

Introduction to Industry 4.0

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Session Overview

1. To define what is meant by the term industry 4.0 / 4th industrial revolution.
2. Discuss the evolution of manufacturing systems, including a review of the 1st, 2nd & 3rd industrial revolutions.
3. To discuss the opportunities brought about by i4.0 and discuss the challenges to implementation.
4. To introduce the terminology & enabling technologies of i4.0 including: cyber-physical systems, artificial intelligence, additive manufacturing, Internet of things (IoT), big data & analytics, augmented reality, simulation & digital twins and advanced automation, robotics & use of smart sensors.

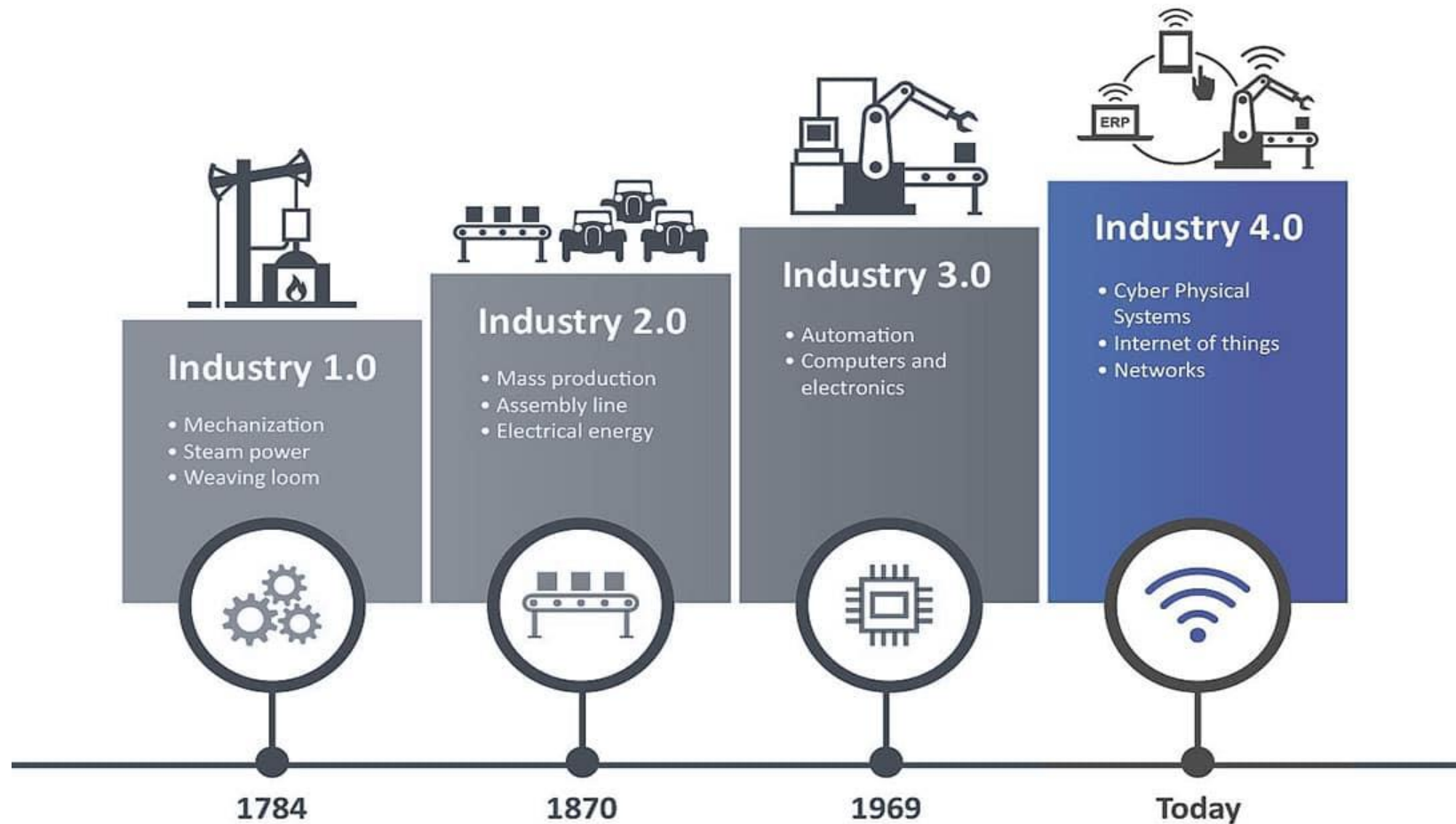
What words come to mind when you think of the term
"Industrial Revolution".



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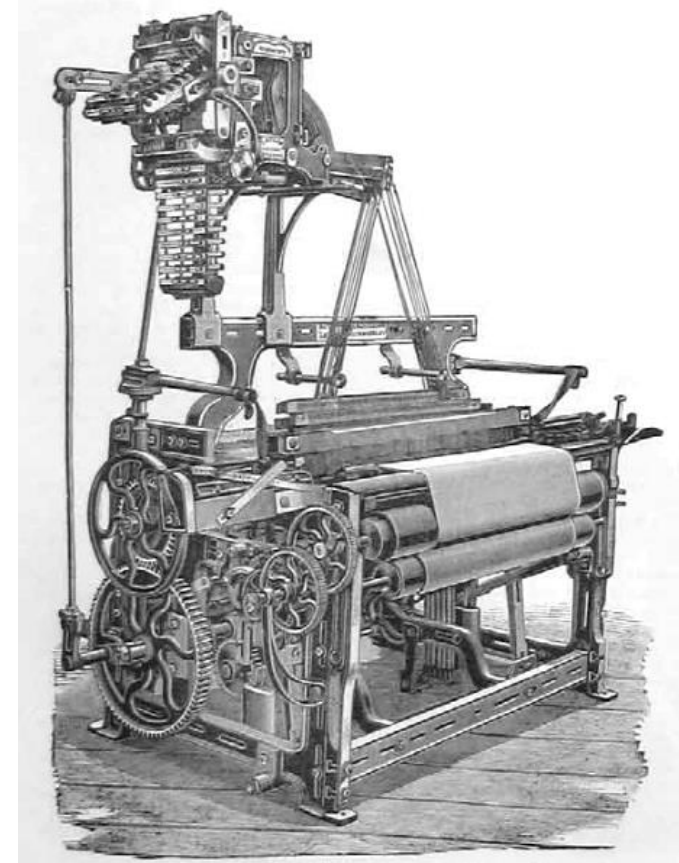
A Brief History



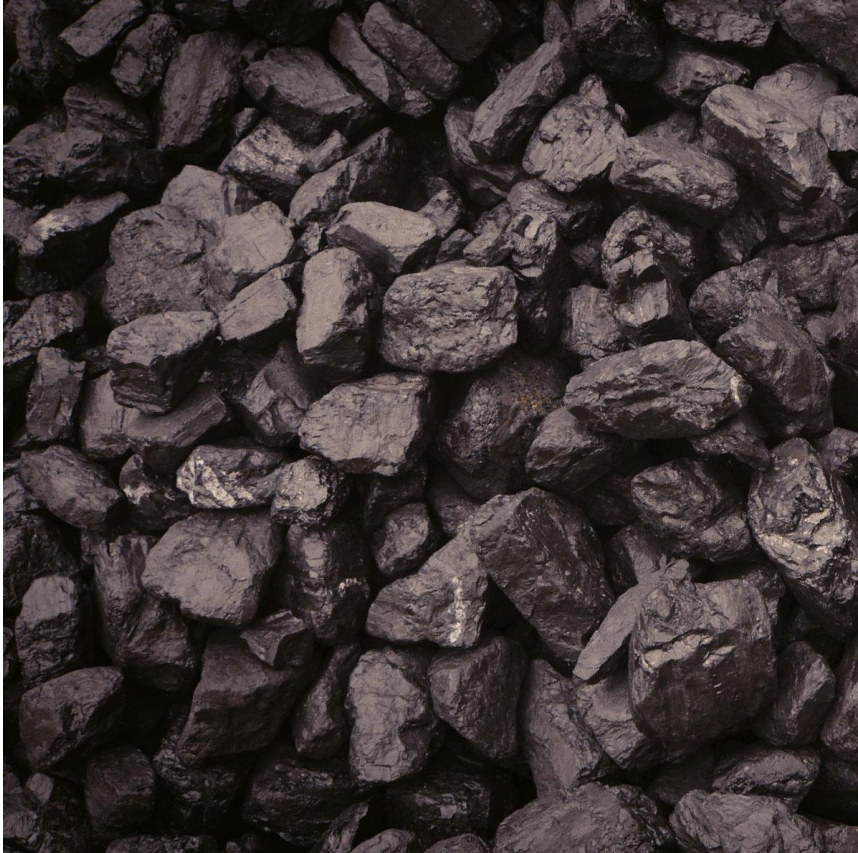
1st Industrial Revolution

(Mechanisation 1760 – 1840)

- The precise start (and end) date of the 1st industrial revolution is still debated among historians.
- Involves the transition away from hand production methods to the adoption of machines, in this sense, it describes the rapid industrialisation or mechanisation of production / manufacturing.
- Largely attributed to the development of mechanised textile production (weaving looms) that replaced hand weaving and spinning wheels in the textiles industry.
- This trend of mechanisation rapidly proliferated into other sectors including metallurgical industries, mining, and transportation for example.



1st Industrial Revolution Enabling Technologies



Coal as Fuel

- A shortage of timber in the mid 18th century resulted in a lack of charcoal as a fuel source.
- As a result, the metallurgical industries (iron and steel production) were forced to look elsewhere for a fuel.
- The fuel they found was coal. When coal is heated in the absence of air it turns into coke.
- It became cheaper to produce than charcoal and could be packed more tightly into a furnaces.

Enabling Technologies Continued



(Illustration of the Corliss Steam Engine)

Steam Power

- The steam engine helped to power the industrial revolution. Before steam power, most factories and mills were powered by water, wind, horse, or man.
- Steam power allowed for factories to be located anywhere.
- It also provided reliable power and could be used to power large machines.
- The left image is of the Corliss steam engine, The 700-ton engine produced a staggering 1,600-horsepower.

Outcomes of industry 1.0

- Technological advancements (locomotives, steam boats & stationary engines).
- Advancement of infrastructure (roads, railways and waterways).
- Development of legislation and standardisation (Laws and safety standards).
- Economic and social reform (rapid population growth, urbanization & job opportunities).

2nd Industrial Revolution

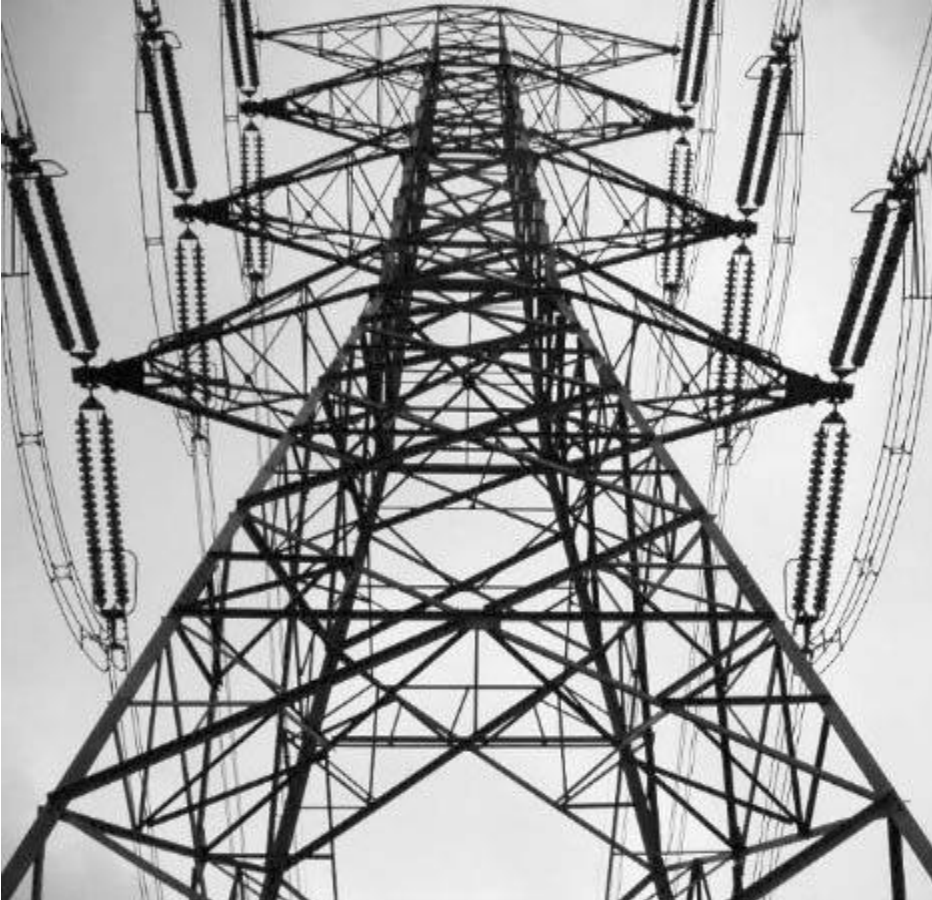
(Mass Production 1870-1914)

- Describes the transition to mass production methodologies.
- Its hard to imagine the world before widespread electrification, yet it was only at the very end of the 19th century that electrical devices began to appear.
- These developments transformed factories and transport networks, launching a series of labour-saving devices.
- Henry Ford's moving assembly line is a widely used example here. His innovation reduced the cycle time to assemble a car from more than 12 hours to one hour and 33 minutes.



(Ford Model T Moving Assembly Line)

2nd Industrial Revolution Enabling Technologies



Electrical Power

- Research into the practical uses of electrical energy in the late 1800s resulted in the development of the light bulb & electric motors for example.
- Electrical power was cleaner and more reliable than alternatives (steam power).
- Development of electric motors made moving assembly lines feasible and achievable.
- Moving assembly lines increased productivity and decreased costs.

Motivation and Outcomes

- Decreasing the cost of production can be seen as the main driving force behind the 2nd industrial revolution (increased production capacity – Lower reliance on labour).
- There was an economic and productivity-based boom in industrialized countries.
- As a consequence, living conditions improved significantly (improved infrastructure) and the prices of goods fell dramatically, modern consumerism begins.
- Urbanization increased rapidly. The population moved into hastily built housing in cities to be nearer to the factories (better work prospects).
- A turbulent time of quick and continuous progress. Ageing assets became obsolete in a short time span.
- The availability of work became unpredictable, with fluctuation in the demand for goods and the increasing impact of mechanisation.

Digitisation

- Simply put, it's the process of taking non-digital (analog) formats of information and turning them into digital formats.
- Mail into email, spreadsheets into Excel, handwritten notes into Google Docs, clay models into CAD files, physical properties into sensor data etc.

Digitalisation

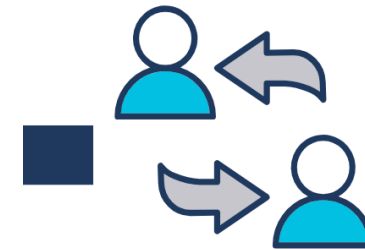
- Digitisation is a precursor to digitalisation.
- The term digitalisation is used to describe transformation of processes (both manufacturing and wider business) by leveraging digital technologies.
- Digitalization of manufacturing is changing how products are designed, fabricated, used, and serviced, just as it's transforming the operations & processes within factories and supply chains.

A Simple Way to Look at Digitization & Digitalization



Strategy

Digital Transformation
impacts the entire business.



Processes

Digitalization
affects processes and interactions.



Information

Digitization
happens to data and information.

Thought Exercise

“You are a process engineer, as part of your day-to-day tasks, you collect defect information from batches of small injection moulded parts as part of a Statistical Process Control (SPC) activity. Traditionally, you record this data on a hand drawn chart using pen and paper. However, a tablet based system now allows you to record this information directly into a Excel sheet. What are some of the benefits of the digitisation of this data?”

■ ■ What are some of the benefits of this form of digitisation? ■ ■

As Time Passes

- Which piece of data is more accurate / legible.
- Which is most likely to get lost?
- Which is most accessible?
- Which is easiest to share?

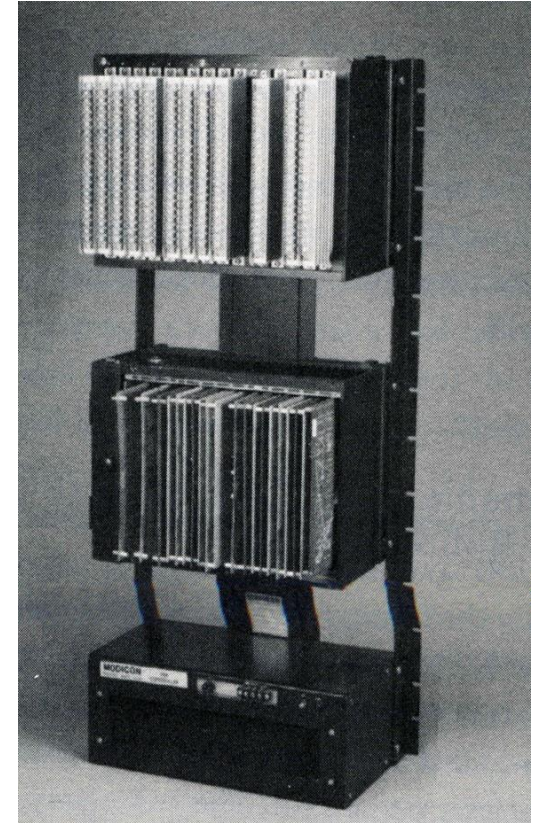
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3rd Industrial Revolution

(Automation & Digitisation 1969-2000s)

- Often described as the digital revolution, describes the move towards automated manufacturing systems.
- The start of the 3rd industrial revolution is often attributed to the introduction of Programmable logic controllers (PLCs) in the late 1960s, a major advancement over manual relay control systems.
- Characterized by the proliferation of automation and digitisation through the use of computer control and the development of new actuation (servo-controlled motors) & sensing technologies.



(Modicon 084 PLC)

3rd Industrial Revolution Enabling Technologies

- Developments in microelectronics, such as the advancement of semiconductor, transistor and integrated circuit technology spurred the development of microcontrollers/processors, digital signal processors, and System on a chip (SoC) devices.
- These advancements resulted in derived technologies such as PLCs, Mainframe computers and PCs.
- The development of computer controlled systems led to the development of automated systems, such as industrial robots.
- Advancements in telecommunications simplified global communications.

Industry 3.0 Motivation and Outcomes

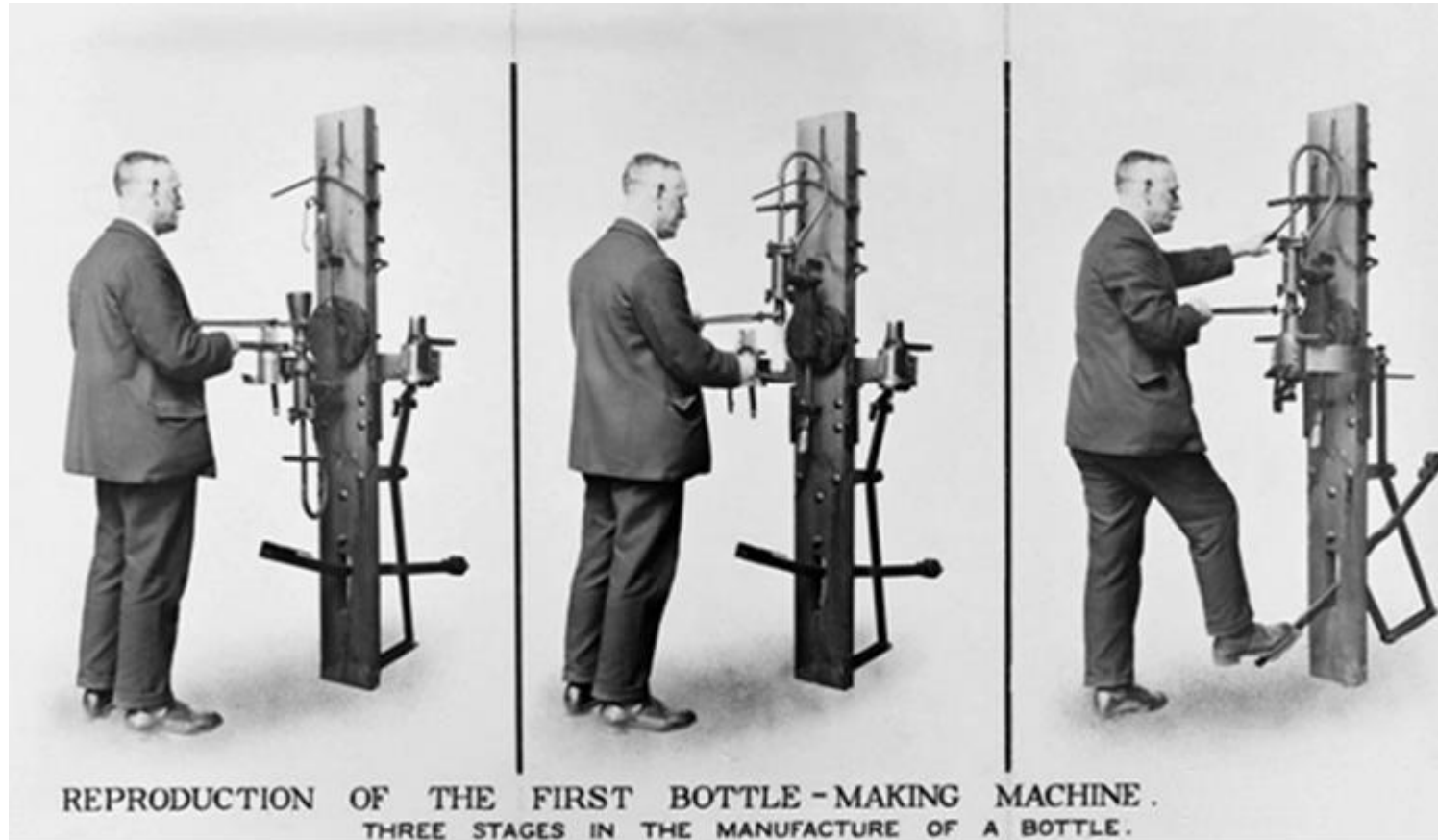
- As well as improving productivity, capacity and reducing operational costs, improving quality (by reducing manufacturing variance) is one of the main driving forces behind automation and the 3rd industrial revolution.
- Quality is improved by eliminating human error, improving consistency and accuracy, giving the ability to create more complex goods, and identifying (and mitigating) process errors in real-time using closed loop control and quality assurance activity.
- Improved working environment (reducing dangerous, boring and repetitive jobs).
- Increased competitiveness, sales and profits and decreased lead times and time to market.
- Displacement of workers (ONS predicts 20 million job losses to automation by 2030).
- Promotes winners and losers – inequality (disproportionate impacts depending on where people live, their gender and their level of education).

Glass Bottle Example

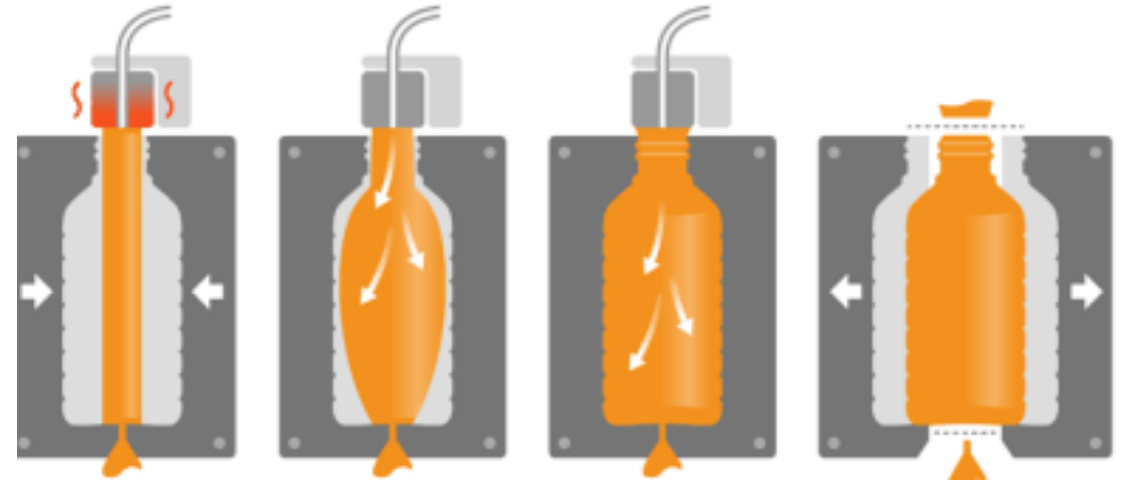
Manual Process – Mouth-Blown bottles



Early Mechanisation – Plank's 3 step process Early 1800s

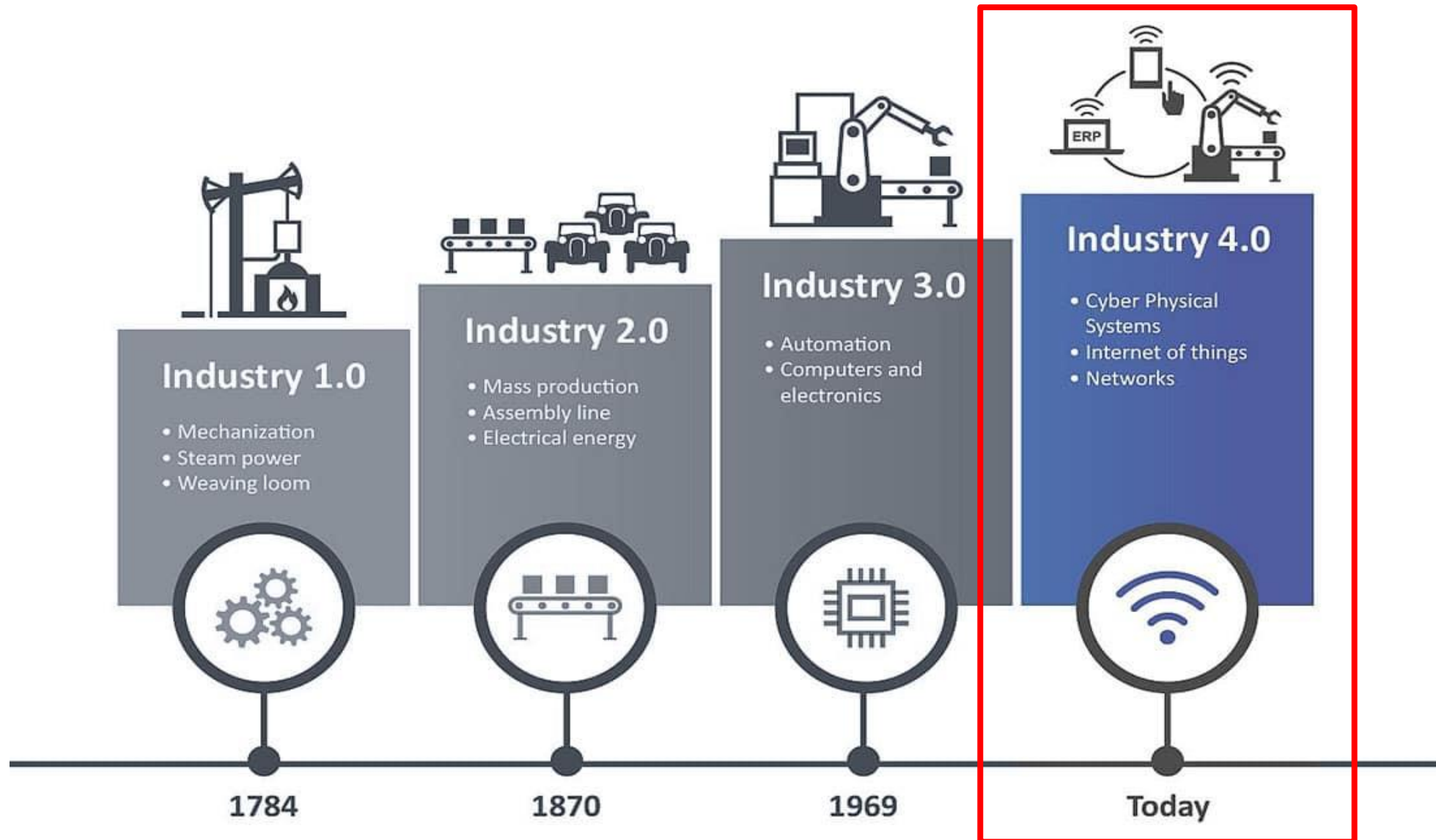


Move to Mass Production– Extrusion Process





- Modern bottle manufacturing is a fully automated process with little to no human labour involved.
- Sophisticated production facilities are capable of vast throughputs, with many manufacturers quoting a capacity upwards of 400000 glass bottles per day.
- Automated inspection systems include wall thickness inspection, damage detection, checking dimensional tolerances, sealing surface inspection, side wall scanning and base scanning.

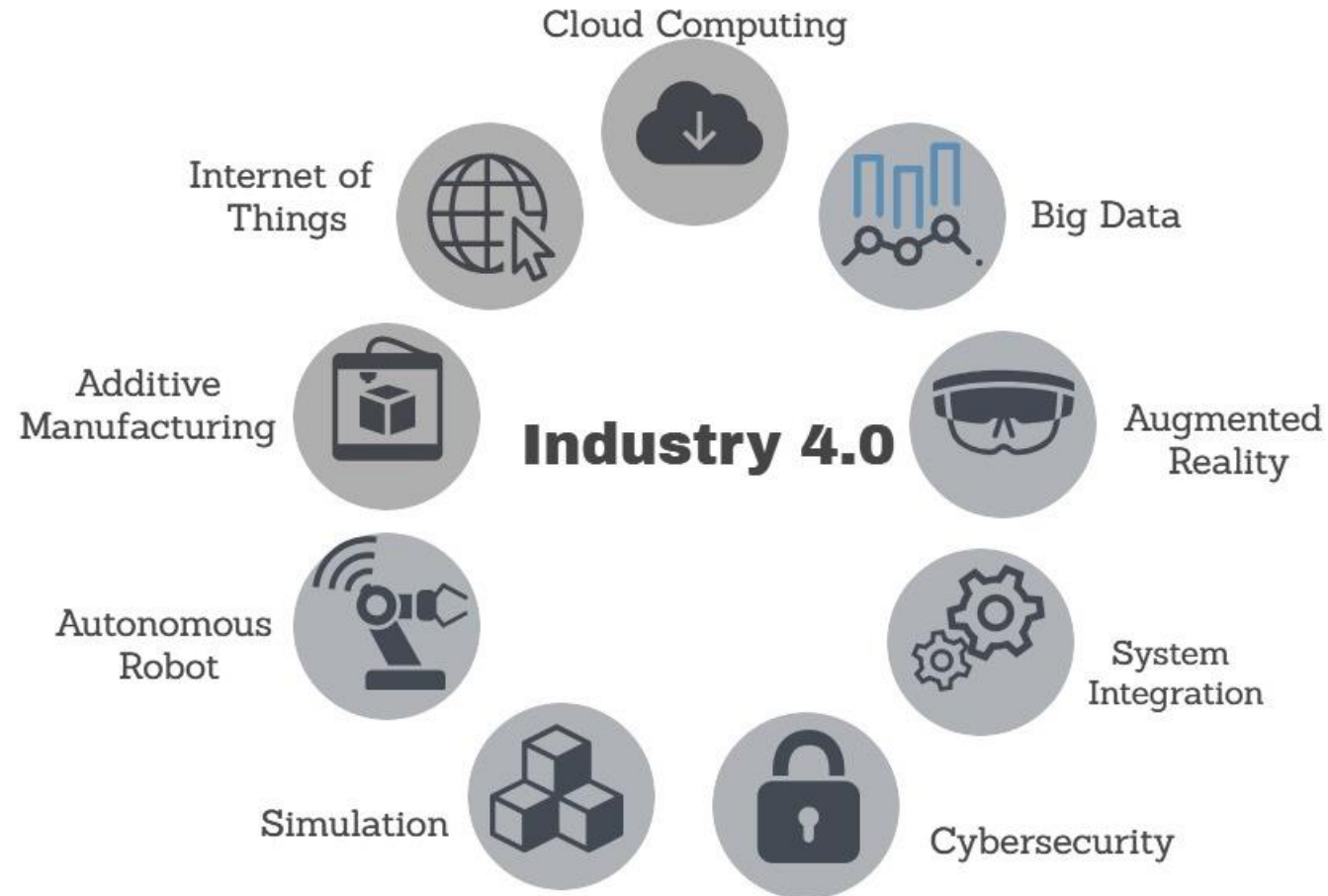


So what is Industry 4.0?

"Industry 4.0 refers to the fourth industrial revolution, and describes the growing trend towards digitalisation of manufacturing, the use of smart/adaptive systems and modern approaches to data exchange between devices and processes within the manufacturing industry, including cyber physical systems, big data analytics and the industrial internet of things (IoT)."

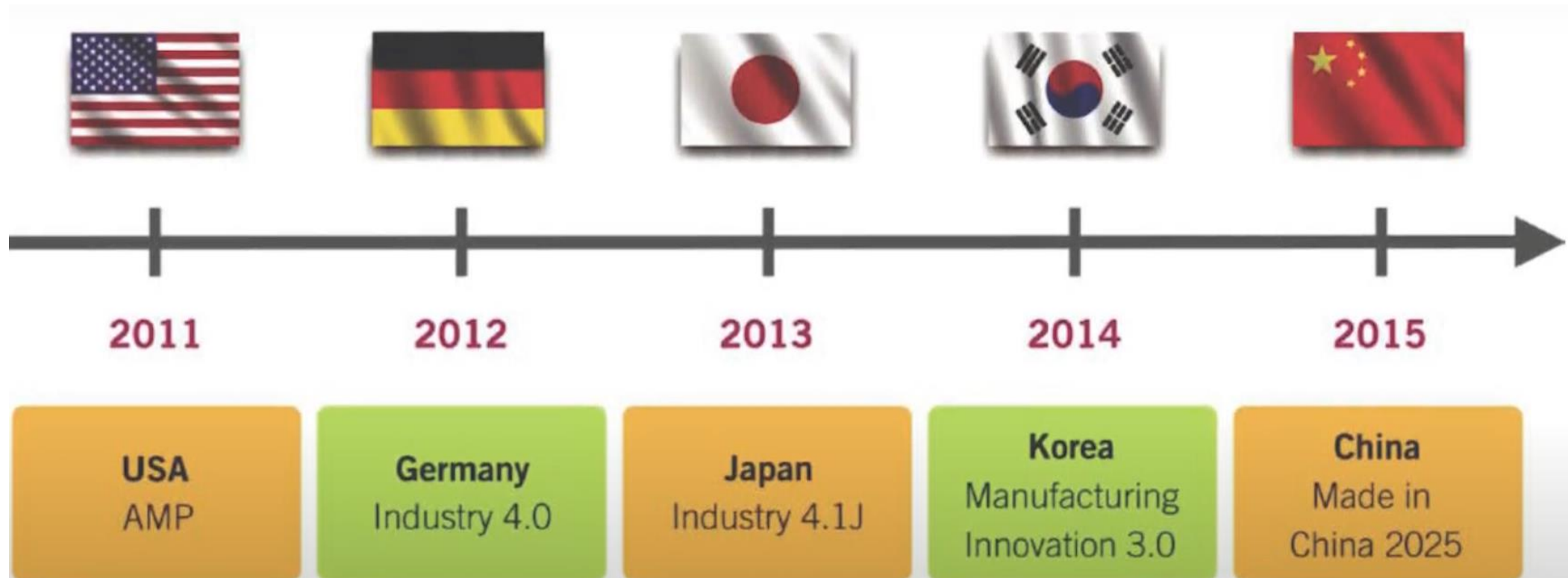
Perhaps a better definition

(The 9 technologies approach)



Not Just i4.0

(Parallels with other global programs)



So What's New?

- The Internet?
- Personal Computing?
- Industrial Robots?
- WIFI (wireless communication)?
- AI (machine & deep learning)?
- Additive Manufacturing?
- Big Data?
- Cloud Computing?
- Internet of Things?

So What's New?

- The Internet? (1969-ARPAnet, 52 years old)
- Personal Computing? (1981-IBM, 40 years old)
- Industrial Robots? (1961-Devol's "Ultimate", 60 years old)
- WIFI (wireless communication)? (1971-ALOHAnet, 50 years old)
- AI (machine & deep learning)? (1943 – McCulloch's ANN, 78 years old!)
- Additive Manufacturing? (1984 – Hull's Stereolithography, 37 years old)
- Big Data? (1990 – Denning's Predictive Machines, 31 years old)
- Cloud Computing? (1959 – McCarthy's Mainframe Timeshare, 62 years old)
- Internet of Things? (1982 – CMU's IoT Coca-Cola Machine, 39 years old)

So What's New?

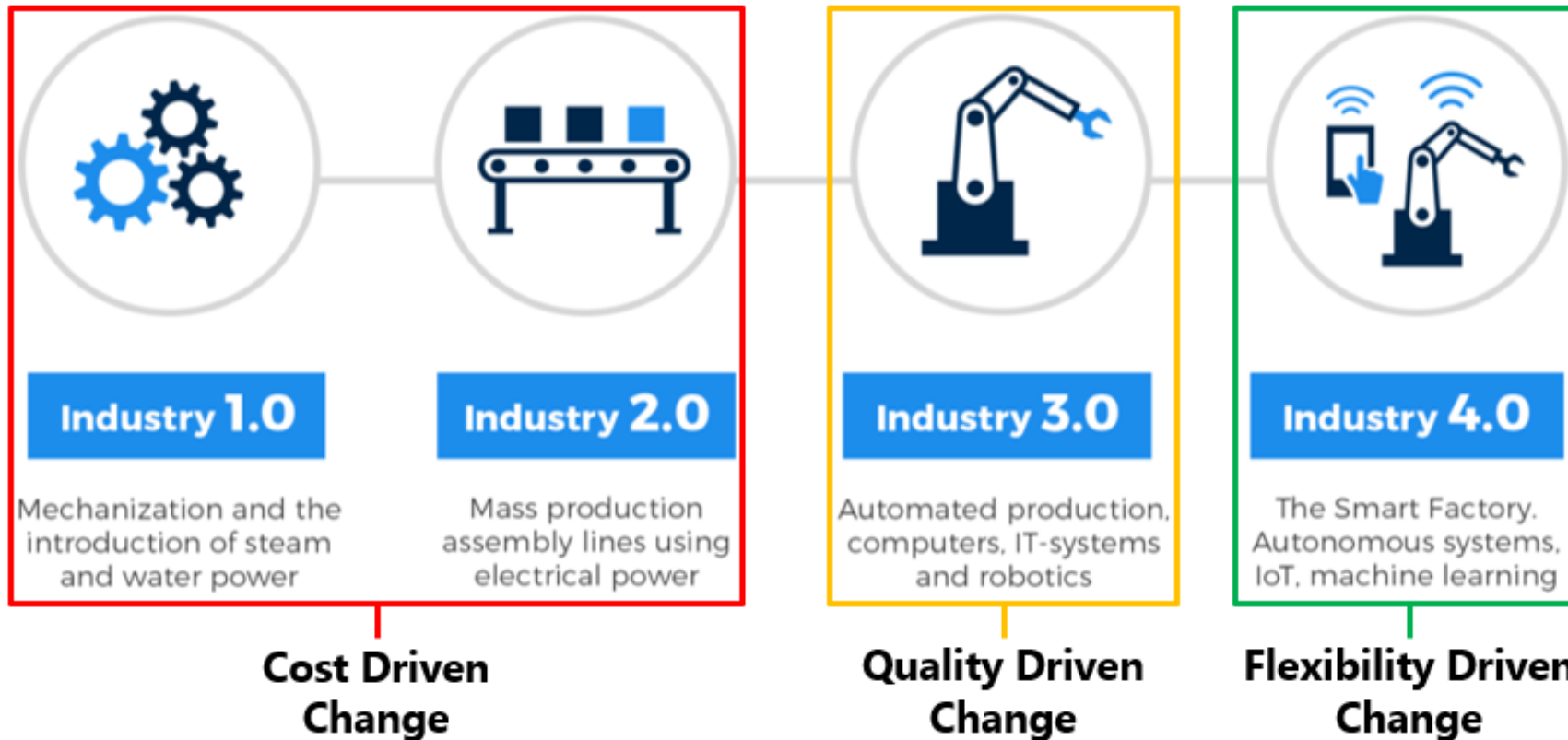
(The 5 A's)

So these i4.0 enabling technologies may not be particularly new, but the 5 A's now allow practical, useful, and robust deployment of such technology in manufacturing systems.

1. Awareness.
2. Availability (commercially available solutions?).
3. Affordability.
4. Accessibility.
5. Adaptability (Specificity of technology).

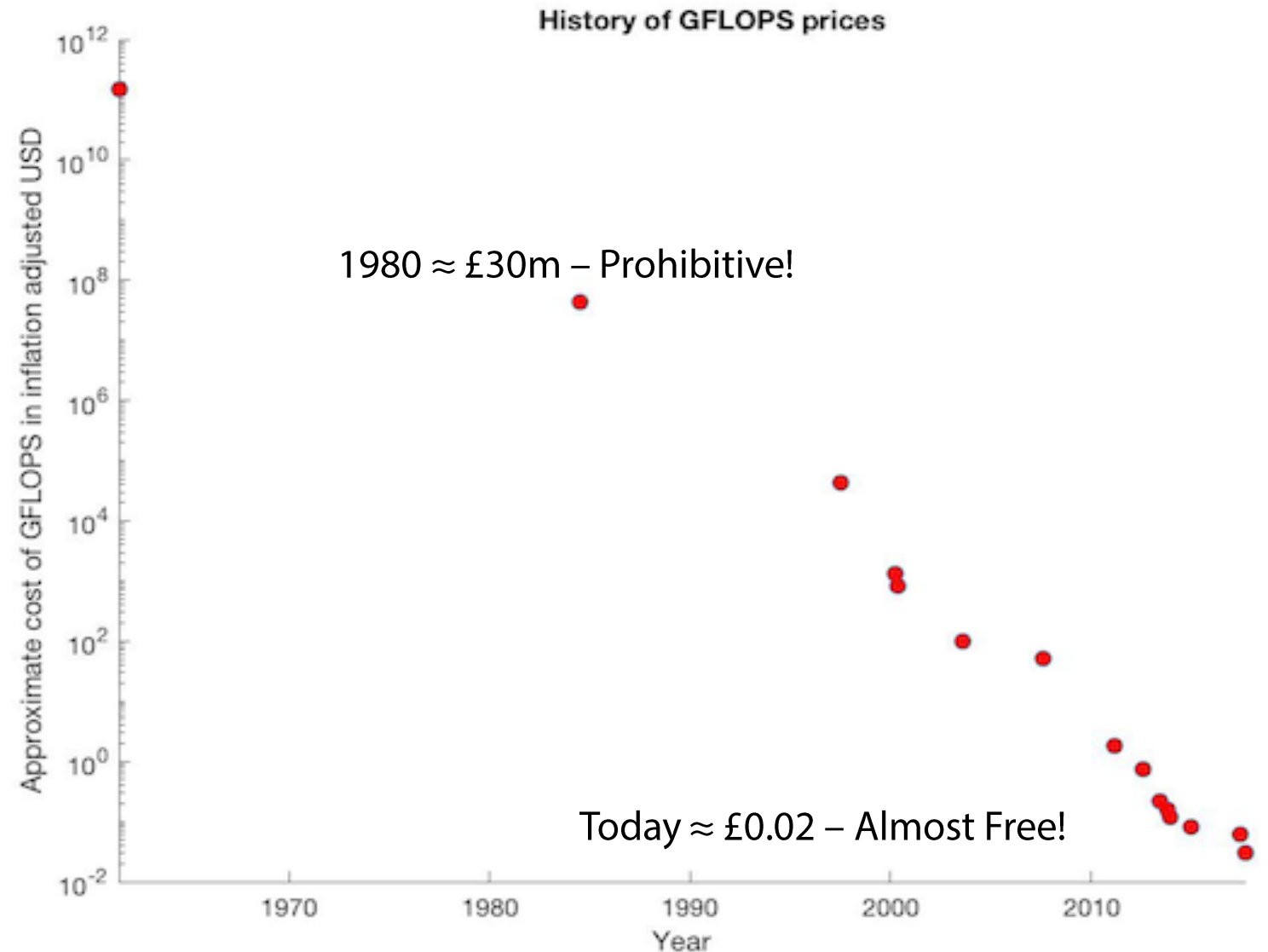
Parallels with Previous Revolutions

Increasing Sophistication & Capability of Enabling Technologies (Moore's Law) →



To Labour the Point

- 80 teraFLOP CPUs have been developed by AMD.
- In the 1980s, CPUs used in supercomputers had approximately 300 megaFLOPS.
- 80 teraflops is 80m megaFLOPS.
- This means, in order to match the performance of this modern CPU, we would require around 266,667 1980s supercomputer CPUs!



How did i4.0 Come About?

Project started by the German Federal Ministry of Education and Research (BMBF) in 2011.

Works carried out at the German Academy of Engineering Science.

Thematic areas included:

- Future Smart factory technologies.
- Cyber-Physical systems.
- Industrial Internet of Things (IoT).

Original BMBF i4.0 Research Agenda

- To investigate and develop industrial network communications standards.
- Cyber (IT) security.
- To understanding the training requirements for employees during digitalisation of manufacturing systems.
- To democratise the proliferation of technology, with particular interest given to uptake by small and medium-sized enterprises (SMEs)

Why?

We've said that that each industrial revolution could be linked to a tangible driving force:

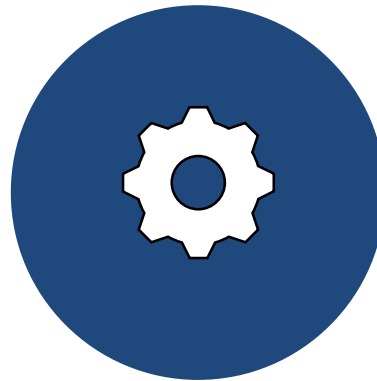
- The first (mechanisation) and second (mass production) industrial revolutions were driven by production cost and capacity.
- The third industrial revolution was driven by a need for improved product quality.
- So what's driving the fourth industrial revolution?

Recap



FIXED SYSTEMS

- Processing & assembly operations are fixed by the equipment configuration or design.
- Often uses bespoke or specialised equipment.



PROGRAMMABLE SYSTEMS

- Capability to change the process/assembly sequence by reprogramming to accommodate new products.
- Still requires physical setup which can result in changeover and downtime losses.



FLEXIBLE SYSTEMS

- The system is capable of changing over between jobs with little or no lost time.
- Often uses processes such as offline programming/simulation and automatic tool changes.

14.0 Multiple Benefits

Increased Flexibility

Improved manufacturing flexibility through use of adaptable machines & advanced / collaborative robotics. These systems can execute functions for a large variety of production scenarios and even one-off / highly customisable goods.

Improved Quality

Advanced sensors and sophisticated control systems, that make use of predictive analytics, constantly monitor the current production in real time. These systems can quickly detect or even predict errors and take mitigating corrective action.



Increased Productivity

Increased levels of automation reduce production lead times and time to market, improve asset utilisation and effectiveness. Predictive forecasting allows for a more informed approach to inventory management.

Increased Speed / Capacity

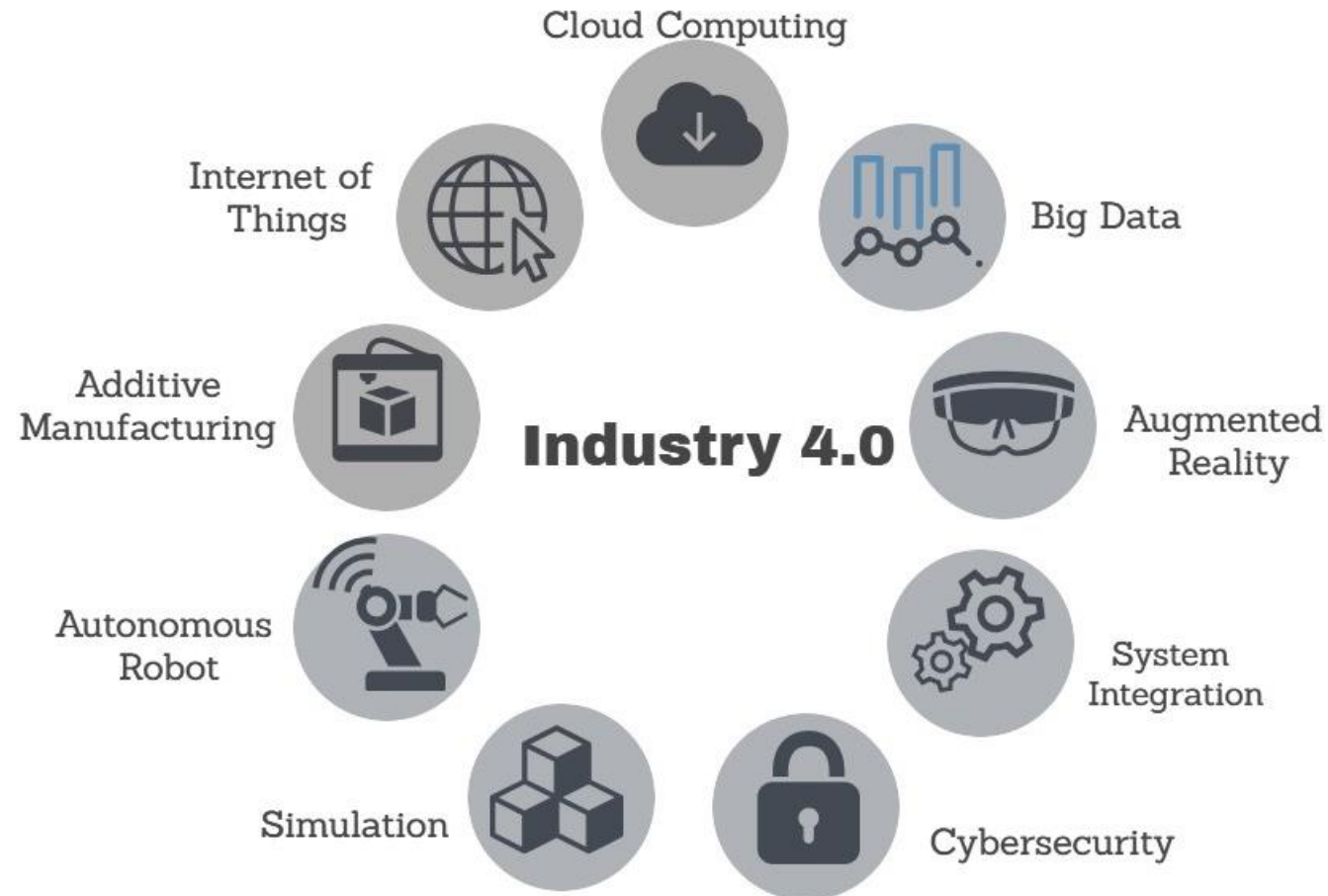
New simulation and rapid prototyping opportunities offer dynamic product improvement & optimise the design, design validation and manufacturing processes. Real-time alerts and interventions allow for higher up-time.

Flexibility

(The Big Target – Batch Size One)

- A key and distinguishing concept of industry 4.0.
- Increasing consumer demand for personalization is forcing manufacturers to adopt new production methodologies that allow mass production of highly customized goods, resulting in 'batch size one'.
- The aim is to produce and deliver an individual product to the customer even in large productions settings.
- The capability to manufacture each individual product to the customers individual specifications, i.e. according to their requirements and desired parameters.
- One of the most important efficiency gains of the Batch Size One concept comes from dramatic reductions in finished goods and work-in-progress inventory throughout the supply chain.

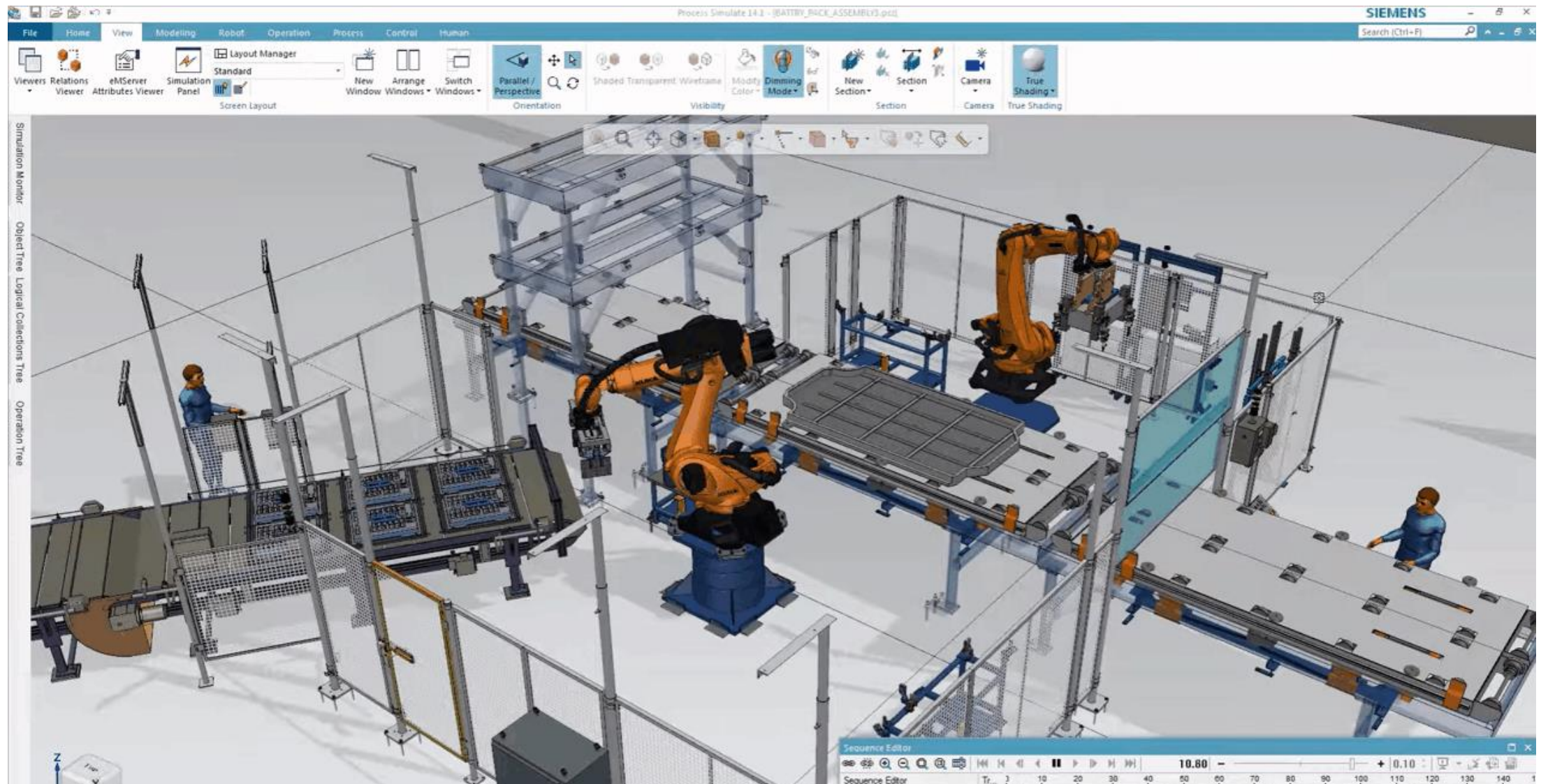
Review of Enabling Technologies

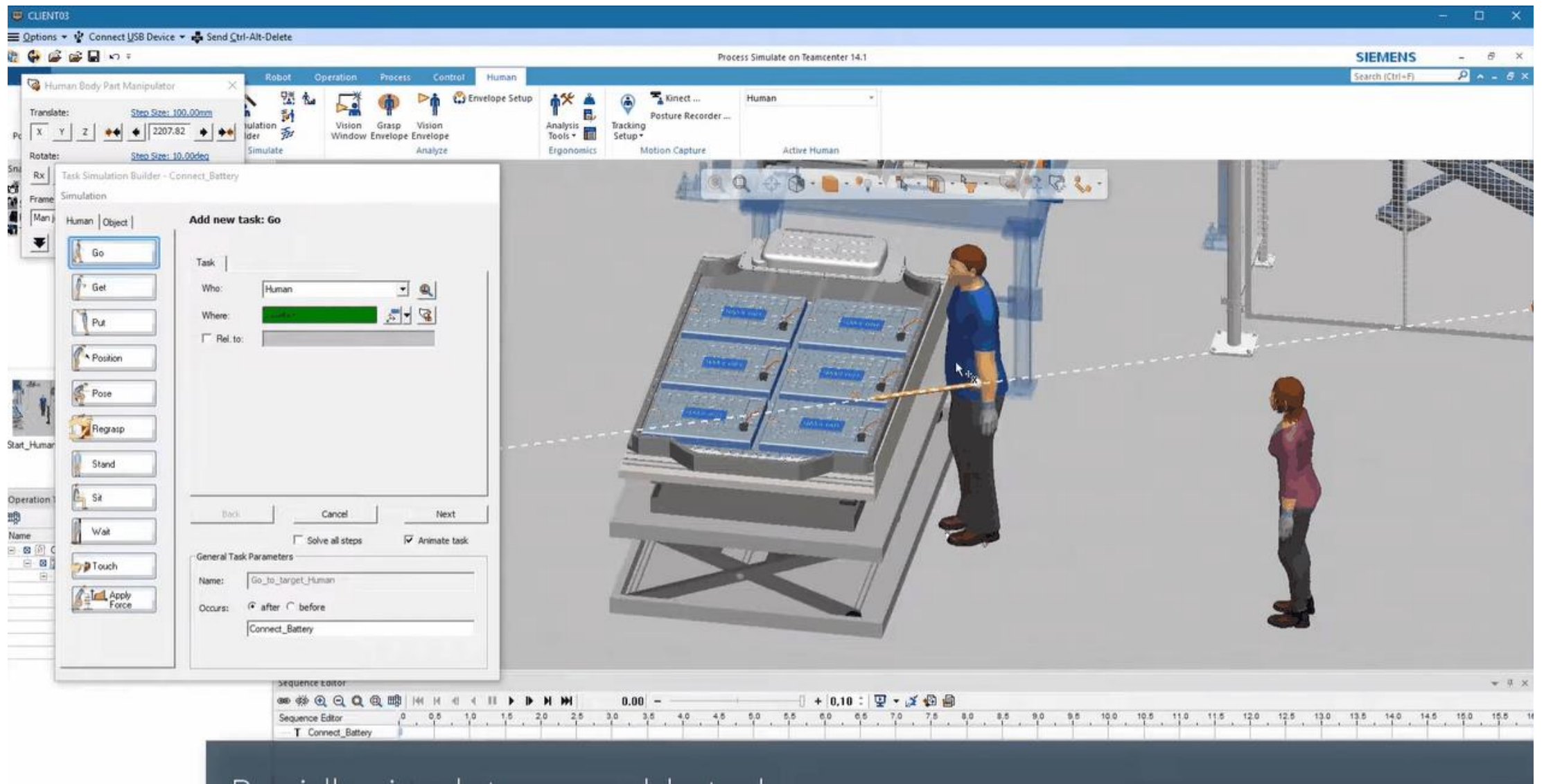


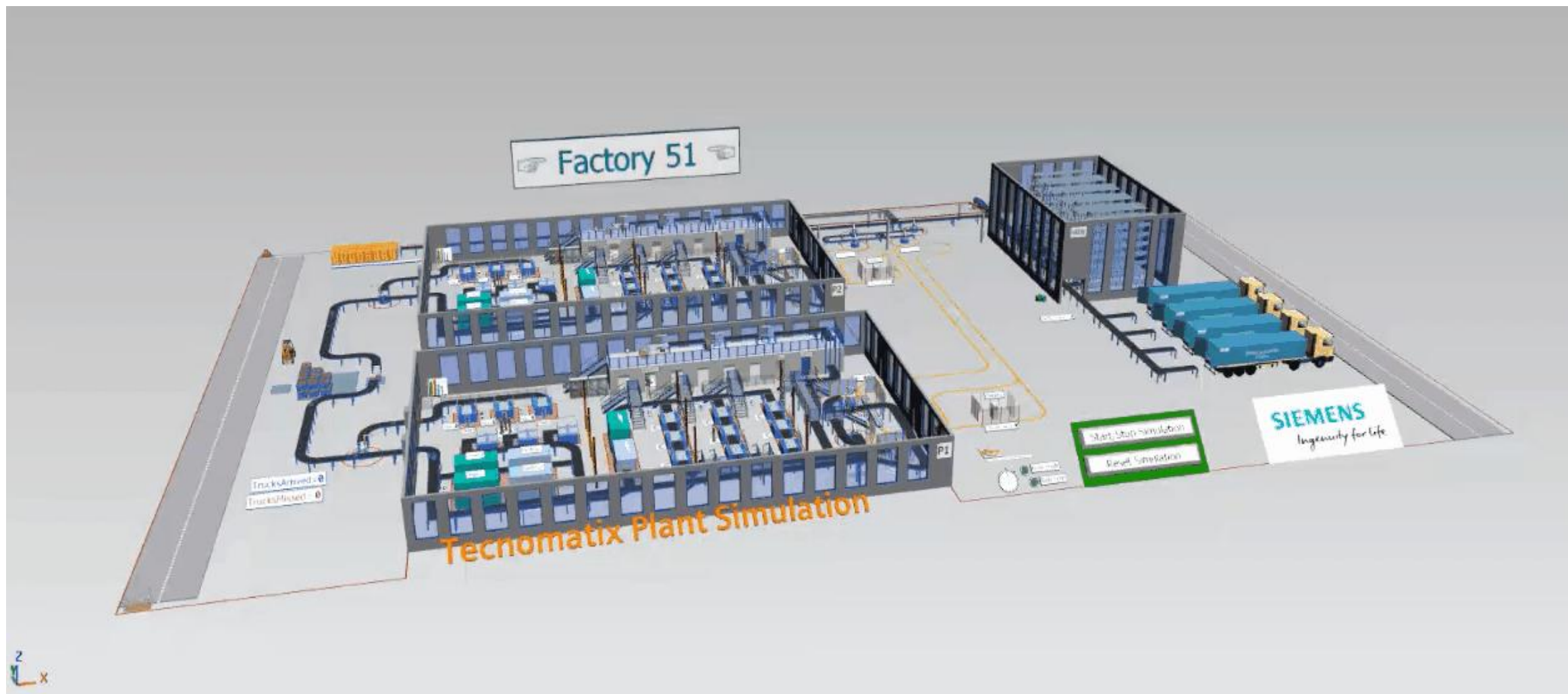
Simulation & Digital Twins

Industrial simulation can be defined as a computer based model of a real production system. Inventory, material handling, assembly, fabrication, transportation and other production activities can all be considered. This allows us to make more informed decisions that can maintain or improve efficiency and reduce operational costs. Simulation plays a key role in modern process optimisation.

- Investment risk reduction
- Waste Minimization
- Efficiency Improvement
- Trial process changes offline
- Reduce energy consumption and save resources
- Detects risks, protecting human operators

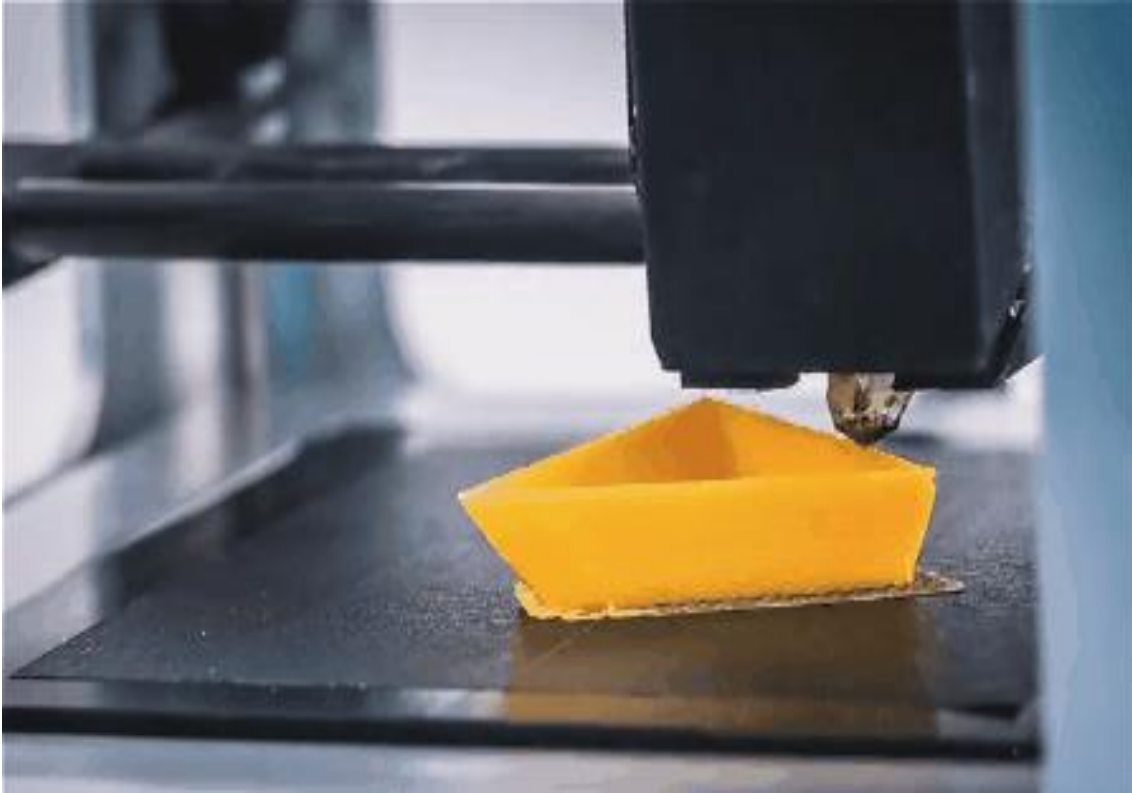




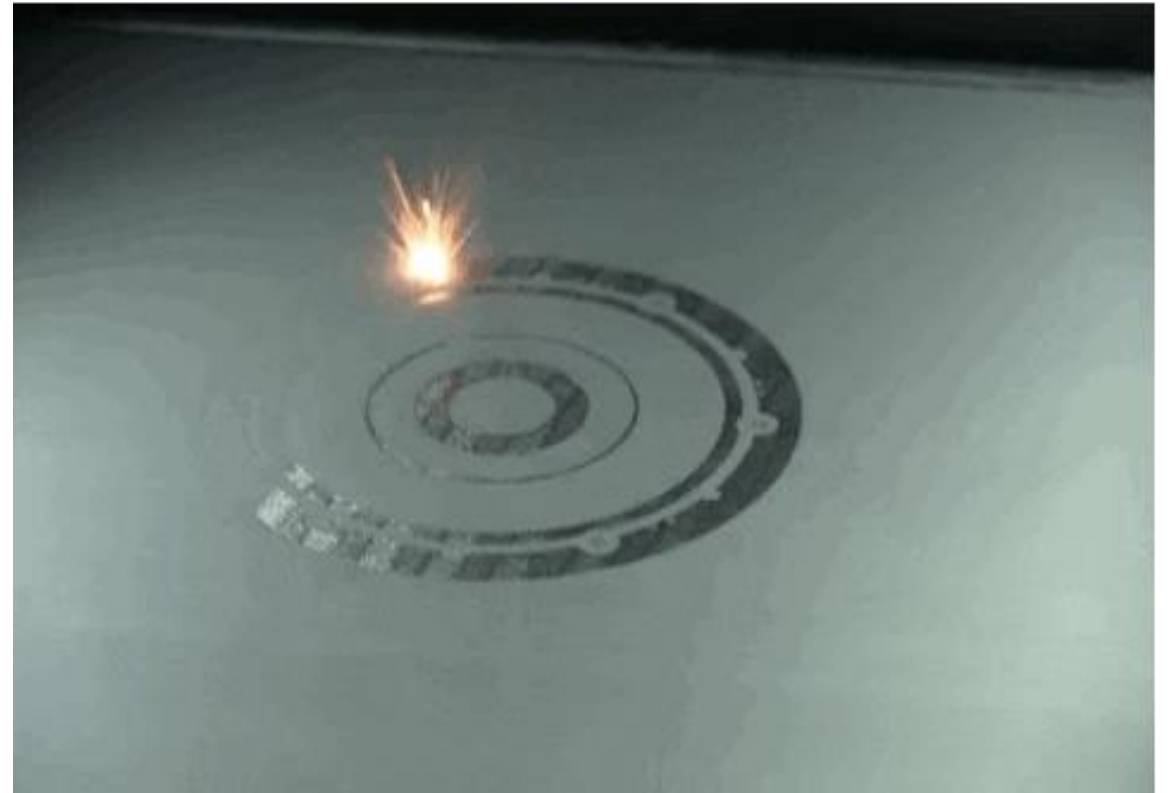


Additive Manufacturing

(3D Printing)



(Fused Deposition Modelling (FDM))



(Selective Laser Sintering (SLS))

Additive Manufacturing

(3D Printing)

- Additive manufacturing uses computer-aided-design (CAD) software to direct machines to deposit material, layer upon layer, in precise geometric shapes.
- As its name implies, additive manufacturing adds material to create an object. By contrast, when you create an object by traditional means (subtractive methods), it is often necessary to remove material through milling, machining, carving, shaping or other means.
- Additive manufacturing seems new to many, but it has actually been around for several decades. In the right applications, additive manufacturing delivers improved performance, complex geometries and simplified fabrication (and tooling).

Additive Manufacturing Benefits

1. Reduced material waste and energy consumption.
2. Ease of prototyping (speed and cost).
3. Improved design freedom and optimisation (lighter, stronger & cheaper)
4. Often faster and less expensive (for small production volumes/runs).
5. Less reliance on inventory.
6. Recreate and optimise legacy parts.
7. Continually improving cost of entry.
8. Continuous product improvement.
9. Consolidation of assemblies.
10. Can easily achieve complex design geometries.



(Airbus 3D printing enabled topology optimisation)

<https://youtu.be/Cy3V3KR1LWc>

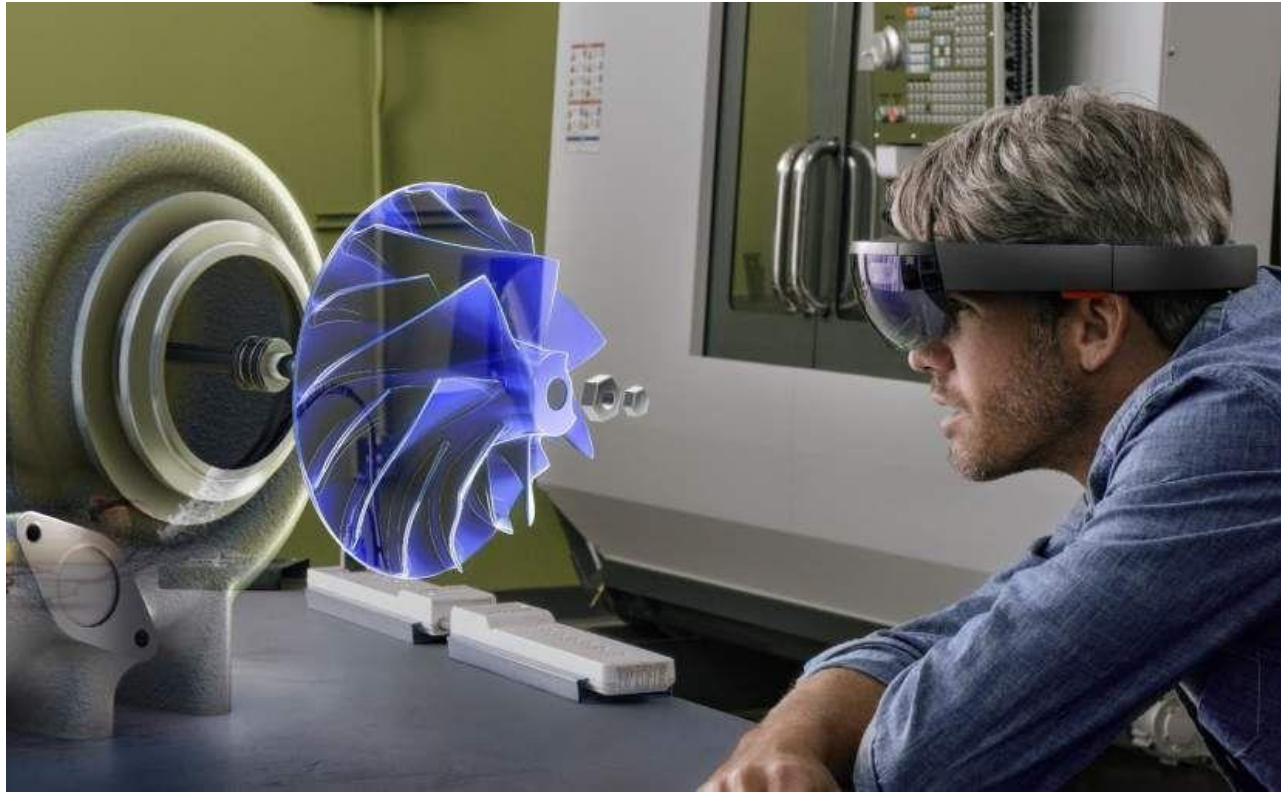
Augmented Reality (AR)



(Renault HoloLens AR Engine Quality Assurance)

Augmented Reality (AR)

- Augmented reality (AR) refers to the combination of real and virtual world images (computer-generated). A real image is captured on video, and that real-world image is “augmented” with layers of digital information.
- Don’t confuse AR with virtual reality. Virtual reality (VR) is a complete immersive experience that shuts out the real world. Augmented reality superimposes a computer generated (CGI) video onto a camera captured video, giving the impression that the CGI objects appear to have a fixed location in the real world.



(Wearable Devices – Superimposed AR)



(Hand Held Devices – Marker-Based AR)

Some AR Applications in Manufacturing

1. Complex assembly tasks with minimal training
2. Maintenance activities
3. Expert support (remote assist)
4. Quality assurance
5. Identifying unsafe working conditions (Hazards)

Cyber Physical Systems

- A cyber-physical system is a computer system in which a mechanism is controlled or monitored by computer-based algorithms or execution software
- Cyber-physical systems are everywhere, from industrial robots and control systems to semi-autonomous vehicles and wearable devices.
- The use of CPS aims to develop more robust & adaptable technologies that can react to changes in the working environment and offer safer human-machine interaction (Cobots are a good example).

Big Data and analytics

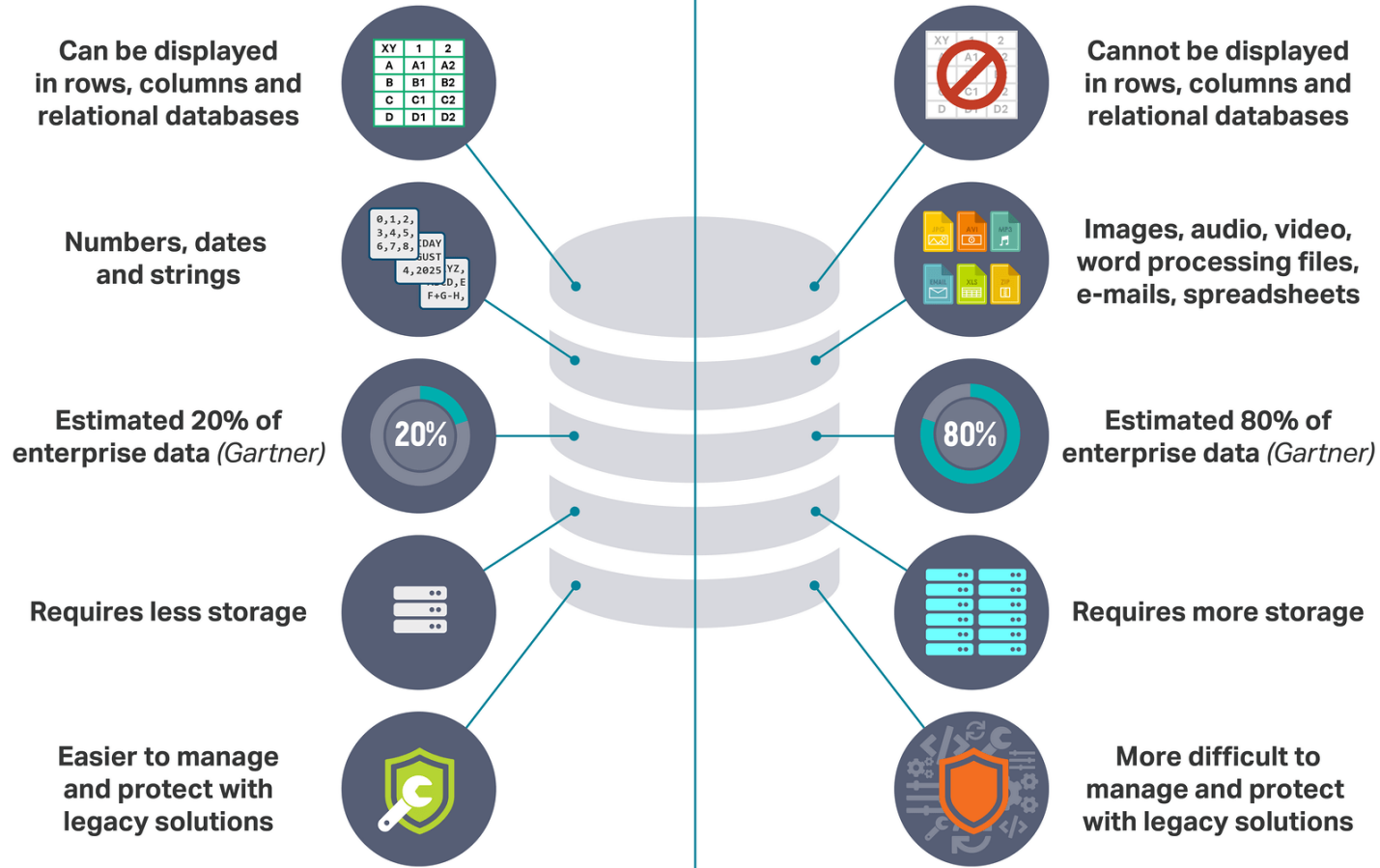
- Describes the collection and comprehensive evaluation of data from a huge variety of sources (production equipment, sensor data, customer management systems and enterprise level data) to support and inform real time decision making.

Q. So what makes data “big data” ?

A. The big four!

- **Volume** (large quantities of data collected)
- **Variety** (multiple forms of data from different sources, structured/unstructured?)
- **Velocity** (the speed at which data is generated and collected)
- **Veracity** (Accuracy, trustworthiness, authenticity of data)

Structured Data vs Unstructured Data



Big Data Benefits / applications



Enables Well-Informed
Decisions in Real-Time



Reduces Wasted Resources



Predicts Risk of
Downtime



Predicts Needs for
Maintenance or Repair



Detects the Presence of
Safety Issues



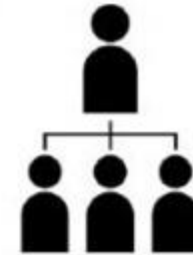
Improves Supply Chain
Management



Notifies Defects in
Work Products



Predicts Workload



Forecasts Staffing
Needs



Can you think of any problems / challenges with Big Data collection?



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Cloud Computing

- Simply put, cloud computing is the delivery of computing services – including servers, storage, databases, networking, software, analytics and intelligence – over the Internet (“the cloud”).
- Aims to remove access to hardware as a barrier to entry.
- The performance of cloud technologies is continually improving towards a goal of millisecond reaction times.
- With industry 4.0, more and more production activities will require increased data sharing across sites outside of company boundaries / networks.
- To allow this level of data collection, transfer and sharing, manufacturers (enterprises) must move away from tangible assets, in the form of hardware based computing, and accept infrastructure, platform & software as a service models (IaaS, PaaS & SaaS)

Benefits to Cloud Computing

- Agility
- Access to more powerful resources
- Cost savings (IT infrastructure)
- Quick access to data from any location
- Consolidation of data organisation & management

Industrial Internet of Things (IIoT)

- The IIoT refers to the billions of industrial devices, anything from the machines and robots in a factory to the engines inside an aeroplane, that are filled with sensors, connected to wireless networks, and collecting and sharing data.
- Think of it as a central hub for data collection, storage, sharing and analysis.
- A single common platform,
- Developed to address the need for standard communications protocol.
- Low-cost micro sensors and high-bandwidth wireless networks allow even the smallest and cheapest devices to be connected to the IIoT, given a level of digital intelligence that allows them to be monitored and tracked, and they can share data on their status and communicate with other devices connected to the IIoT.



Can you think of any problems with relying on this one platform (IIoT) for all industrial data storage and sharing?

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IloT & Cyber Security

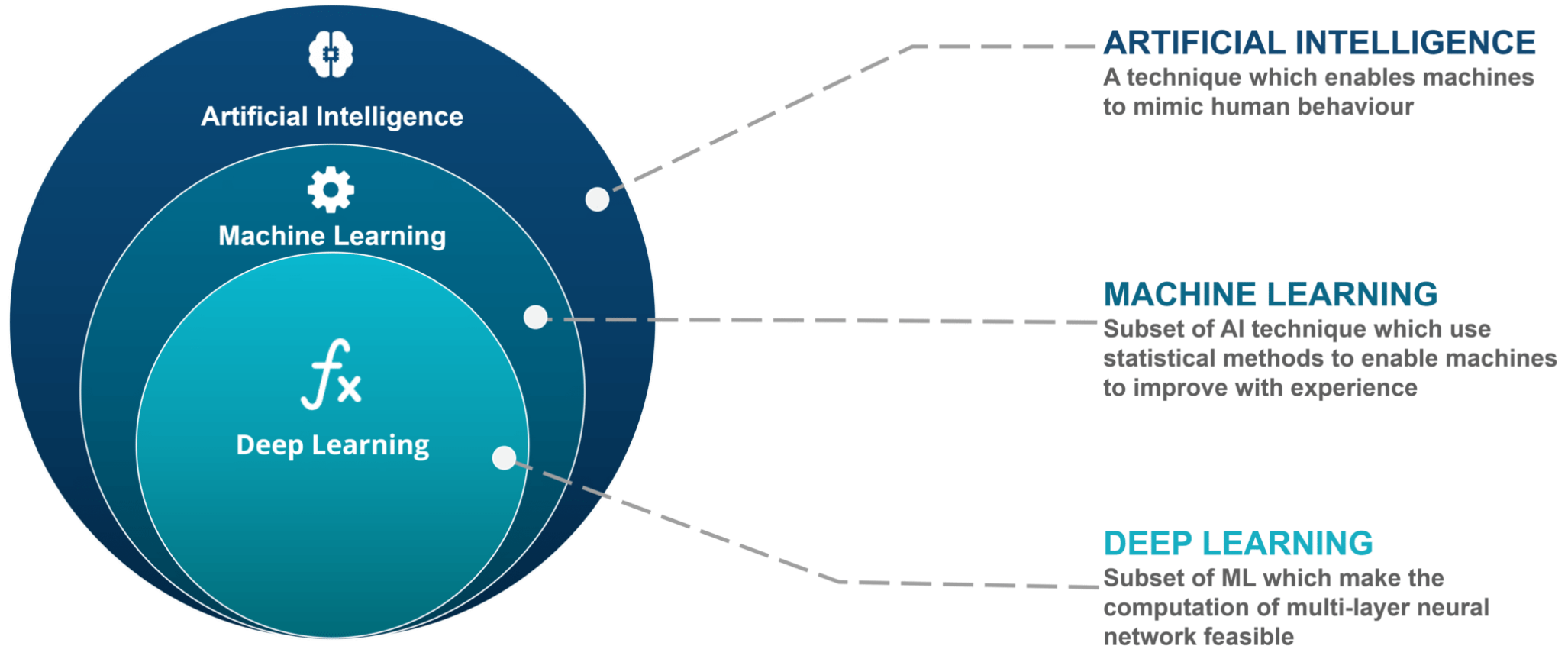
- With the increased connectivity and use of standard communications protocol (IloT) that come with industry 4.0, the need to protect these critical manufacturing systems from threats (hacking etc) increases dramatically.
- As a result, developing secure and reliable communications, as well as sophisticated identity and access management solutions (such as biometrics), has become essential.

Questions brought about by this change

- Who manages (or polices) IloT cyber security? The individual manufacturer? The wider enterprise? A group of enterprises as a collective? The IoT Platform suppliers? government or global organisations?
- The “shared responsibility” mindset to security and governance of the IoT will not always work.
- Is it right that organisations whom supply these IoT solutions/ platforms (Microsoft azure, google, amazon AWS, IBM & Cisco) have this level of access and control over other manufacturers/companies data?

Artificial Intelligence (AI)

(Machine Learning)



Machine Learning, Manufacturing and i4.0

- Machine learning is a branch of artificial intelligence (AI) focused on building applications that learn (or predict) from data and improve their prediction accuracy over time without being explicitly programmed to do so.
- Machine learning works by using large volumes of data and statistical methods to train sophisticated algorithms. These can then be applied to new data to identify common features, differences, hidden patterns and predict future outcomes from the data.

Domestic AI

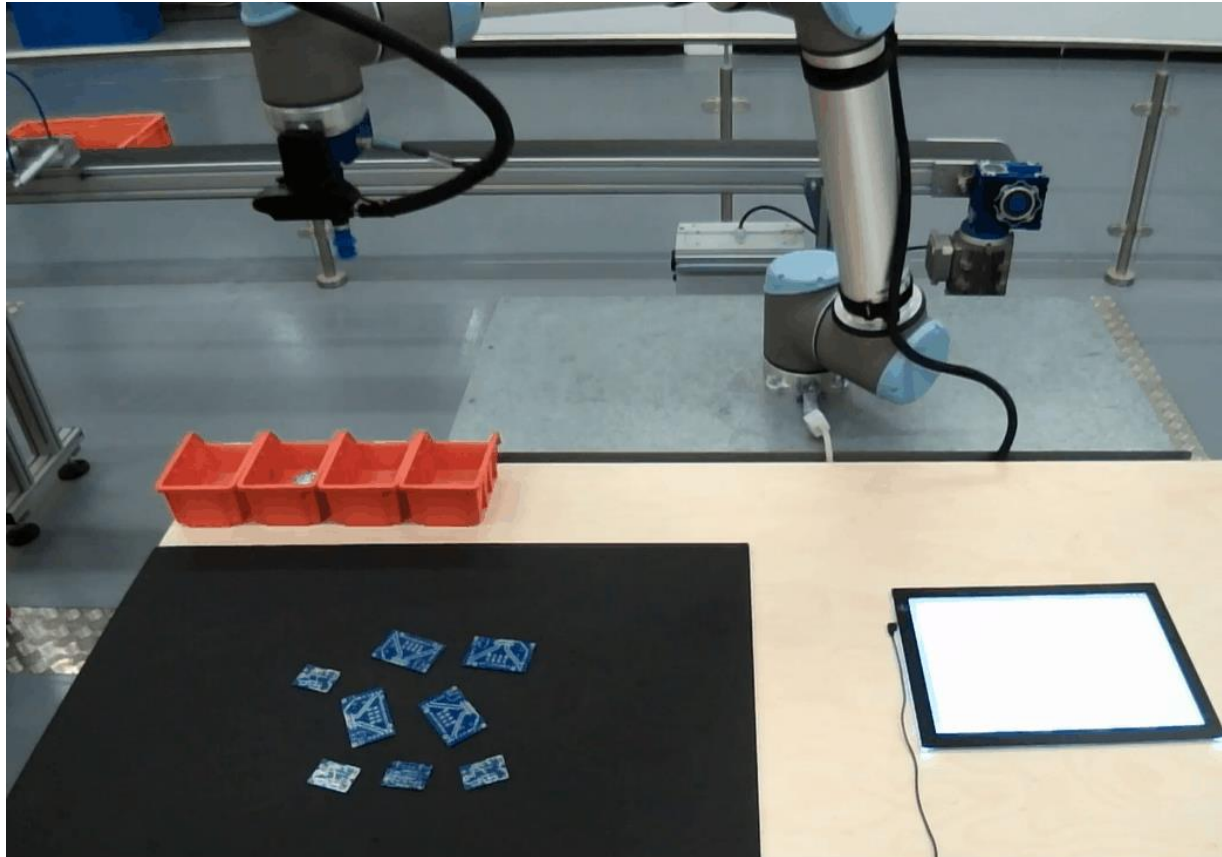
Examples of machine learning (AI) are all around us:

- Digital assistants on our smart phones search the web and play music in response to our voice commands.
- Websites recommend products and movies and songs based on what we bought, watched, or listened to before.
- Chatbots on automated phone calls are developed to recognise a wide range of accents.
- Handwriting recognition algorithms are used in mail sorting and application forms.
- Spam detectors stop unwanted emails from reaching our inboxes.
- Self-driving cars are being developed (i.e. Tesla autopilot) that use machine learning to interpret video feeds from camera systems (computer vision), the ML algorithms can detect road signs, markings, and hazards in the road and take corrective action.

Industrial Examples

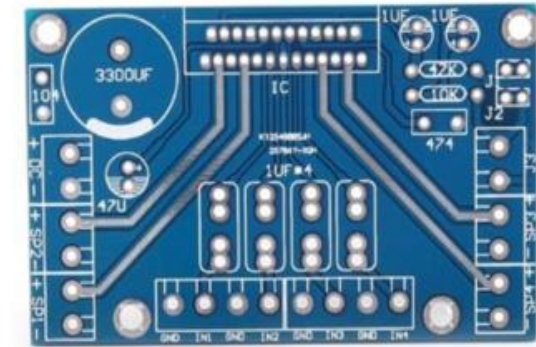
- Google was able to reduce electricity usage in its data centres by 40% by using custom ML algorithms to control the cooling fans in its server facilities.
- Many manufacturers now use ML to monitor and predict key performance indicators (KPIs) such as overall equipment effectiveness (OEE).
- ML is also being used for predictive maintenance. Data is collected over time to monitor the state of equipment/machines. The goal is to find patterns that can help predict and ultimately prevent failures.
- Logistics companies are able to save vast sums of money on parts each year by understanding when each vehicle would need servicing based on the actual routes and terrain it had driven.
- Industrial robots can use ML with camera systems to allow them to learn their working environment, move and detect and avoid obstacles autonomously.
- ML algorithms are used in quality inspection systems to spot defects in products before they reach the consumer (interesting example - VW uses Acoustic camera).

Machine Learning at UWTSD

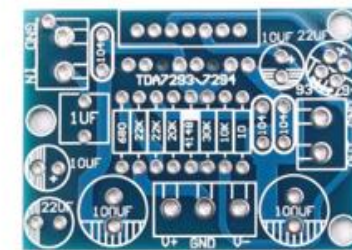


Types of Printed Circuit Board

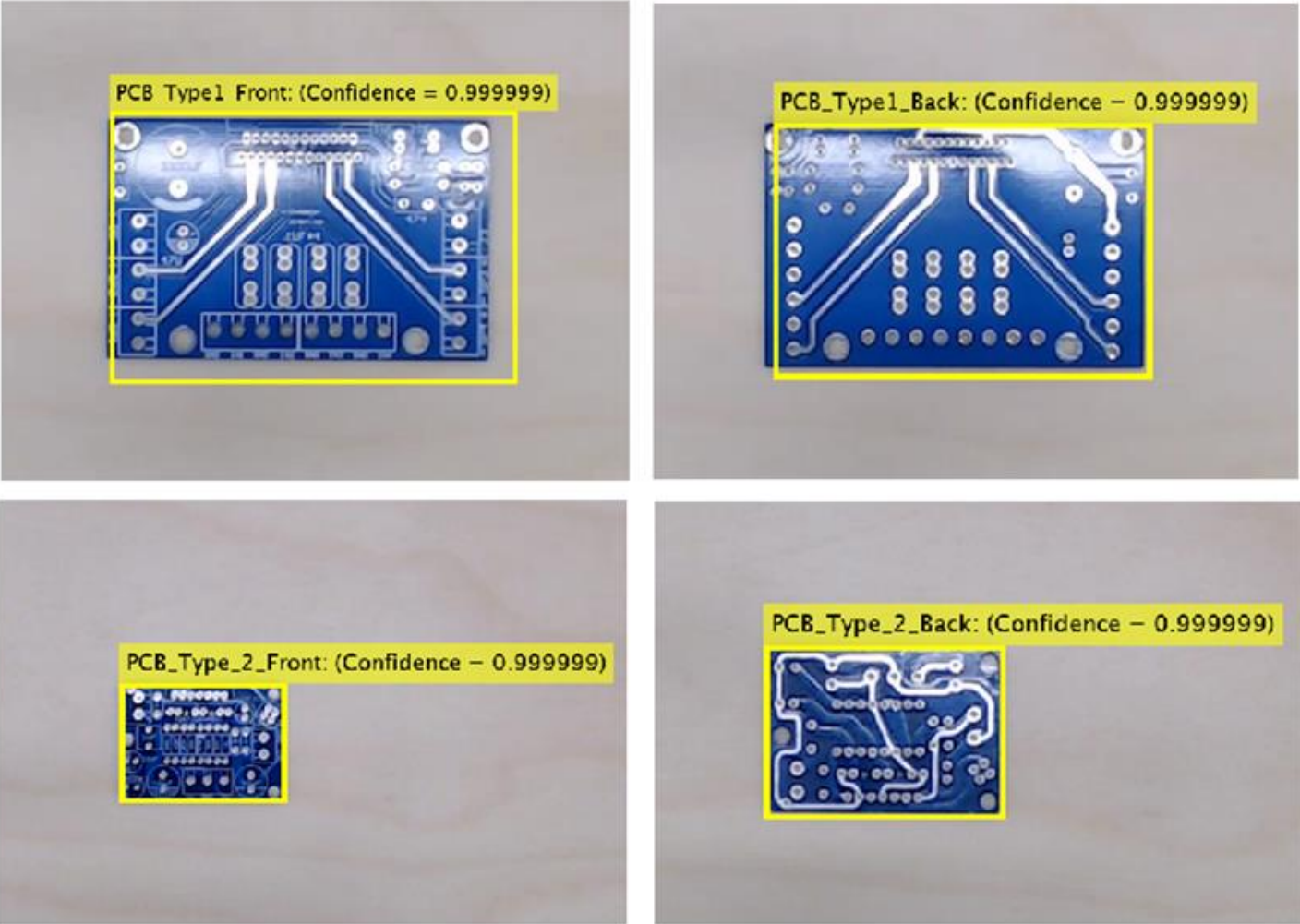
PCB Type 1



PCB Type 2



Deep Learning Object Detector Trained in the Automation Laboratory



Defect Detector Trained to Identify Through Hole Defects

