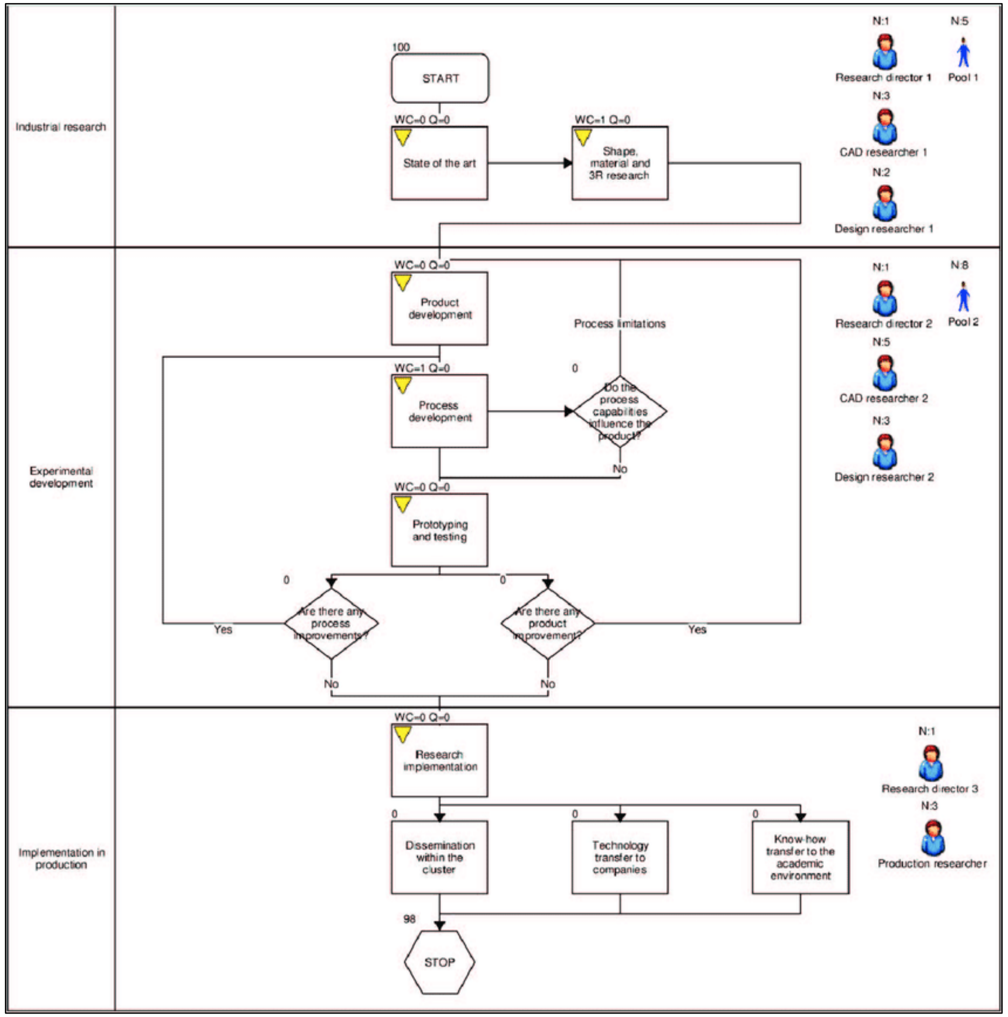
Design for Environment

Design for Sustainability



Business Process Modeling (BPM)

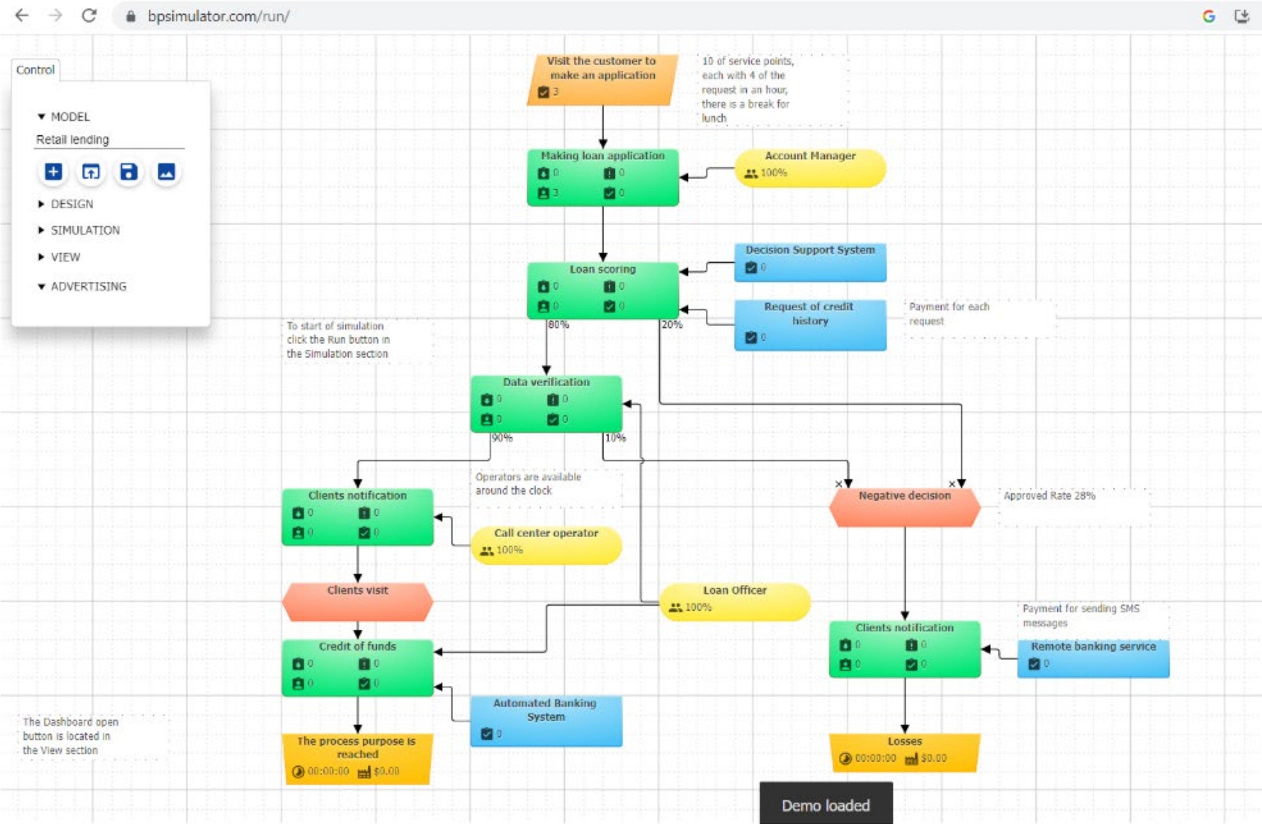
- To accomplish strategic business goals, manufacturing firms must focus on process effectiveness and efficiency
- Business process modeling (BPM) is the technique that involves the detailed study and analysis of the entire business process in order to digitalize the activity and achieve the best results
- This approach calls for a methodical and organized overview of the entire system, in which each task in the process is described by means of technical parameters such as productivity, variability, time needed, defect rate, resource costs etc.
- By running a simulation on the model (discrete event, continuous, Monte Carlo, etc.), insight about improvement opportunities can be gained



Source: M. Dragomir, Ș. Bodi, O. Iamandi, D. Dragomir, Applying SigmaFlow Simulation Software for Improving the Quality of an R&D Project, Proceedings of the 2014 ICPR-AEM & QIEM, Cluj-Napoca, pp. 143-147

BPMN (Business Process Modeling Notation)

- Business process modeling can be done using a multitude of symbolism approaches
- BPMN 2.0 (Business Process Modeling Notation) is the current international standard adopted by most companies and software solutions
- By having common notation, the modeling process is sped up, continuous improvement is more effective and simulation software can be deployed with ease



Source: https://www.bpsimulator.com/run/ - Demo model

Copyright: prolis lab2k, 2019

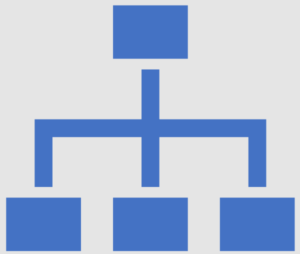
Value Stream Mapping (VSM)

- One of the most powerful tools of Lean manufacturing is Value Stream Mapping that seeks to identify the connections between processes and among the company and its external stakeholders
- The focus is on determining and maximizing useful activities and the times used to accomplish them, as well as to identify the main types of waste within the production system
- Overproduction, delays, unsynchronized processes and unnecessary or oversized inventories are targeted for reduction to make sure the company is focused on producing value for the customers, when and how they require it by employing a “pull” approach
- Dedicated software can simulate the situation and help in discovering improvement scenarios
- Also, by factoring in the variability reduction of Six Sigma, the production process is oriented towards the needs of the beneficiaries without burdening the machines or the workers

Organizational simulation - ISO 9001

- Simulation can help in the implementation of all aspects of quality management, either technical or organizational in nature
- Simulation of planning and execution activities leads to a more efficient organization and avoids waste of resources
- Many times, the difficulties arise when simulation systems are focused on specific issues and can’t interface with other software
- Integrated organizational simulations can be achieved using complex packages (e.g., Dassault Systèmes CATIA v6)

Organizational simulation



ISO 9001:2015

Common components of an ISO 9001 software system include:

- human resources administration
- documented information tracking and control, backup & archive
- equipment status monitoring and maintenance (corrective & preventive)
- product design review and validation
- inventory and component management using RFID
- corrective action follow-up system
- improvement project management
- customer relations management
- complaint handling
- quality and non-quality cost identification
- management of logistics, tooling, consumables, measurement devices, etc.

OUTLINE OF VR/AR

- Staff training and development
- Task completion assistance
- Co-location for complex tasks
- Problem solving support
- Customer communication

Staff training and development using VR/AR

- VR and more recently AR are well recognized as technologies that have the capability to support processes related to the development of the human resources in a production company
- These tools can increase the frequency and quality of training, by sensorial immersion, while maintaining a low cost and avoiding equipment unavailability
- They are instruments for businesses to improve employee skills and to add new skills, before they are needed on the production line
- Some areas, such as occupational health and safety and emergency intervention can benefit even more from VR/AR training as they help fulfill compliance requirements and safeguard lives

Staff training and development using VR/AR

- The cost of VR and AR equipment and software is going down constantly and the complex systems that were only affordable to big companies and complex industries are becoming common place even for small and medium sized companies
- Training and development using these solutions has a high level of efficacy and is well received by the younger generation of workers, that have been brought up in the digital world
- There is no need to stop the main production processes, there are no expensive equipment that can be damaged and there is no raw materials or consumable that are needed for training
- However, having customized solutions and performing the training on time will require the firms to have specialized personnel or a close relationship with dedicated service providers

Task completion assistance

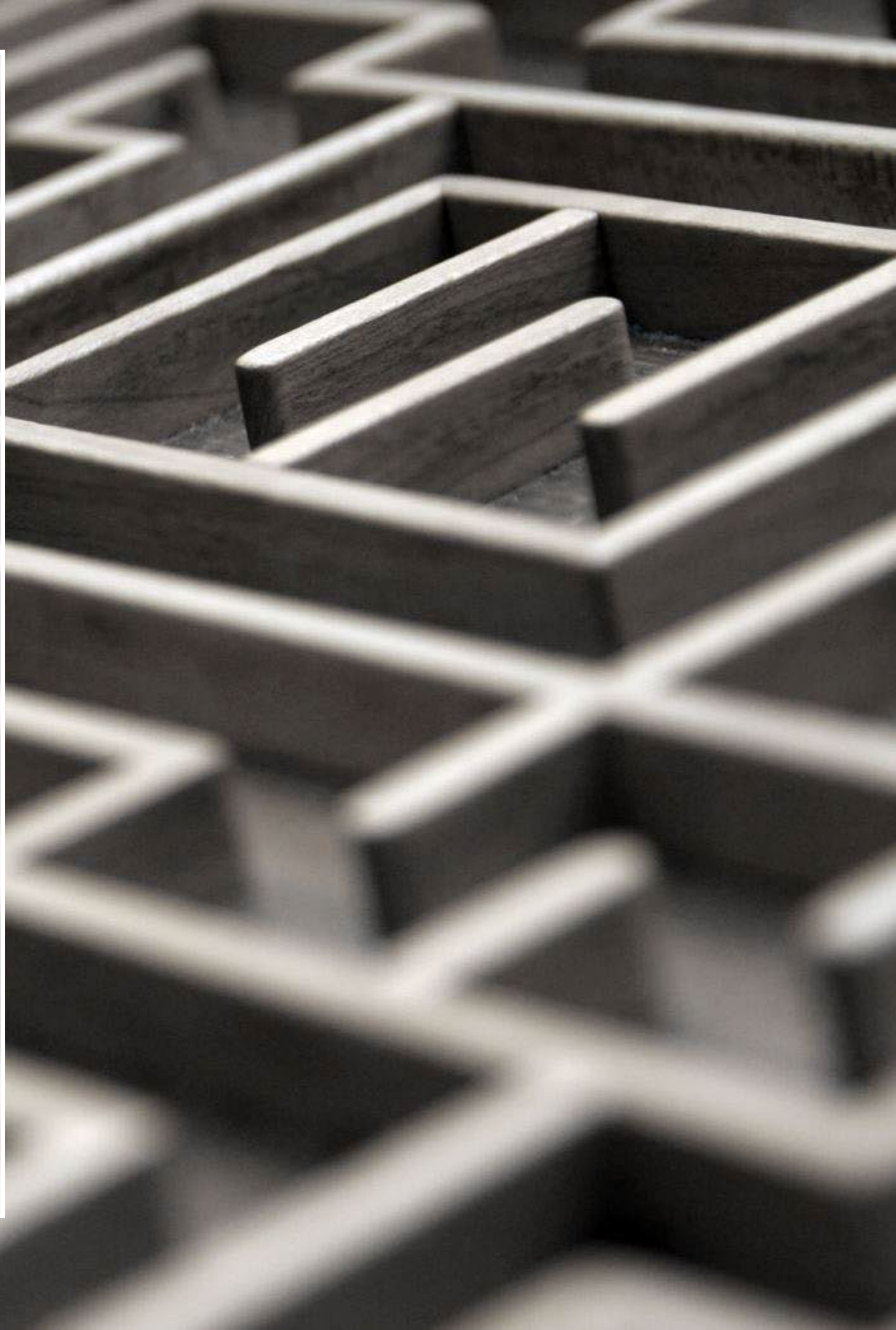
- Usually, at operator level, the main instrument needed is a VR or AR headset that can display accurate processes information
- This can be done asynchronously, mostly as a teaching tool, or it can be done using digital twin software in a real-time, synchronous, manner, which also contributes to assisting the user in completing their jobs
- When process simulations, smart equipment and VR/AR equipped user interact in delivering a certain result, less effort is spent in making sense of the environment and accommodating to the manufacturing process, and more time is directly productive, thus increasing process yields and other important parameters, such as capability and stability
- In VR, information is presented in a more realistic and authentic manner, increasing the users’ engagement and allowing them to anticipate the appearance of errors, defects and non-conformities

Co-location for complex tasks

- Augmented reality is formed when real-life situations are enhanced by VR elements over imposed on the active process
- Digital artefacts from the virtual environment are brought in the physical environment, beyond the capabilities of human operators, assisting in visualization, interaction and data processing
- Co-location tools allow a shopfloor operator and computer operator to collaborate via the AR device to solve a task
- Usually, the computer operator is an expert that can share information across large distances and to multiple audiences, increasing competitiveness
- Co-location can be used for assisting sales, to perform delicate operations, or to enable the sharing of know-how by the companies engaged in Quality 4.0

Problem solving support

- Quality engineering depends to a high degree on problem solving, which should be fast and precise, to help in treating customer complains or internal non-conformities
- When VR or AR technology is used, employee creativity can be increased since they form a risk-free environment to test and re-test innovative solutions
- In addition, these tools can be used to increase employee involvement, mostly by bringing a concrete, physical, dimension, to the usually abstract concepts used by quality specialists, like variability or satisfaction
- Visualization is a strong driver for product and design engineers to get involved into process improvement efforts



Customer communication with VR

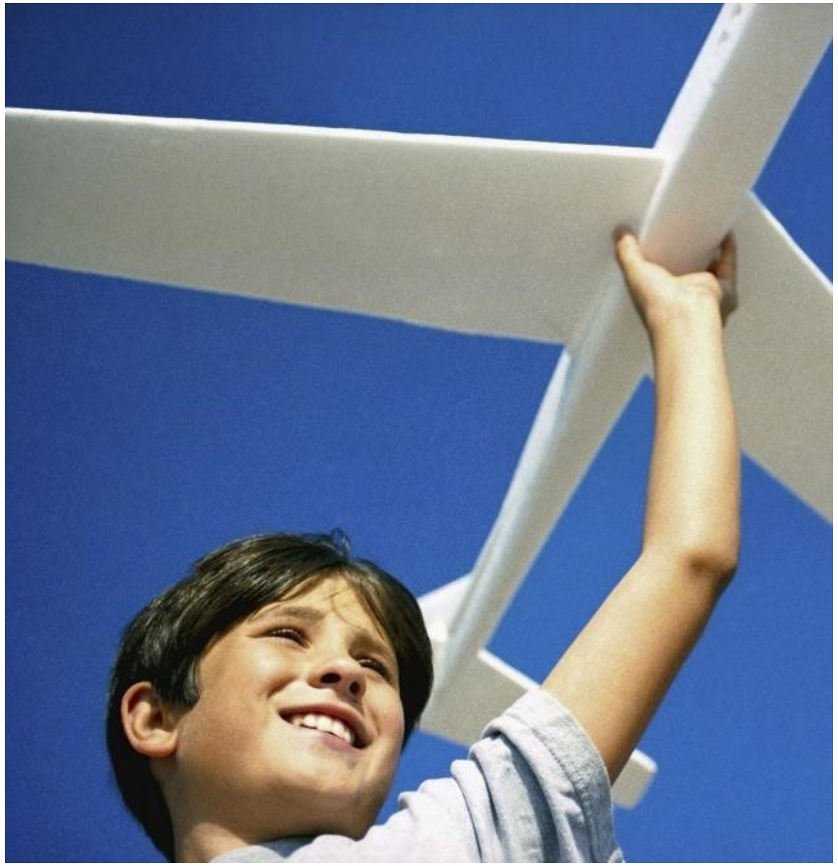
- VR technology offers customers a new way to experience products or services by allowing them to see them in detail and interact with them before making a buying decision
- It can be especially useful in situations in which both the customer and the company can’t anticipate all the details or emotional connections related to a consumer product/solution once it is integrated with the existing framework in which it will perform its functions (e.g., in the fashion industry, in interior design, landscaping, etc.)
- In other types of interactions, companies can gather data about customers' preferences even if they are manifested in an unconscious way. For example, VR technology can record users’ actions, from how they react to the product, what uses they find for it or even biometric data, such as eye tracking, heartbeat rate or respiration rate.
- This way, customer involvement with the product as well as brand awareness and loyalty can be significantly increased, although some ethical boundaries must be observed

OUTLINE OF 3D RINTING

- Product mock-up and validation
- In-process custom devices
- Focus group support
- Fast&consumable tools/products
- Process validation

Product validation

- The most important step in validating an idea is to create a prototype or minimum viable product, and the fastest way to do this is with a 3D prototype created using additive manufacturing
- Product validation can save a company huge costs, either by advancing the correct form/function of a product or by avoiding egregious mistakes
- Printing a 3D prototype can be done in increasingly complex steps, with more and more expensive materials, until it enables a business to thoroughly examine the functionality and aspect of the product
- Any changes that need to be implemented based on testing under real-life conditions will save the company from producing scraps, creating customer insatisfaction or compromising its image



In-process devices

- Sometimes, even classical manufacturing using machining processes or nonconventional manufacturing using electro-chemical or similar methods require specific tools, devices and verifiers
- These should be adapted to the product being manufactured and the operations being performed
- 3D printing can significantly shorten the time needed to develop them and, at the same time, it allows for faster improvement iterations and reduced costs
- Modern 3D printers can also use metallic materials and achieve a high durability and resilience of the devices, suitable for Quality 4.0 implementations

Focus group

Making a quick 3D prototype and using it in a focus group can help gather more details about what the targeted market niche wants from the product or how the company can answer its requirements

The focus group members can provide more and better feedback thanks to the physical form of the prototype, in comparison to written descriptions or computer/VR simulated models

An entire social movement of “makers” has developed across the globe, with creators working in dedicated makerspaces and contributing to the advancement of innovation and entrepreneurship ecosystems through well researched physical products that can become market success

Fast&consumable tools/products

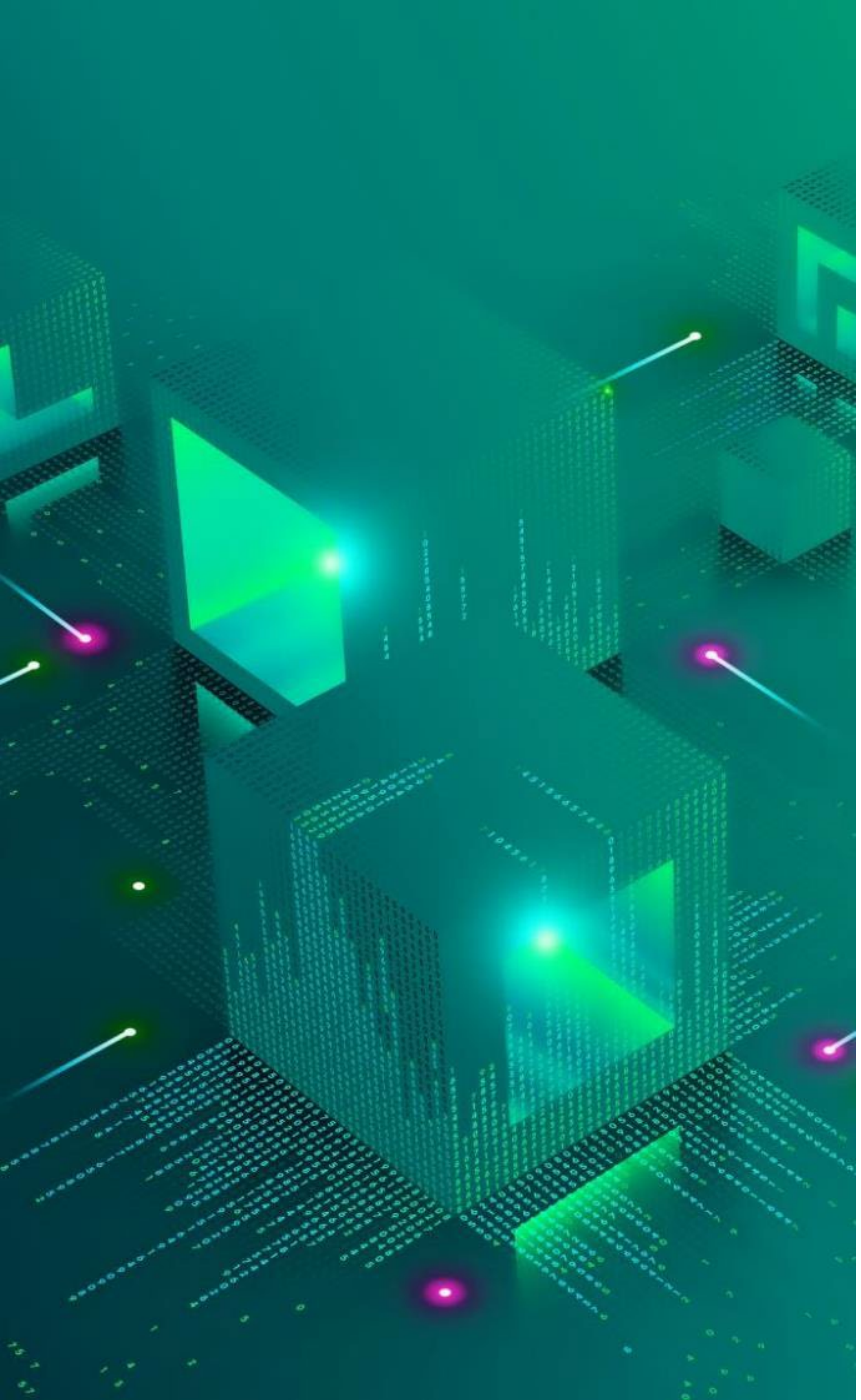
- In some instances, certain tools or even fully developed products are not needed for a long time, in a high quantity or with increased durability
- For situations like medical treatments, event organization or product demonstrations, fast and consumable artefacts can be created through 3D printing
- Once they are used and no longer needed, these quick turnover products can be recycled as part o a circular economy approach
- Such situations are convenient for the producers and the consumers, but are also in the public interest, as they reduce taxpayer costs related to waste management

Process validation

- In quality management, process validation is an important step to ensure a correct and timely approach before production is ramped up and mass manufacturing takes place
- Nowadays, customers have complex and detailed requirements, thus bringing about the necessity to perform mass customization, which transforms process-based work into a connected series or network of project-based deliveries, usually starting from a core product to which specific modules can be attached
- In such an environment, 3D printing technologies can help by lowering the time and resource commitment of creating these specific modules, thus fostering unique customizations
- Aesthetic elements (e.g., inserts, skins, interaction elements) which contribute highly to customer satisfaction can be easily approached in this way

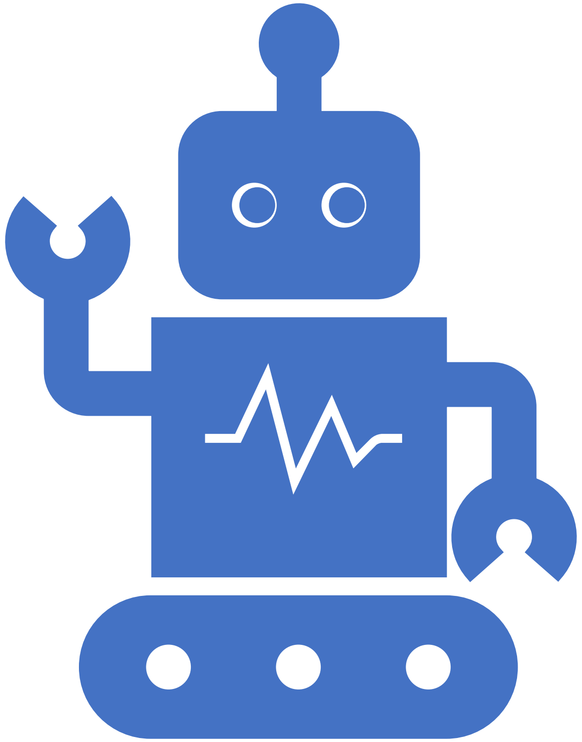
OUTLINE OF DIGITAL TWINS

- DT&AI for quality
- APQP/PPAC
- SPC/MSA
- DoE
- PERT&CPM



DT&AI for Quality

- Digital twins have been evolving for decades from integrated computer aided systems that support manufacturing processes, up to the level of today, when they faithfully mimic in the virtual environment the situation from the real factory floor and allow bi-dimensional communication and interaction
- Also, the most recent incarnations make use of artificial intelligence solutions that assist human decision-making or even make decisions themselves
- In a way, all the technologies presented above in this course, can become part of a fully functional digital twin
- A digital twin can assist designers, engineers and managers in delivering more effective processes or products by providing an accurate and up-to-date model of the original, on which development, problem-solving and improvement can be carried out
- The quality function of an organization can benefit from the use of digital twins and artificial intelligence in matters pertaining to enhancing process performance and eliminating non-compliance



DT&AI for Quality

- Artificial intelligence, especially machine learning algorithms, that have the possibility to detect and anticipate trends and correlated seemingly unrelated events, is of great help in managing risks and opportunities
- By storing large amounts of data of all types (sensor information, images, key performance indicators, customer related information) and performing frequent checks on it, DT systems can present the humans involved with timely solutions to quality problems
- In case of emergency situations or unacceptable risks, the AI systems can also shut down threatening operations, before they can hurt the operators or create dangerous accidents

APQP/PPAC

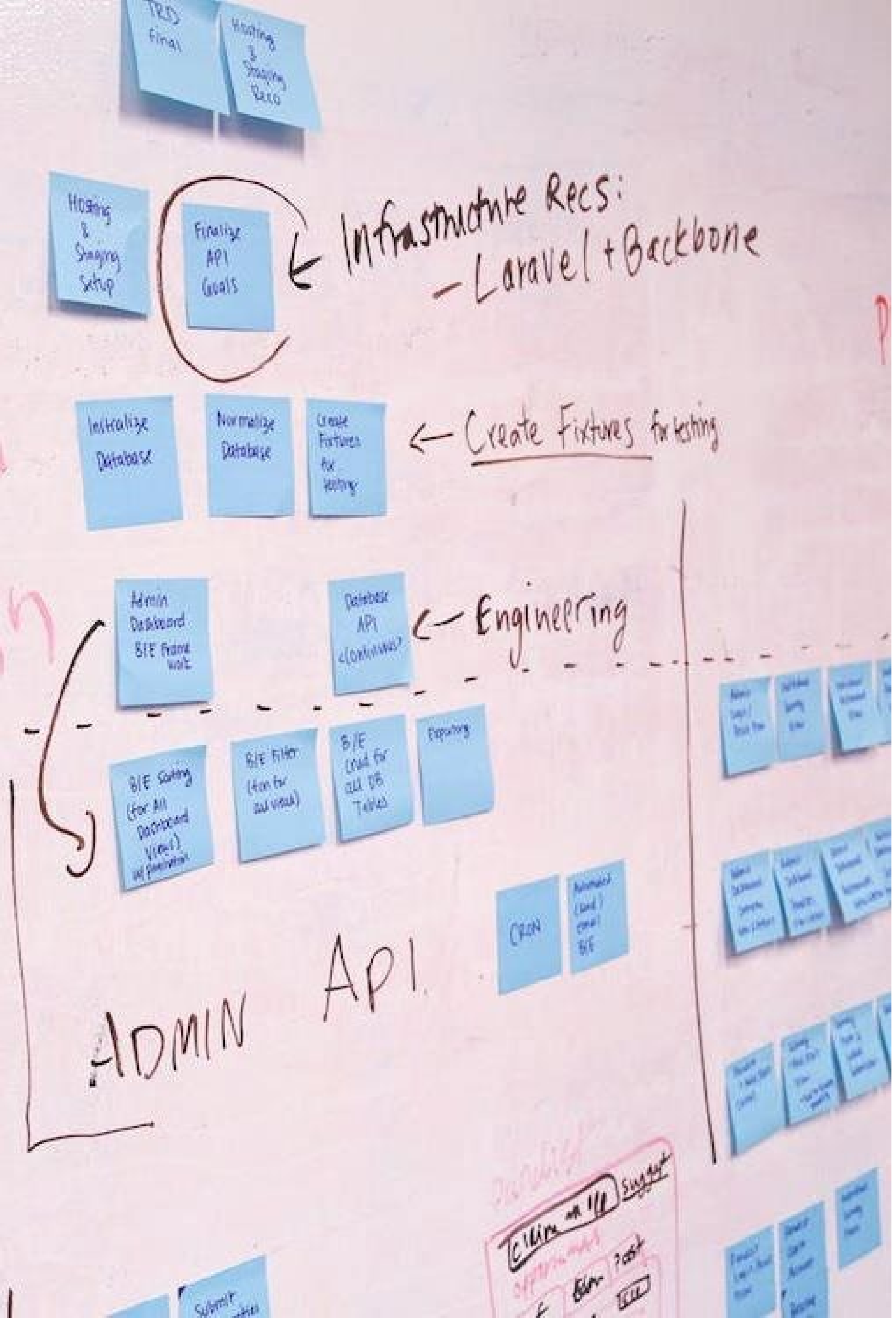
- Both the Advanced Product Quality Planning (APQP) and the Production part approval process (PPAP) are complex quality management tools for high-tech industries, such as automotive, aerospace or consumer electronics
- The combine across multiple conceptual chains specific tools (e.g., FMEA for risk management), dedicated forms and decision-making gates, with the aim to ensure quality is “built-in” into the products
- The employment of digital twins across the factory floor can significantly speed up these two processes and help to avoid delays, miscommunication and errors that lead to costly rework
- AI enabled digital twins can parse the procedures with little to no control or supervision from the human workers, expect for the final approval step

SPC/MSA

- Statistical Process Control (SPC) and its metrology counterpart, Measurement System Analysis (MSA) can significantly benefit from real-time integration with the operations they are used to control
- By implementing the tracking of variability within the production or measurement processes, more timely measures can be implemented when certain unwanted trends or events are detected
- Also, the digital twin system allows for long time storage of significant amounts of data, extending the process improvement approach over longer stretches of time
- Statistical information can further be derived from interactions of the production process and the digital copy when implementing improvement scenarios

Design of Experiments

- Design of Experiments is a statistical tool for process improvement that is usually implemented via specialized software such as Minitab to limit the workload when working with multiple parameters to improve performance
- By employing a digital twin solution, digital data is communicated faster in both directions, improvement results are evaluated on the spot and entire procedure can be caried out remotely
- In such cases, multiple runs can be performed rapidly, with a lower experiment consignment for each, thus allowing for the identification of fainter variability sources and the high-level tune-up of the process being analyzed



PERT&CPM

- Time optimization of projects to be implemented in manufacturing companies can also be of interest for the quality management function of the organization
- Dedicated methods like Program Evaluation and Review Technique (PERT) or Critical Path Method (CPM) can decidedly be automated with the help of the digital twins
- Software systems can find the best combination of activities within the available time frame and taking into account the existing constraints
- However, if a digital twin is implemented, the methods become “live” and permit the adaptation to changing conditions
- The furnished results can support the flexibility and agility of the project management approach

Instead of an ending

- The digital transformation of industry and all its related sub-fields, including quality engineering and management is an ongoing effort that takes place across the globe
- Both companies and universities, as well as other professional bodies contribute to the refining of these approaches daily, with the aim to support the improvement of competitiveness
- The aim of this training material for students is to give them an introductory understanding of the myriad possibilities that exist in the field
- Once they graduate, it is up to them to become part of this trend and contribute to further development of Quality 4.0 topics

Instead of an ending

- Of course, the presented approach must be understood in relation with the Quality 4.0 concept developed by the well-known Juran Institute
- Their specific model can be studied in detail here: https://www.juran.com/blog/quality-4-0-the-future-of-quality/
- The viewpoint presented in the current e-book focuses mostly on the topics that are relevant to manufacturing, while at the same time, dealing also with traditional quality topics seen through the lens of Industry 4.0

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