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Industry 4.0 Applications in Smart Factory

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Abstract

Industry 4.0 (I4.0) contains an abundance of digital technologies that transform most companies by changing the characteristics of their production systems. Indeed, there is a wealth of research examining the enabling technologies of Industry 4.0 and their applications in the manufacturing context. However, these technologies are evolving exponentially, establishing the need to examine technological advancements in the Smart Factory domain constantly. The aim of the report is to provide an overview of Industry 4.0 applications. The report could be used for further researches as a repository of applications and as a starting point to explore the adoption of Industry 4.0 technologies.

Riassunto

L'industria 4.0 comprende un'abbondanza di tecnologie digitali che trasformano le aziende cambiandone le caratteristiche dei sistemi produttivi. Sono infatti numerosi gli studi che esaminano le tecnologie abilitanti dell'Industria 4.0 e le loro applicazioni nel contesto manifatturiero. Tuttavia, queste tecnologie si stanno evolvendo con velocità esponenziale, stabilendo quindi la necessità di esaminare costantemente i progressi tecnologici nel dominio delle Smart Factory. L'obiettivo del rapporto è fornire una panoramica delle applicazioni dell'Industria 4.0. Il rapporto potrebbe essere utilizzato per ulteriori ricerche come repository di applicazioni e come punto di partenza per esplorare l'adozione delle tecnologie Industria 4.0.

Keywords: Smart Factory, Digital technologies, Industry 4.0, Digital Transformation, Internet of Things

Introduction

Throughout the past, people have always been dependent on technology. Admittedly, the technology of each period might not have the same form and substance as today, but it was unquestionably a transformative force for industries at their time. Accordingly, industries constantly strive to employ the available technologies to gain a competitive advantage while developing them to reach new levels of advancement.

Nowadays, industrial production has reached the spring of a new industrial revolution, where a wide variety of new technologies are integrating cyberspace with the physical world.

Industry 4.0 (I4.0) is an outcome -still not fully developed- of the fourth industrial revolution. This fourth revolution reflects the adoption of cyber-physical systems, the Internet of Things (IoT), cloud computing, and Big Data analysis, allowing companies to implement smart technologies in their industries and factories, establishing a network of connected machines that interact, visualize the entire production chain and make decisions autonomously (Kagermann, Helbig, Wahlster, 2013). The aforementioned is expected to impact all disciplines, industries, and economies. While in some ways it is an extension of the computerization of the 3rd Industrial Revolution (Digital Revolution), due to the velocity, scope, and systems impact of the changes of the fourth revolution, it is being considered a distinct era (Marr, 2018). The Fourth Industrial Revolution disrupted almost every industry worldwide and generated a massive shift at an unprecedented pace (Popkova, Ragulina, & Bogoviz, 2018).

The Industry 4.0 concept refers to the digital transformation of manufacturing processes and related industries (Teichert, 2019). The emergence and growing importance of new digital technologies, such as Cloud Computing, Big Data, Embedded Devices, 3D-Printing, and Artificial Intelligence, to name a few, increase the pressure on organizations to adjust their business strategy and align it with the technological changes in the environment (Mergel, Edelmann, Haug, 2019). The new technological advancements are remarkably remodeling the strategic setting of organizations, altering the characteristics of competition, customers' expectations, business regulations, and manufacturing procedures.

The aim of Industry 4.0 is to utilize cutting-edge technologies to enhance the manufacturing system's agility, flexibility, and responsiveness to unpredictable events. It sets a Smart Factory where the Internet, sensors, software, and other advanced technologies work collectively to optimize manufacturing practices and improve operational processes. As a result, I4.0 empowers a company to react swiftly and efficiently to the current turbulent market changes by offering more personalized products and increasing operational productivity in a ceaseless growth manner.

Initially, the concept of Industry 4.0 resulted from an initiative to increase competitiveness in the German manufacturing industry called Industrie 4.0, which evolved to a globally adopted term.

The concept was generated and revealed by a German initiative of the federal government with universities, academic communities, and German private Industrial companies to increase productivity and efficiency of the national industry and expanding the country's industrial abilities that have been enabled by the digital transformation of the production processes in several industrial areas (Kagermann, Helbig, Wahlster, 2013). The German Federal Ministry of economic affairs and energy mentions in its Plattform Industrie 4.0, "Industrie 4.0 refers to the intelligent networking of machines and processes for an industry with the help of information and communication technology".

However, Industry 4.0 is not a technology but somewhat resembles a cluster of different technologies which is nursing the manufacturing's digital transformation through the integration of previously disparate systems and processes into interconnected computer systems across the value and supply chain (Zheng, Ardolino, Bacchetti, & Perona, 2020).

The author considers a list of six enabling technologies, namely, Industrial Internet of Things (IIoT), Additive Manufacturing (AM), Industrial Analytics, Advanced human-Machine interface (A-HMI), Cloud manufacturing (CMfg), and Advanced Robotics, with particular attention to the main application areas such as Smart Factory and Smart Life Cycle.

Based on the considerations above, this study aims to comprehend the degree of I4.0 adoption by companies across countries and industrial sectors through a database containing forty-five case studies of companies that successfully implemented I4.0 enabling technologies.

This report presents a literature review to highlight essential topics such as the fourth industrial revolution, digital transformation, including Industry 4.0 enabling technologies and application areas. The second part of the report includes a description of the database containing a representation of the search method in acquiring case studies, selection procedure, the database attributes, a representation of collected cases, and final remarks.

Literature review

This section will glimpse the historical predecessors that led to the fourth industrial revolution and the reasons behind considering current technological advancements as disruptive and revolutionary.

Industrial Revolution

In modern history, the Industrial Revolution changed from an agricultural and craftsmanship economy to one dominated by industry and machine manufacturing ("Industrial Revolution," n.d.). The main features involved in any Industrial Revolution are tecnological, socioeconomic, and cultural changes. Essentially these technological advancements introduce new production and manufacturing processes transforming the industrial scenery. The industrialization technological changes have driven paradigm shifts that are called "industrial (re)evolutions" (Huberman, Meissner, & Oosterlinck, 2017). The first industrial revolution started at the end of the 18th century to the beginning of the 19th. The most significant innovations evolved in the industries in the application of mechanization. Mechanization was the turning point where the industry sector replaced agriculture and became the backbone of the societal economy (Mohajan, 2019).

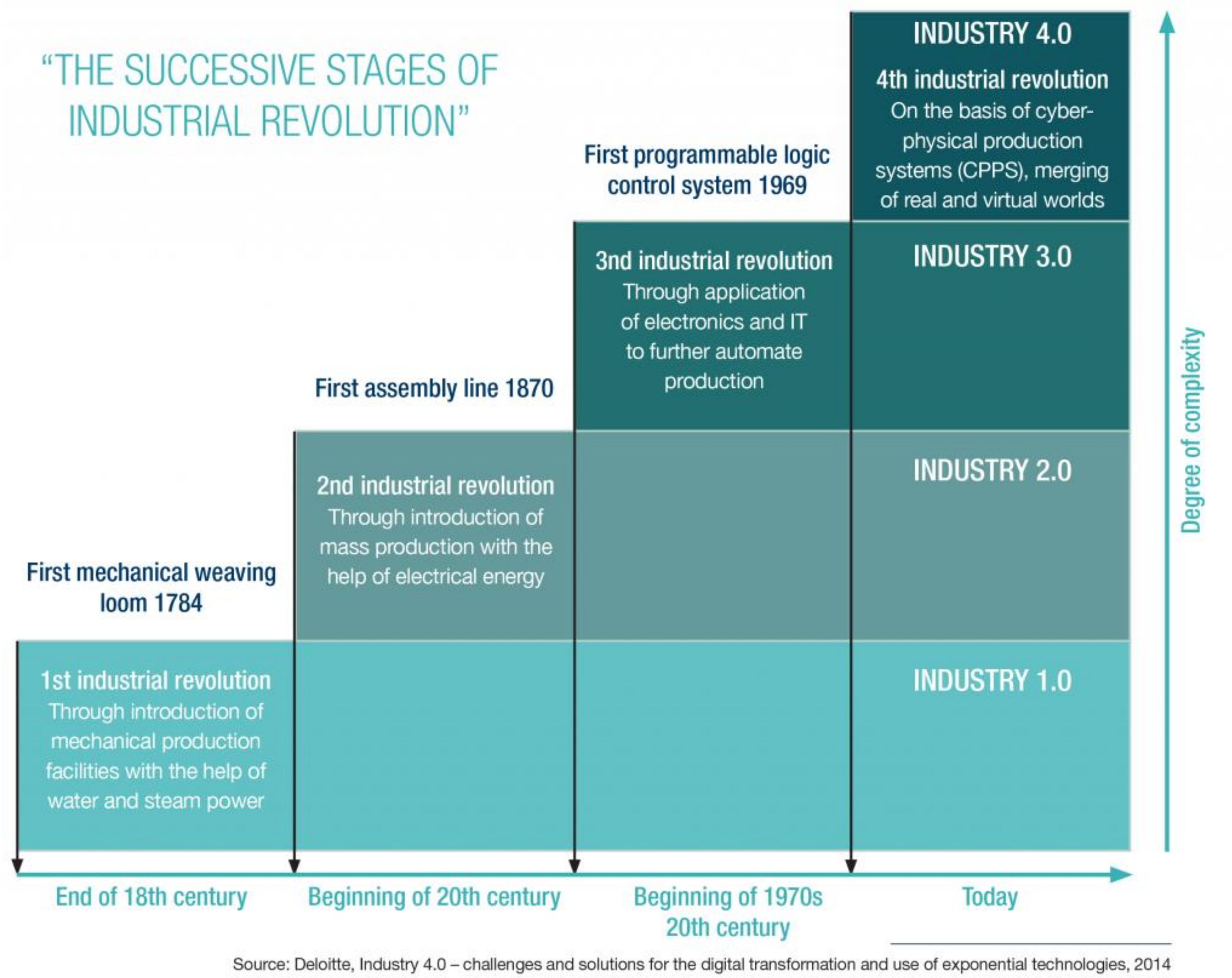
Following the first Industrial Revolution, the world went through a second one almost a century later. It sprang at the end of the 19th century, with extensive technological advancements leading to new energy sources (electricity, gas, and oil) and communication methods (the telegraph and the telephone). Finally, at the beginning of the 20th century, the market witnessed the invention of automobiles and planes (Huberman, Meissner, & Oosterlinck, 2017).

In the second half of the 20th century, the third revolution brought forth the appearance of electronics, computers, and the internet -in conjunction with creating a worldwide fiber-optic network- driving the era of Globalization 3.0, enabling a quick and seamless global network of individuals and groups (Taalbi, 2018). Furthermore, Internet technology and the evolution of information and communication technology (ICT) completely revolutionized the business world, leading to a radical change in each area of the manufacturing paradigm (Huberman, Meissner, & Oosterlinck, 2017). In addition, the industry sector went through the adoption of machines and process automation. Two significant inventions emerged in this revolution, Programmable Logic Controllers (PLCs) and Robots, bringing an era of high-level automation ("The 4 Industrial Revolutions," 2019).

Arriving at the fourth industrial revolution -also referred to as Industry 4.0. Distinguished by rising automation and the employment of smart things (machines, vehicles, factories, and other objects), data-driven insights improve activities across the value chain to be more efficient and productive. Manufacturers achieve information transparency and better decisions by collecting facility floor operational data and integrating it with other related data across the enterprise (Kodama, 2018).

In January 2016, Klaus Schwab, Founder and Executive Chairman of the World Economic Forum published a book called The Fourth Industrial Revolution(Schwab, 2016). After that, the phrase "Fourth Industrial Revolution (4IR)" has been practised to express and examine the influence of emerging technologies on almost all aspects of human development in the early 21st century, including social, environmental, and economic evolution. Klaus Schwab, informs us in his article, The Fourth Industrial Revolution; What It Means and How to Respond (Schwab, 2016b). "We stand on the brink of a technological revolution that will fundamentally alter the way we live, work, and relate to one another. The transformation will be unlike anything humankind has experienced before in its scale, scope, and complexity. We do not yet know just how it will unfold. Still, one thing is clear: the response to it must be integrated and comprehensive, involving all stakeholders of the global polity, from the public and private sectors to academia and civil society." Klaus demonstrates three reasons (velocity, scope, and systems impact) why today's transformations are not only a part of the Third Industrial Revolution. Instead, they represent a signal to the arrival of a Fourth and distinguished one. The pace of modern inventions has no historical precedent. The technologies are evolving at an exponential rather than a linear speed compared with previous industrial revolutions (Schwab, 2016). Furthermore, the impact of today's transformations is causing a global disruption in all the industry sectors (Popkova, Ragulina, & Bogoviz, 2018). Also, the magnitude and intensity of these changes are remodelling the production, management, and governance systems. Starting a new section in human advancement, enabled by improvements comparable with those of the first three industrial revolutions blending the physical and digital worlds and combining technologies in ways that generate both opportunities and challenges. The revolution's momentum, magnitude, and intensity have pushed businesses and countries to reexamine how they should evolve, create value, and leverage those disruptive technological advancements. The Fourth Industrial Revolution signifies a series of radical shifts in economic, political, and social value being created, exchanged, and distributed (Qin, Liu, & Grosvenor, 2016). Figure 1 represents the schematic diagram of the overview for the industrial revolutions.

Figure 1: Stages of Industrial revolutions



Introduction to Industry 4.0

Industry 4.0 is indicating a shift in the traditional manufacturing scenery. the modern trend of automation and data exchange in manufacturing technologies. The concept of Industry 4.0 (or Industrie 4.0 in the original German) was initially presented in 2011 to characterize the modern trend of automation and data exchange in manufacturing technologies that ultimately reduce human intervention in a controlled environment of highly digitized manufacturing activities (Qin, Liu, & Grosvenor, 2016). The concept was generated and revealed by a German initiative of the federal government with universities, academic communities, and German private Industrial companies to increase productivity and efficiency of the national industry and expanding the country's industrial abilities that have been enabled by the digital transformation of the production processes in several industrial areas (Kagermann, Helbig, Wahlster, 2013). The German Federal Ministry of economic affairs and energy mentions in its Plattform Industrie 4.0, "Industrie 4.0 refers to the intelligent networking of machines and processes for an industry with the help of information and communication technology." Its name stems from recognizing that the inclusion of an emerging structure in cyber-physical systems in manufacturing and logistics processes changes the whole production and business paradigm while adding value to the whole product lifecycle (Dalenogare, Benitez, Ayala, & Frank, 2018). the term "Industry 4.0 " was chosen to indicate the fourth industrial revolution (Qin, Liu, & Grosvenor, 2016). Industry 4.0 uses digital technology to solve business problems; more specifically, Industry 4.0 uses digital technology to create new and better industry practices. Thus, industry 4.0 presents a better way of doing business, including new capabilities and processes, reducing costs, empowering organizations, enhancing decision-making, and creating new and better ways of serving customers.

In summary, Industry 4.0 aggregates existing ideas into a new value chain that plays a crucial role in transforming whole value chains of life cycles of goods while developing innovative products in manufacturing that involve the connection of systems and things that create self-organizing and dynamic control within the organization. Thus, industry 4.0 describes a future scenario of industrial production characterized by new levels of controlling, organizing, and transforming the entire value chain with the life cycle of products, resulting in higher productivity and flexibility through three types of effective integration: horizontal, vertical, and vertical end-to-end engineering integration. Hence, these can predict product performance degradation and autonomously manage and optimize product service needs and consumption of resources, leading to optimization and reduction of costs. Next, aspects of creating dynamic, real-time optimized, and self-organizing cross-company value networks through the Cyber-Physical Systems (CPS), Internet of Things (IoT), artificial intelligence, additive manufacturing, cloud computing, and others are added. All these components are requirements and are parts of the visionary concept of Industry 4.0

National initiatives related to Industry 4.0

Despite the fact that the term Industry 4.0 was founded by Germany, public institutions and private companies worldwide initiated various programs to target the radical changes in the development of different domains caused by the strategic adoption of digital technologies (Oztemel & Gursev, 2018).

The Italian Ministry of Economic Development stated in the implementation decree of (Transizione 4.0) plan to appoint 7 billion euros of resources mobilized for all those companies that concentrate on innovation, green investments, design and aesthetic innovation, and training 4.0. Accordingly, Transizione 4.0 plan will allow companies to make ongoing investments operational and plan subsequent ones with more prominent assurance(Ministero dello sviluppo economico, 2019).

In the US, the industrial giant General Electric and other industrial organizations (IBM, Intel, and other non-American organizations) launched the Industrial Internet Consortium in 2014 to regulate the preferences for the industrial Internet and target the convergence between information technologies and the industrial environment (Itasse, 2016). However, the difference between Industry 4.0 and the Industrial Internet is that the Industrial Internet is expressed as the third industrial innovation wave instead of a fourth industrial revolution (I-SCOOP, 2021).

Japan introduced Society 5.0 in the 5th Science and Technology Basic Plan. The aim is to focus on the human-centred society and support economic progress by resolving social obstacles with a system that blends physical and digital domains, spreading beyond just the digitalization of the economy and enabling the digital transformation of society itself (Keidanren, 2016).

In Turkey, some public institutions prioritized the key emerging digital technologies, including artificial intelligence, sensor technologies, the internet of things, big data, cloud computing, and other technological advancements, by promoting and funding the projects related to digital transformation (Oztemel & Gursev, 2018). On the other hand, Taiwan constructed a national development plan in 2017 to motivate the development of new digital solutions, the smart machinery industry, and build smart cities (Oztemel & Gursev, 2018). More examples about the adoption of the concept of Industry 4.0 and the increasing interest in digital transformation can be seen in the United Kingdom's (Industry 4.0 and the workaround fourth industrial revolution by the Engineering Employers' Federation (EEF)), China (where the Industry 4.0 outline is at the basis of ‘Made in China 2025’) and numerous other initiatives. Essentially all of the initiatives are leveraging the Industry 4.0 concept, despite their various titles.

Definitions of Industry 4.0

Industry 4.0 empowers the manufacturing sector with factory equipment that comes outfitted with various sensors to transmit a wide array of data (Big data). Cloud computing functionalities allow data aggregation from different industrial environments combined with analytical tools to extract insightful information from related data. (Liao, Deschamps, Loures, & Ramos, 2017) Indicates, that the fusion of digital data and physical objects empowers industrial sectors to evolve faster and more significantly than in any of the three previous industrial revolutions.

Consequently, Industry 4.0 is a revolutionary concept that attracts the attention of governments, companies, and academic scholars. Hence, the existence of different perceptions on the application of Industry 4.0, Table 1 shows some definitions of Industry 4.0.

Table 1: Industry 4.0 definitions

Authors	Defenition
(Kagermann, Helbig, Wahlster, 2013)	Utilizing the power of communications technology and innovative inventions to boost the development of the manufacturing industry.
(Koch, Kuge, Geissbauer, 2014)	Industry 4.0 stands for the fourth industrial revolution and is best understood as a new level of organization and control over the entire value chain of the life cycle of products; it is geared towards increasingly individualized customer requirements.
MacDougall (2014)	Industry 4.0 or the Smart industry refers to the technological evolution from embedded systems to cyber-physical systems. It connects embedded system production technologies and smart production processes to pave the way to a new technological age which will radically transform industry and production value chains and business models".
McKinsey (2015)	Digitization of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous cyber-physical systems, and analysis of all relevant data.
(Pfohl, Yahsi, & Kurnaz, 2015)	Industry 4.0 - the fourth industrial revolution, focuses on the end-to-end digitization of

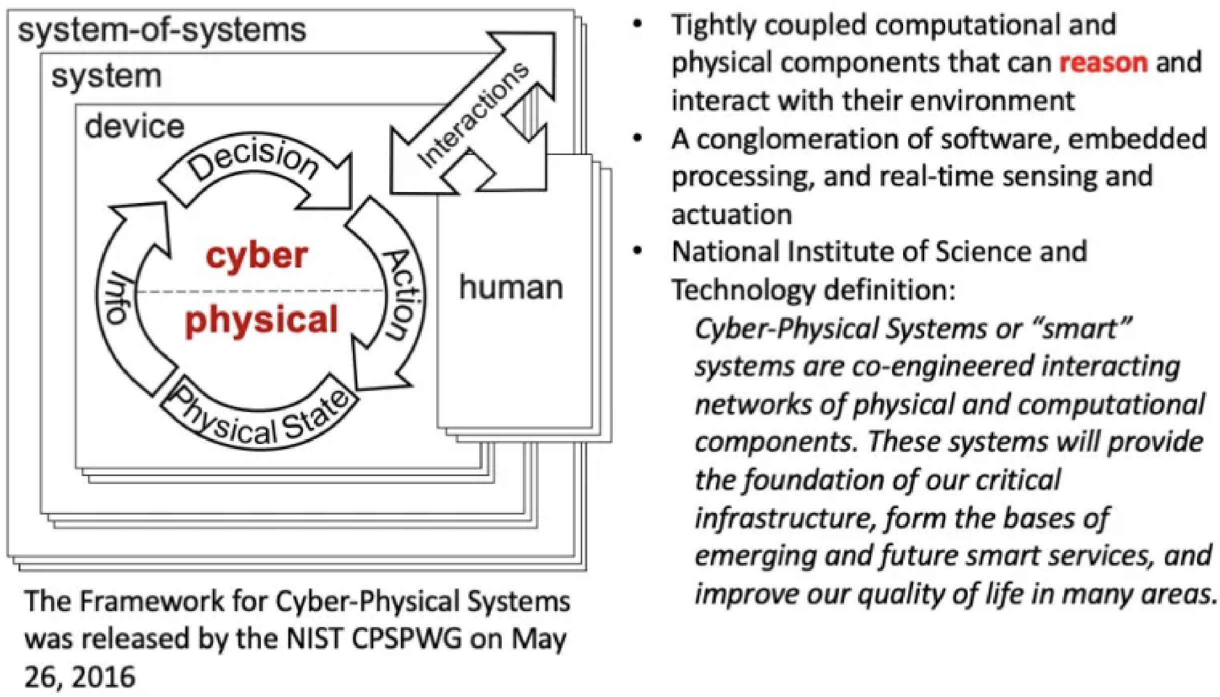
	all physical assets and integrating digital ecosystems with value chain partners.
Deloitte (2016)	The term Industry 4.0 encompasses a promise of a new industrial revolution, one that marries advanced manufacturing techniques with the Internet of Things to create manufacturing systems that are not only interconnected but communicate, analyze, and use the information to drive further intelligent action back in the physical world.
(Mrugalska & Wyrwicka, 2017)	The modern and more sophisticated machines and tools with advanced software and networked sensors can be used to plan, predict, adjust and control the societal outcome and business models to create another phase of value chain organization and it can be managed throughout the whole cycle of a product. Thus, Industry 4.0 is an advantage to stay competitive in any industry. To create a more dynamic flow of production, optimization of value chain has to be autonomously controlled.

Most of the definitions listed in the table above and many others represent the meaning of Industry 4.0 to be consist of crucial topics related to 'Cyber-Physical Systems (CPS),' 'Internet of Things (IoT),' 'Big Data' and 'Cloud Computing' in many of the referenced researches (Tay, Chuan, Aziati, & Ahmad, 2018). Accordingly, further understanding of these topics is required to gain a deeper comprehension of Industry 4.0.

Cyber-physical systems (CPS)

Cyber-physical systems (CPS) can be described as an emerging set of systems that involve engineered computing and communicating systems interfacing with the physical world. These systems can be used in the manufacturing environment to optimize and automate operational processes, creating a single, decentralized platform for the entire facility floor (Oztemel & Gursev, 2018). The term cyber-physical system was presented in 2006 by the United States National Science Foundation's then Program Manager Dr. Helen Gill (Lee, 2015). CPS is about the intersection, not the union, of the physical world and cyberspace, representing a complex intersection between physical and computational elements. Through aggregation and analysis of data collected by sensors, CPSs enable self-management and self-governing of specific activities and interact with humans via interfaces, Figure 2 below represents a view of the framework for Cyber-physical systems (Griffor, Greer, Wollman, & Burns, 2017).

Figure 2: Cyber-physical systems framework



Internet of Things (IoT)

Any scientific paper, article, or research about recent technological advancements must refer to the Internet of Things concept regardless of the sector under discussion. Accordingly, IoT is an umbrella term that refers to a network of devices, sensors, objects, assets, or 'Things,' with the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction (Kosmatos, Tselikas, & Boucouvalas, 2011). The scope of IoT can also include monitoring and controlling the network of physical objects to automate it autonomously.

Cloud Computing

Cloud computing -also called the cloud- in its simplistic form, represents a network of remote servers hosted on the internet to store data for further processing, rather than managing the data in local servers. The cloud also includes services (SaaS, PaaS, IaaS, MaaS) and delivery models (public cloud, private cloud, hybrid cloud, and community cloud) (Wang et al., 2010). Accordingly, Cloud computing is essential in many current and future evolutions, acts as a vital enabler in digital transformation and industry 4.0 projects (Oztemel & Gursev, 2018). Moreover, the cloud is one of the main reasons for the disappearance of the traditional industrial automation pyramid.

Big data

Big data is a term used to describe large, ever-growing sets of data -a combination of structured and unstructured data types- stored digitally and available for further use. Data as defined is meaningless for businesses unless used with the proper analytical tools will translate it into insightful information identifying hidden patterns and trends (Khan, Khan, & Zomaya, 2019). Big data is the core of industry 4.0, as manufacturers are using it nowadays to ditect hidden opportunities for improving their value and supply chain, enhance overall equipment productivity, and better satisfy their customers.

Digital transformation

Industrial transformation has gained a lot of attention and interest from industrial organizations in recent years. The emergence and growing importance of new digital technologies, such as Cloud Computing, Big Data, Embedded Devices, 3D-Printing, and Artificial Intelligence, to name a few, increase the pressure on organizations to adjust their business strategy and align it with the technological changes in the environment (Mergel, & Edelmann, & Haug, 2019). The new technological advancements are remarkably remodelling the strategic setting of organizations, altering the characteristics of competition, customers' expectations, business regulations, and manufacturing procedures. The digital transformation affects multiple areas of an organization, requiring a strategy that provides a familiar and steady recognition of the relevant domains to be addressed and the prioritization of digital transformation activities by understanding the current state of organizational activities and how to reach the desired long-term plan. Consequently, assessing an overall digital transformation status and mapping a practical path towards a beneficial future digital maturity state is vital for organizations. Digital maturity matters as companies with a higher level of digital maturity gain a competitive advantage over other competitors. A digital maturity model can assist companies in developing a precise roadmap for their transformation activities to move forward in the digital maturity paradigm (Robledo, 2017). In general, the digital transformation maturity of most companies remains relatively low, as the main focus of many organizations is on internal goals such as automation, process optimization, and increased productivity, without a clear vision for long-term goals (Gong & Ribiere, 2021).

The word "transformation" signifies radical and permanent changes within the organization that exceed the steady incremental improvements affecting the strategy, structure, and power distribution (Teichert, 2019). However, there are many definitions for the term "digital transformation", but a unified accepted definition does not exist yet.

Moreover, other terms are used interchangeably in existing research and scientific articles that imply similar aspects of digital transformation, namely, "digitalization" and "digitization" (Mergel, & Edelmann, & Haug, 2019), with an absence of explicit or unified description to address what these related terms signify and the differences between them.

In one of its educational resources about Digital transformation, the strategic and tactical digital business and marketing consultancy firm (i-SCOOP) addresses the confusion about the previously mentioned terms. It argues that sometimes those terms do have various definitions because they are adopted by people with different backgrounds and used in multiple contexts, which is perfectly ok, concluding that it is expected considering that we are at the early stages of digital transformation maturity levels with so many new technologies emerging in various areas unfolding further aspects and different perspectives ("Digital Transformation: Online Guide to Digital Business Transformation," n.d.).

Authors ChengGong, VincentRibiere in their research "Developing a unified definition of digital transformation." (Gong & Ribiere, 2021) concluded a unified definition of Digital Transformation as follows:

"A fundamental change process, enabled by the innovative use of digital technologies accompanied by the strategic leverage of key resources and capabilities, aiming to radically improve an entity* and redefine its value proposition for its stakeholders." *(*An entity could be: an organization, a business network, an industry, or society.)*

This report refers to digital transformation as an umbrella term comprising a vast number of processes, interactions, activities, innovations, disruptions, and industries. Its relation to the adoption of technological developments ranging from plant connectivity, big data, cloud computing, and business intelligence to more recent emerging ones, artificial intelligence, edge computing, and deep learning in the manufacturing sector.

IT/OT Convergence in the era of Industry 4.0

Another topic mentioned alongside Industry 4.0 repeatedly is the convergence of information technology and operational technology. IT/OT convergence is the integration of information technology (IT) systems with operational technology (OT) systems (Clemons, 2020). Information technology encompasses the use of computers, storage, networking devices, and other hardware devices to create, process, store, secure, and exchange all forms of electronic data. On the other hand, operational technology has traditionally held an association with manufacturing and industrial control systems, such as supervisory control and data acquisition (SCADA) (Clemons, 2020).

Information technologyand operations technology have been around since the third industrial revolution. However, they have traditionally been at the opposing edges of the technology spectrum. The idea of converging the two domains started at the end of the 20th century through connecting and exchanging data between Information technology (ERP systems) and operations technology (automation and control system). Interestingly enough, with the rise of Industry 4.0 technologies -addressed in the “Industry 4.0 enabling technologies” section- more specifically, the Industrial Internet of Things (IIoT) revolutionizes the traditional structure of information flow in the manufacturing sector, tearing down the walls between IT and operations (Lutkevich, 2020).

IT/OT convergence is presented by integrating machines with the network systems through connected systems of sensor and actuator networks (WSANs), bridging the gap between the IT and OT departments, allowing organizations to improve operational performance (Lutkevich, 2020). Ultimately, the two opposing edges of the spectrum are converging. As a result, the boundaries between IT and OT are a blur and, more importantly, no longer even matter.

Integrations in Industry 4.0: vertical and horizontal integration

The terms “horizontal integration” and “vertical integration” are used in several contexts. From an operational perspective, a horizontally integrated organization establishes an end-to-end value chain through partnerships while internally maintaining activities around its core competencies. On the other hand, a vertically integrated organization retains as many of the activities of its value chain internally as possible (McLaughlin, 2020). Deriving from a business strategy perspective, it refers to mergers and acquisitions strategies, horizontal by acquiring organizations with similar products or customer segments, or vertical by internalizing outsourced services (Schuldenfrei, 2019; GmbH, 2019).

This section will explore the two integrations from the context of Industry 4.0, which revolves around technologies, processes, and systems that facilitate the collection, communication, and use of data.

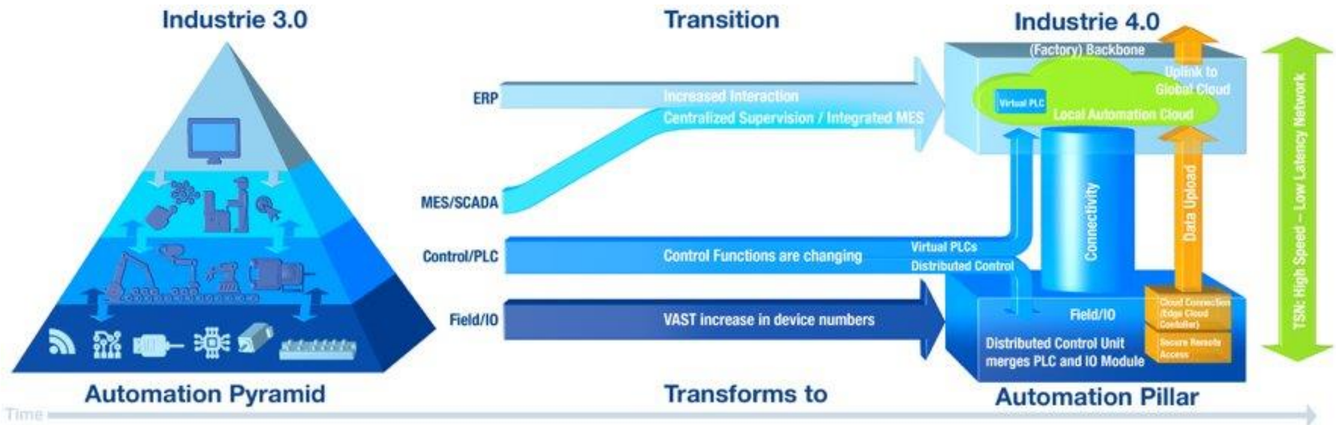
Figure 3 provides a holistic view of both integrations in the context of industry 4.0 (Gehrke, Kühn, Rule, & Standley, 2015).

Figure 3: vertical and horizontal integration under Industry 4.0

vertical integration:

Vertical integration in Industry 4.0 ties together the organization's logical layers, dramatically changing the concept of the "Traditional automation pyramid," stirring all the levels of this pyramid and affecting the associated systems of each level (Greenfield, 2017). With this integration in place, data will become available for all organizational systems and logical layers flowing freely between them. Put simply, the traditional pyramid concept is fainting, as seen in Figure 4 (Greenfield, 2017).

Figure 4: Automation Networks (From Pyramid to Pillar)



Belden's Oliver Kleineberg points out in the IoT Solutions World Congress, “The familiar automation pyramid is changing to an automation pillar to better reflect the changing locations of control systems and the ability to share data at all levels rather than sequentially; from one layer to the next.” (Greenfield, 2017)

Horizontal integration:

The second is horizontal integration, which is not about the hierarchical view of several systems as vertical integration but the mentioned end-to-end value chain: from a supplier and the processes, information flows, and IT systems in the product development and production stage to logistics, distribution, and distribution ultimately the customer (Fatorachian & Kazemi, 2018).

The second is horizontal integration, which does not involve alignment within the organization and the hierarchical view of its systems. Instead, industry 4.0 horizontal integration involves connecting all parts of the organization’s end-to-end value chain, establishing a network to connect the entire supply chain, from suppliers and manufacturing, logistics and distribution, all the way to the customer, ensuring visibility, production adaptability, collaboration, and constant communication (Schuldenfrei, 2019; GmbH, 2019).

Industry 4.0 enabling technologies

Industry 4.0 contains the key to obtaining real-time results and data, transforming the industry into new levels of cost savings, efficiency improvement, and optimization of processes (Riel & Flatscher, 2017). Through promoting new ways for humans and machines to work together (Human-machine interfaces), enabling organizations to achieve more meaningful insights, diminishing the level of uncertainty, and enhancing the decision-making process with a data-driven customer-centric approach (Fettermann, Cavalcante, Almeida, & Tortorella, 2018).

However, Industry 4.0 is not a technology but somewhat resembles a cluster of different technologies that drive industrial and organizational improvements, enabling vertical and horizontal integration through a combination of digital and manufacturing technologies (Dalmarco, Ramalho, Barros, & Soares, 2019). In other words, This cluster of distinct technologies is nursing the manufacturing's digital transformation through the integration of previously disparate systems and processes into interconnected computer systems across the value and supply chain (Zheng, Ardolino, Bacchetti, & Perona, 2020).

This report considers a list of six enabling technologies, which are mentioned in Table 2.

Table 2: Enabling Technologies definitions

Technology	Definition	Source
Industrial Internet of things (IIoT)	A network of physical objects (sensors, machines, tools, switches, and other items within the industrial environment) enables the collection of devices' status (temperature, speed, usage, and other types of input data) and communication of this information between those objects and other control systems.	(Boyes, Hallaq, Cunningham, & Watson, 2018)
Industrial Analytics	The application of mathematical techniques and procedures to view and convert the data collected through the IIoT network into useful information, which can then be used to optimize processes or support decisions within the industrial environment.	(Oztemel & Gursev, 2018)
Cloud manufacturing (C-Mnfg)	System for the provision of online storage services for manufacturing digital resources, applications, and data in a virtual server, without requiring any installation. In addition to analyzing and proposing service packages for utilizing resources and meeting the desired requirements.	(FH Vorarlberg, 2016)
Advanced human-Machine interface (A-HMI)	A combination of particular devices (tablets, smart glasses, and others) and software application enables humans to engage and interact with machines, either in reality or in a virtual sense.	(Gonzalez, 2015)
Advanced Automation	Refers to sophisticated automated systems, machinery, and equipment that automize operational processes mostly require little or no human interaction to operate, apart from top-level guidance.	Oztemel & Gursev, 2018)
Additive manufacturing	Process of joining materials in successive layers to make objects from 3D model data to 'unlock' design options and achieve the excellent potential for mass-customization	(Durão, Christ, Zancul, Anderl, & Schützer, 2017)

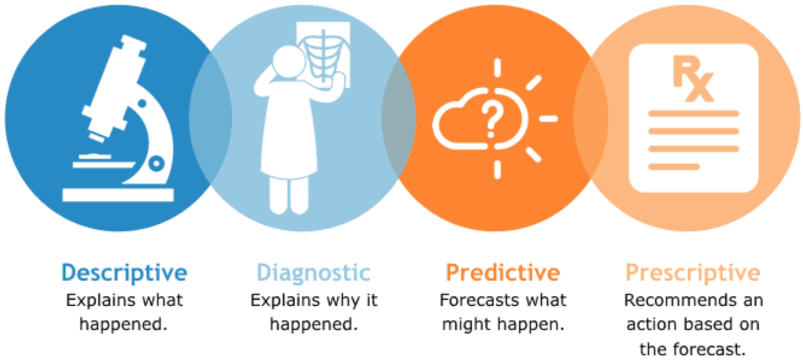
Industrial Internet of Things

As discussed earlier, IoT refers to a network of physical objects that are digitally interconnected, promoting machine-to-machine communication and the transfer of data over the Internet (Boyes, Hallaq, Cunningham, & Watson, 2018). Industrial-IoT is a subcategory of IoT (Khodadadi, Dastjerdi, & Buyya, 2016). The term points to the use of IoT technology in an industrial context, particularly in the manufacturing environment, where different sensors, Radio Frequency Identification (RFID) tags, software, and electronics are integrated with industrial operational equipment (machines, tools, devices) and embedded systems to gather real-time data about the condition and performance of these types of equipment (Aberle, 2015). Manufacturers who successfully implement Industrial-IoT projects in their environment can significantly improve processes, reduce costs, enhance efficiency, and provide unprecedented real-time visibility and traceability along the supply chain (ARNOLD, KIEL, & VOIGT, 2016).

Industrial Analytics

Industrial analytics is a subcategory of data analytics. The term points to the use of data analysis techniques in an industrial context, particularly in the manufacturing environment. After collecting data sets (structured and unstructured) generated by Industrial-IoT devices and other systems connected to the IoT network (ERP, CRM, and MES systems), Industrial analytics converts these massive amounts of data sets into information that can provide actionable insights. Machine learning models and data visualization can aid data analytics processes (Oztemel & Gursev, 2018). Machine learning techniques apply powerful computational algorithms to process massive data sets, while data visualization tools enable manufacturers to comprehend the story the data tells more easily. Ultimately, by taking previously isolated data sets and collecting and analyzing them, companies can now find new ways to optimize the processes that significantly affect yield. The four types of industrial analytics are shown in Figure 5 (Mehta, 2017).

Figure 5: Types of Analytics



Cloud Manufacturing

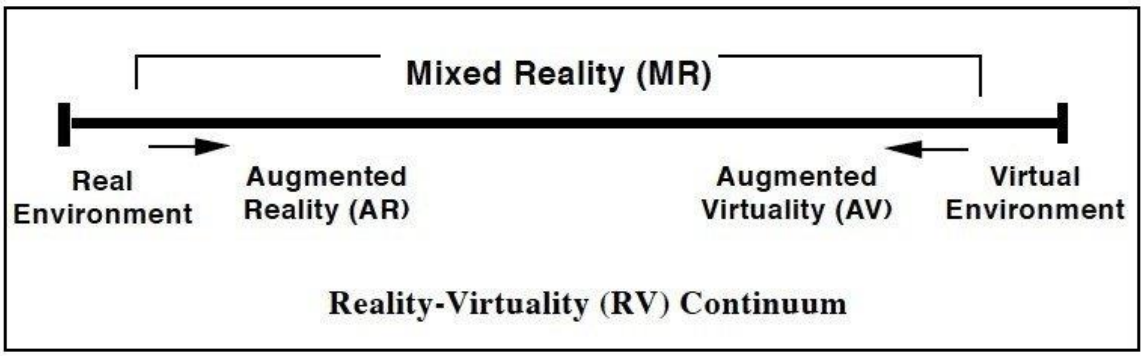
Cloud manufacturing is also referred to as manufacturing-as-a-Service (MaaS) (FH Vorarlberg, 2016). Cloud manufacturing is an identical, networked, and remote production resource system that can be accessed through the internet (Arnold, Kiel, & Voigt, 2016). Offering manufacturers a shared use of a networked manufacturing infrastructure to use the internet to share manufacturing-related information reduces costs and makes better products (FH Vorarlberg, 2016).

Cloud computing is rising as one of the primary enablers for the manufacturing industry; it transforms traditional manufacturing systems by designing intelligent networks that foster effective collaboration. Cloud manufacturing is the manufacturing version of cloud computing adoption in the manufacturing sector. In cloud manufacturing, distributed computing resources are provisioned through cloud services and managed in a centralized way (Vaidya, Ambad, Bhosle, 2018).

Advanced human-Machine interface (A-HMI)

The advanced human-Machine interface combines particular devices (tablets, smart glasses, and others) and software applications that enable humans to engage and interact with machines, either physically or in a virtual sense (Khodadadi, Dastjerdi, & Buyya, 2016). A-HMI includes technologies that represent virtual reality (VR), augmented reality (AR), and mixed reality (MR). Mixed reality as introduced by (Kiyokawa, Takemura, & Yokoya, 1999) combines real and virtual environments along the reality-virtuality continuum encompassing augmented reality and augmented virtuality technology, as shown in Figure 6. In manufacturing, A-HMI is used to help in the assembly process, maintenance tasks, and training sessions and improve decision-making in product development stages (Gonzalez, 2015).

Figure 6: Mixed Reality on the Reality-Virtuality Continuum



Advanced Automation

Advanced Automation is also known as advanced robotics. While robotics has been in the manufacturing environment since the third industrial revolution, with contemporary advancements in technology within the context of industry 4.0, a new age of advanced robotics is arising, intelligently performing complex and delicate assignments (Ghobakhloo, 2018). Advanced robotics are equipped with cutting-edge software and sensors, allowing them to recognize, analyze and act upon the information they receive from the environment and even cooperate and acquire new knowledge from humans (Oztemel & Gursev, 2018).

In manufacturing plants, advanced automation is represented by the use of:

- collaborative robots ("cobots"): designed to work safely around humans, relieving workers from repetitive and risky assignments (Inc., 2018).
- Autonomous mobile robots (AMRs): designed to move inventory within a facility, assist in the picking process and provide a flexible sortation solution without an operator (Lodwig, 2020).
- Autonomous guided vehicles (AGVs): used in various fields to maintain processing and handling throughout the manufacturing facility.

Additive Manufacturing

Additive manufacturing, or 3D printing, is a fundamental technology enabling Industry 4.0. Additive manufacturing operates by utilizing digital 3D models to build parts layer by layer with a 3D printer (Durão, Christ, Zancul, Anderl, & Schützer, 2017). Within the context of Industry 4.0, 3D printing is emerging as a valuable digital manufacturing technology. Nowadays, additive manufacturing proposes a tremendous scope of opportunities for manufacturing, from tooling to mass customization across various industries (Esmaeilian, Behdad, & Wang, 2016).

3D printing technology allows storing the part's design files in virtual records, moreover, printing the part on-demand and closer to the point of need. Such an approach can reduce transportation distances, internalize the spar part production, therefore costs, and simplify inventory management by storing virtual records instead of physical parts (Holmström, Partanen, Tuomi, & Walter, 2010).

To better clarify the different functionalities of these enablers, the author divided the I4.0 enabling technologies into subcategories called "Technology Details" which are represented in Table 3.

Table 3: Technology Details

Technology	Technology Detail	Definition
Industrial Internet of things (IIoT)	Connectivity	Refers to connecting physical objects within the industrial environment to a network and enabling data transmission back to an enterprise server or system for processing.
	Cellular Connectivity	Mobile Private Network (MPN) that allows real-time, secure data capture and analysis and provides a network compatible with 5G technology
	D2C Extended Connectivity	establishing connectivity between physical objects within the industrial environment to a cloud-based application platform and set of tools to monitor objects remotely and manage remote content.
Industrial Analytics	Descriptive Analytics	Describing or summarising the existing data using applications of mathematical techniques and procedures includes two main techniques: data aggregation and data mining.
	Diagnostic Analytics	An application of data analytics to investigate the causes and effects of situations is characterized by data discovery and root cause analysis techniques.
	Predictive Analytics	An application of mathematical concepts to gain information from data and use it to show the relationship between data to predict future outcomes based on changes in the dataset. Includes domains such as data science and machine learning
	Perspective Analytics	Describes the application of data analytics using mathematical models to create a set of complex alternatives from the available data, which is then used to prescribe the best possible solution, including domains such as: advanced analytics and deep learning.
Cloud manufacturing (C-Mnfg)	Manufacturing as a service (MaaS)	A shared use of a networked manufacturing infrastructure where organizations use the internet to share manufacturing information reduces costs and makes better products.
Advanced human-Machine interface (A-HMI)	Augmented Reality	A collection of Human-Computer Interaction (HCI) techniques can insert virtual objects to coincide and interact with humans in a physical environment.
	Virtual Reality	Application of computer technology to design an interactive world, allowing the user to control the virtual object and whole virtual scene in real-time.
	Mixed Reality	Brings together real-world and digital factors. Humans can

		interact with and manipulate physical and virtual items and environments using next-generation sensing and imaging technologies.
Advanced Automation	Collaborative Robots	Also known as a cobot, is a robot programmed and designed to work with human instruction, allows humans and machines to operate in a shared learning environment.
	Autonomous mobile robots (AMRs)	A robot that can recognize and travel through its environment without being supervised directly by an operator or on a fixed, predetermined path.
	Autonomous guided vehicles (AGVs)	Computer-controlled and wheel-based load carriers that move along the facility's floor without an onboard operator or driver.
Additive manufacturing	3D printing	The manufacturing of solid objects by installing layers of material in relation to blueprints stored as a digital model. Includes methods such as selective laser sintering, electron beam melting, fused deposition modeling, and stereolithography.
Multiple I4.0 technologies	CPS (Cyber-Physical Systems)*	This term is used in the context of describing the use and implementation of multiple industry 4.0 technologies.

Industry 4.0 Application Areas

<u>**Smart Life Cycle**</u>

Industry 4.0 and its enabling technologies are transforming the very foundation of traditional approaches to product development and life cycle management, enabling a modernized approach to product lifecycle management - referred to here as Smart Life Cycle (Ferreira, Faria, Azevedo, & Marques, 2016).

However, in the Case Collection procedure and categorization, Smart Life Cycle as a macro process refers to the use of Industry 4.0 enabling technologies in the manufacturing facilities. Including processes such as: New Product Development and Product Lifecycle Management.

New Product Development: Refers to the creation of new products by evaluating all the characteristics and functions. It also involves the adjustment of existing products to achieve specific enhancements and answer new customer needs. Digital technologies can transform this process, starting with the design phase by connecting all users involved in formalizing the product information model and improving the effectiveness of data source collection. Accordingly, users can employ this data to acquire information about potential design features and improvements that satisfy underlying customer needs. Coupled with Machine Learning, information collected from the product life cycle lead to product design optimization. Augmented reality and other visualization technologies can also boost the product development process as it provides a detailed vision of the end product to assess and evaluate.

Product Lifecycle Management: According to Gartner, Product life cycle management (PLM) is "a philosophy, process and discipline supported by software for managing products through the stages of their life cycles, from concept through retirement. As a discipline, it has grown from a mechanical design and engineering focus to being applied to many different vertical-industry product development challenges." Absent the new technological advancements of the fourth industrial revolution, PLM traditional digital systems can only provide support in the design phase by creating a digital version of the product, after which further stages are carried out solely in the physical world, creating a gap between the digital world and the physical world (Grealou, 2021).

Thanks to the current technologies, manufacturing companies can establish a digital infrastructure through digitizing manufacturing and production processes using IIoT connectivity, industrial automation, and control systems to monitor and manage all processes from product design to sales (Ferreira, Faria, Azevedo, & Marques, 2016).

Smart Factory

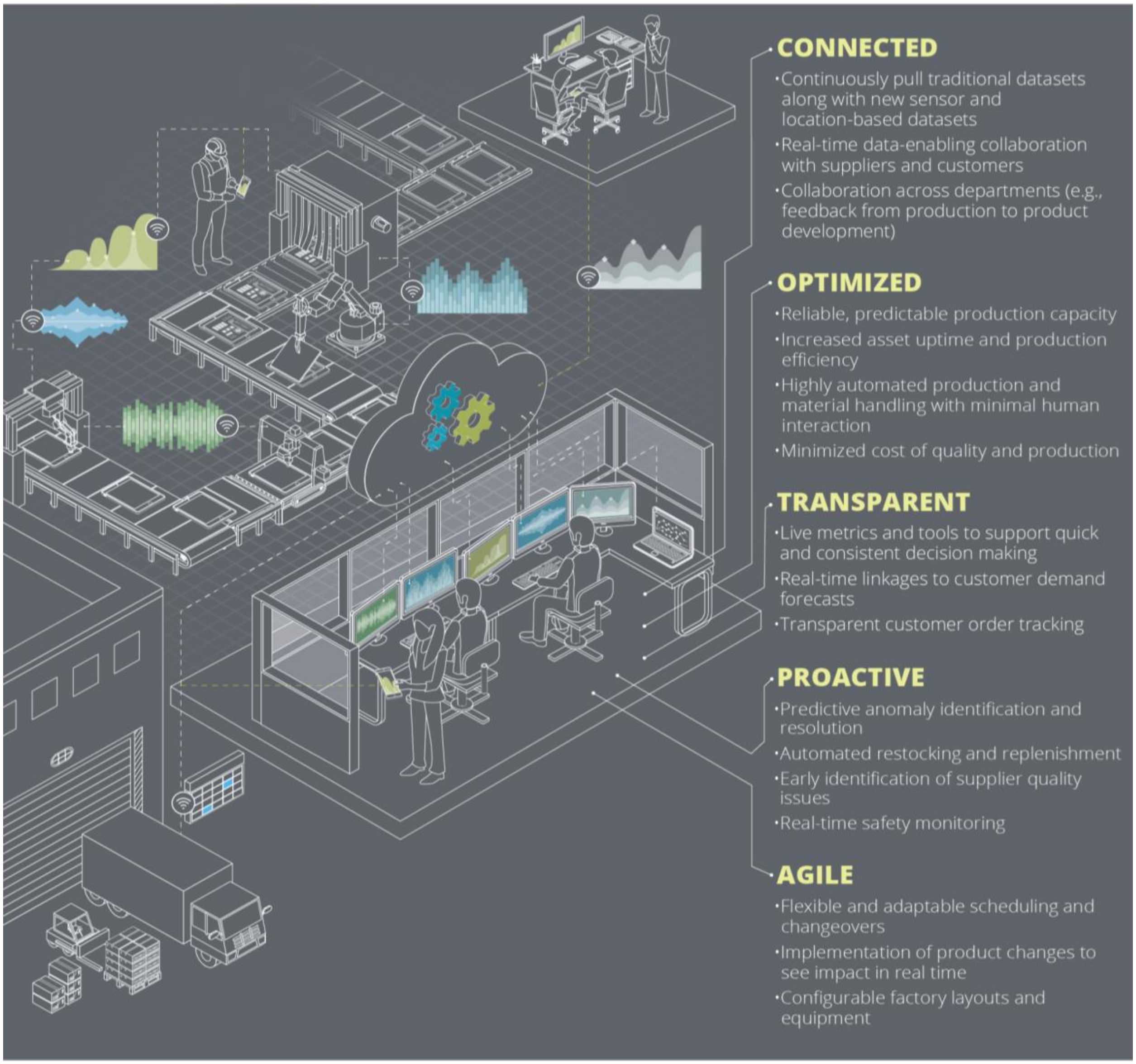
Historically, automation was part of the factory to some extent. The new technological advancement and enabling technologies of industry 4.0 are currently transforming traditional automation in the manufacturing environment and related industrial sectors from an individual and discrete activity to a completely connected and flexible system (Oztemel & Gursev, 2018). An actual smart factory represents the digitization of the manufacturing facility operations to collect and integrate data from interconnected physical, operational, and human assets. By converging IT and operations, smart factories can autonomously monitor and control the entire production process and other types of activities across the whole manufacturing network.

To drive manufacturing, maintenance, inventory tracking, digitization of operations through the digital twin, and other types of activities across the entire manufacturing network. The result can be a more efficient and agile system, less production downtime, and a more remarkable ability to predict and adjust to changes in the facility or broader network, possibly leading to better positioning in the competitive marketplace. Industry 4.0 enabling technologies have made smart manufacturing practices fully comprehensive (Shi et al., 2020). Smart factories use completely integrated, collaborative manufacturing systems to proactively address issues, improve manufacturing processes and respond to new demands (Burke, Mussomeli, Laaper, Sniderman, &

Hartigan, 2016). Smart factory initiatives might also be referred to as "digital factory" or "intelligent factory."

Deloitte defines a Smart factory as "a flexible system that can self-optimize performance across a broader network, self-adapt to and learn from new conditions in real or near-real time, and autonomously run entire production processes." Figure 7 represents the smart factory and some of its major features: connectivity, optimization, transparency, proactivity, and agility. Each of these features has a role in enabling more informed decisions and can help organizations improve the production process. It is important to note that no two smart factories will likely look the same, and manufacturers can prioritize the various areas and features most relevant to their specific needs (Burke, Mussomeli, Laaper, Sniderman, & Hartigan, 2016).

Figure 7: Key characteristics of Smart Factory



Source: Deloitte analysis. Deloitte University Press | dupress.deloitte.com

However, for the Case Collection procedure and categorization, smart factory as a macro process refers to the use of Industry 4.0 enabling technologies in the manufacturing facilities. Including processes such as: Production, Maintenance, Logistics, Quality, Safety & Compliance, Training.

Production: Industrial production has reached the edge of a new industrial revolution. Accordingly, companies have to develop production systems considering the need for solid product individualization and highly flexible production processes. Furthermore, production and manufacturing practices have been deeply affected by the new technological advancements of industry 4.0 by digitizing operational activities through Industrial IoT, enabling connected machines on the shopfloor to exchange data within the network or with other software. One of the technologies that are transforming production processes is additive manufacturing and its related technology, 3D printing, which is different from conventional manufacturing processes. It provides the user with the capability to build highly complex products and requires lower to no setup time. The technologies above and others enhance the plant productivity and overall equipment efficiency besides reducing cost and material waste.

Logistics: The logistics domain is also affected by the scope of industry 4.0 technologies since it provides various opportunities to leverage big data. Internal logistics deals with the handling and storage of stock inside the factory. This process is responsible for ensuring secure and practical production supply, so accuracy and time-efficiency are essential. Furthermore, with RFID adoption for material identification and tracking, I4.0 enabling technologies can propose many approaches for transforming internal logistics. Such the case with IoT implementation allows the ability to monitor and track material through all manufacturing stages using digital-ID. Furthermore, Advanced robotics can offer an intelligent, flexible, and reliable internal transportation method. The robots are armed with sensors, cameras, and scanning devices, all linked to intelligent software, allowing them to analyze the environment, avoid obstacles and navigate autonomously between various destinations.

Maintainance: The issue of maintenance is one of the most critical operations within a manufacturing plant; a well-structured maintenance strategy enables organizations to reach a high level of efficiency in production with minimal downtime and enhance resource utilization. Additionally, it remains a delicate task to predict when to maintain equipment and machinery. If done too soon, a plant may unnecessarily swap out expensive parts well before they are worn, adding costs. On the other hand, postponed maintenance will cause unplanned downtime, negatively affecting production plans. Adopting technologies such as IoT, cloud services, and advanced analytics; allows factories to deploy preventive maintenance systems to analyze machine condition indicators against historical information using machine learning algorithms that automatically provide maintenance engineers with alerts and diagnostics before any functional failures—resulting in improved operating efficiencies, prediction asset failure, and fewer inspections.

Quality: The primary intention of this process is to ensure that a manufactured product or performed service adheres to a defined set of quality standards. Enhancing quality defect detection in factory-made products and enabling accurate data analysis from the production process be accomplished by utilizing the power of IoT and analytical tools. In addition, a more sophisticated level of control is possible using an artificial intelligence solution that independently monitors equipment and adjusts it automatically to keep products within desired specifications.

Safty and Compliance: Manufacturing safety is vital as it protects human resources from industrial accidents, injuries, illnesses, and deaths; factories need to create a safe workplace for employees. In tasks considered dangerous for human workers, manufacturers can utilize

Collaborative Robots to perform these hazardous tasks efficiently while reducing physical strain and pressure on workers.

Training: Formal technical training sessions include the use of complex 3D graphics and paper-based instructions and often require the existence of experts for further explanation. However, these traditional techniques lacked relevance to actual workshop repair and maintenance scenarios and provided poor trainees technical engagement. Industry 4.0 offers many ideas to solve these issues; Advanced human-Machine interfaces (A-HMI) can replace traditional training manuals with Augmented Reality-empowered visual representation of training content with the ability to update instructions and scenarios instantly.

Case Studies on the adoption of Industry 4.0

Nowadays, there is a remarkable shift occurring as enterprises adopt Industry 4.0 technologies to manage and optimize all aspects of their manufacturing processes and remain competitive. On the other hand, customers' expectations have evolved to more express delivery, advanced product customization, and overall better service where companies are expected to meet these growing needs. All these factors combined with the current unpredictable turbulent market environment, create a challenging setting for companies that are still operating with outdated legacy equipment and did not adapt to a more data-driven integrated landscape (Noren, 2021). To better understand the adoption level of Industry 4.0 and related technologies the author collected a comprehensive set of companies' stories and their journey in adopting Industry 4.0 enabling technologies in a database. This database will be used by other parties for further quantitative and qualitative analysis.

Cases Collection

This part of the report summarizes the methodology adopted in acquiring information, the case studies selection procedure followed by an introduction to the database attributes.

Methodology

The method chosen for collecting these cases is Secondary Research, (Sims, 2006) defines this method as; "Also known as desk research, secondary research is the most common research method employed in the industry today. It involves processing data that another party has already collected. With this form, researchers will consult previous studies and findings such as reports, press articles, and previous market research projects to come to a conclusion."

The secondary research method was conducted using available data on Internet through google search engine.

Picking the source of data or material is crucial as it ensures the authenticity and credibility of the collected information; accordingly, the author chose” I4.0 Technology providers” websites as the primary source of information.

I4.0 Technology providers apply to companies that offer consultancy services and software solutions related to Industry 4.0 enabling technologies. In other words, they are companies that supply cutting-edge products and services that are driving the fourth industrial revolution (IoT-Analytics, 2019). However, the case collection database name these companies as “Partners” and will be referred to as such. A list of partners and associated websites are available in Appendix 1.

Case selection

After picking a reliable source of data for the case studies (Partner’s website), the selection procedure depended on several criteria listed below according to priority:

- Relevance of project implemented. The most crucial criterion in selecting Industry 4.0 case studies is on projects that included implementing any of the technological advancements - mentioned in Table 2- in a manufacturing environment.
- Comprehensive case selection. Another essential factor that has been taken into consideration besides the relevancy of projects is the diversity and coverage of all the Industry 4.0 enabling technologies.
- Completeness of information including:
    - Company name, the owner of the implemented project
    - The issue faced by the company before implementing the project

- The implemented solution, services, and products provided by the partner
- Results and benefits gained from deploying industry 4.0 related applications.

➢ In addition to other secondary affecting factors including:

- Date of project implementation. Favouring more current projects as it includes the adoption of most advanced technologies.
- Location of the facility under development. Providing a worldwide view of companies' adoption of industry 4.0.
- Industry sector. Including case studies from various sectors.

Case studies Database

The database is essentially a collection of all the cases sourced from the partners' websites (mentioned in **Appendix 1**) and passed the case selection criteria (listed in the "Case selection" section).

It is worth mentioning that the attributes/variables used to construct the database and categorize selected cases were formulated by other parties and simply adopted by the author. Therefore, this section will present the attributes/variables in the database and associated elements/categories. The purpose of the Database is to provide a structured dataset for future researchers to conduct further analysis on the adoption of Industry 4.0 in the manufacturing environment and related industrial sectors.

Database Structure: An excel sheet table is used to collect data that consists of records (rows) which are identified by the *company name* (I4.0 project owner) and each record is divided into fields (columns) which are identified by *attributes*. Fields contain *elements* representing the cross-section between rows and columns. For more information about the database attributes and elements please refer to **Appendix 2**.

Appendix 3 provide a summary for all the collected cases concerning the adoption of I4.0 in the manufacturing context, which includes the company name and a decription of the project implemented.

Summary of collected cases

Since the recorded cases in the database contain a large amount of data, the author decided to use pivot tables to provide a summarized informative view of the collected case studies, where each table contains a different attribute and the associate number of cases.

Table 4. Sectors

Sector	Num. of cases
Automotive	9
Machinery	7
Food	6
Electronics / electrical	5
Aerospace	3
Building	3
Chemistry and Pharmaceuticals	3
Clothing / Shoes / Accessories	3
Capital goods	2
Metal industry	2

Luxury	1
Plastics	1

Table 4 shows the number of collected case studies per each industrial sector in which the company operates.

Figure 8: Regions

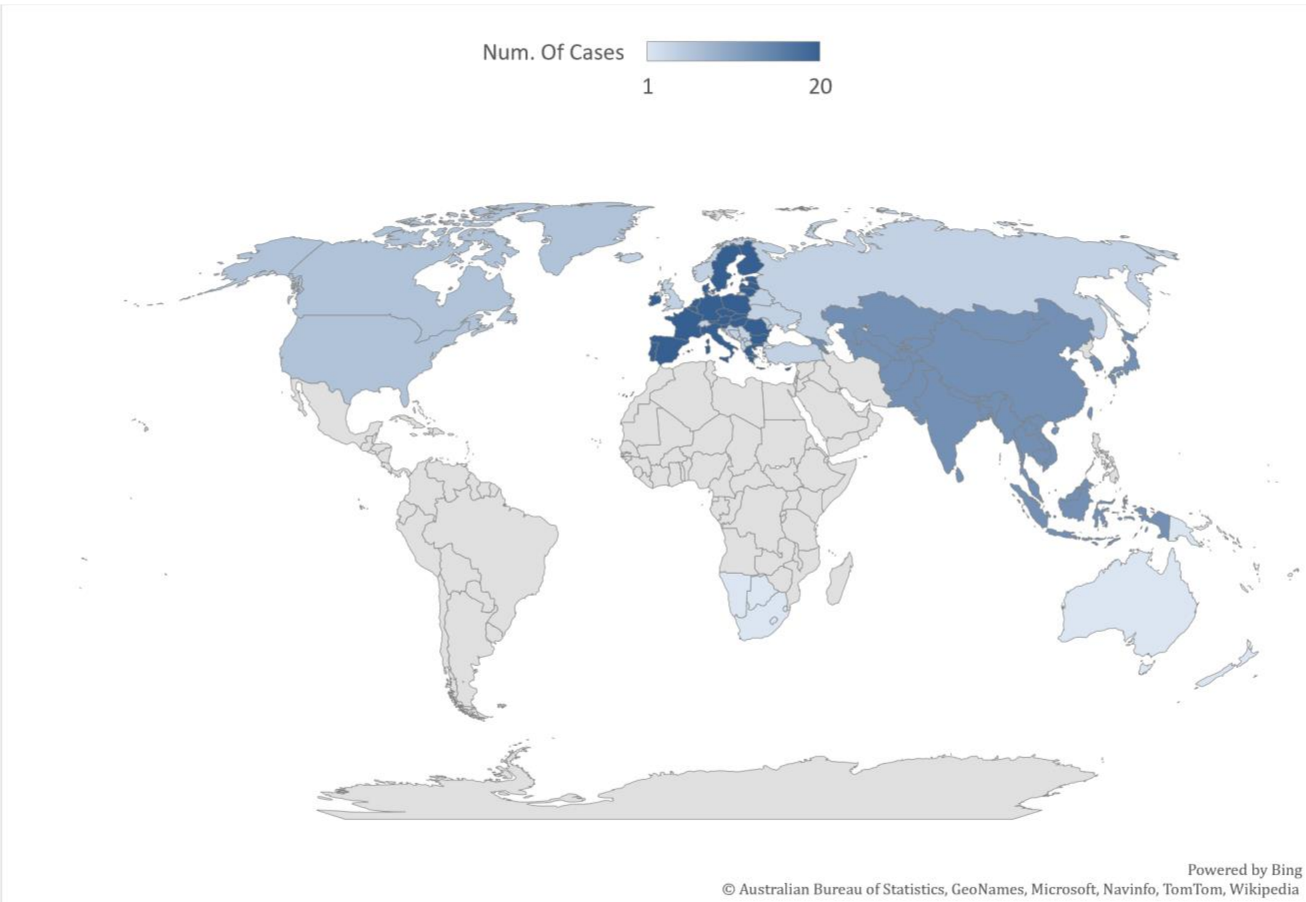


Table 5: Regions

Regions	Num. of cases
European Union	20
Asia	13
Northern America	6
Europe	4
Oceania	1
Southern Africa	1

Figure 8 and Table 5 shows the number of collected case studies per each geographical area in which the company's factory (plant or facility) resides.

Figure 9: Year of implementation

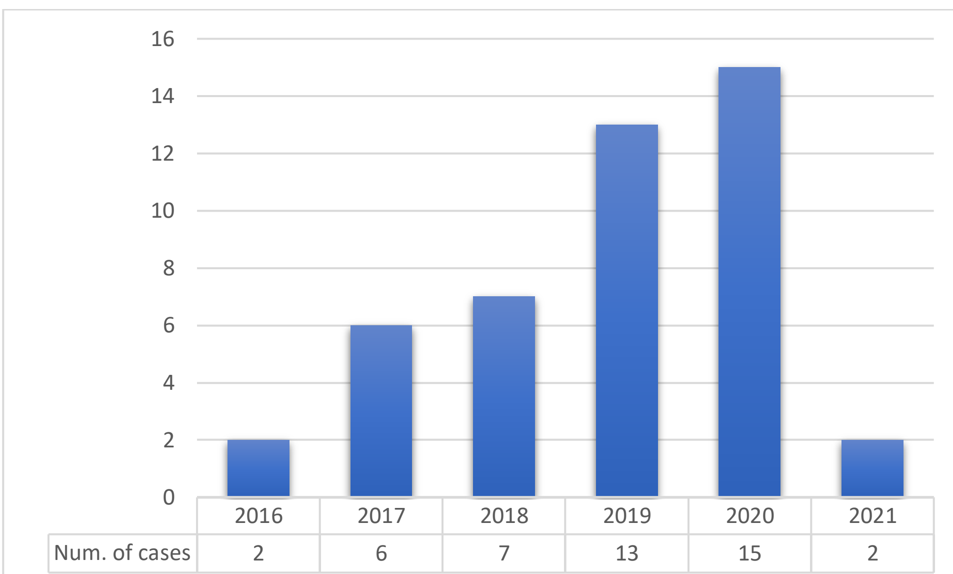


Figure 9 shows the percentage of collected case studies per year in which the company implemented the new technology.

Figure 10: Enabling Technologies

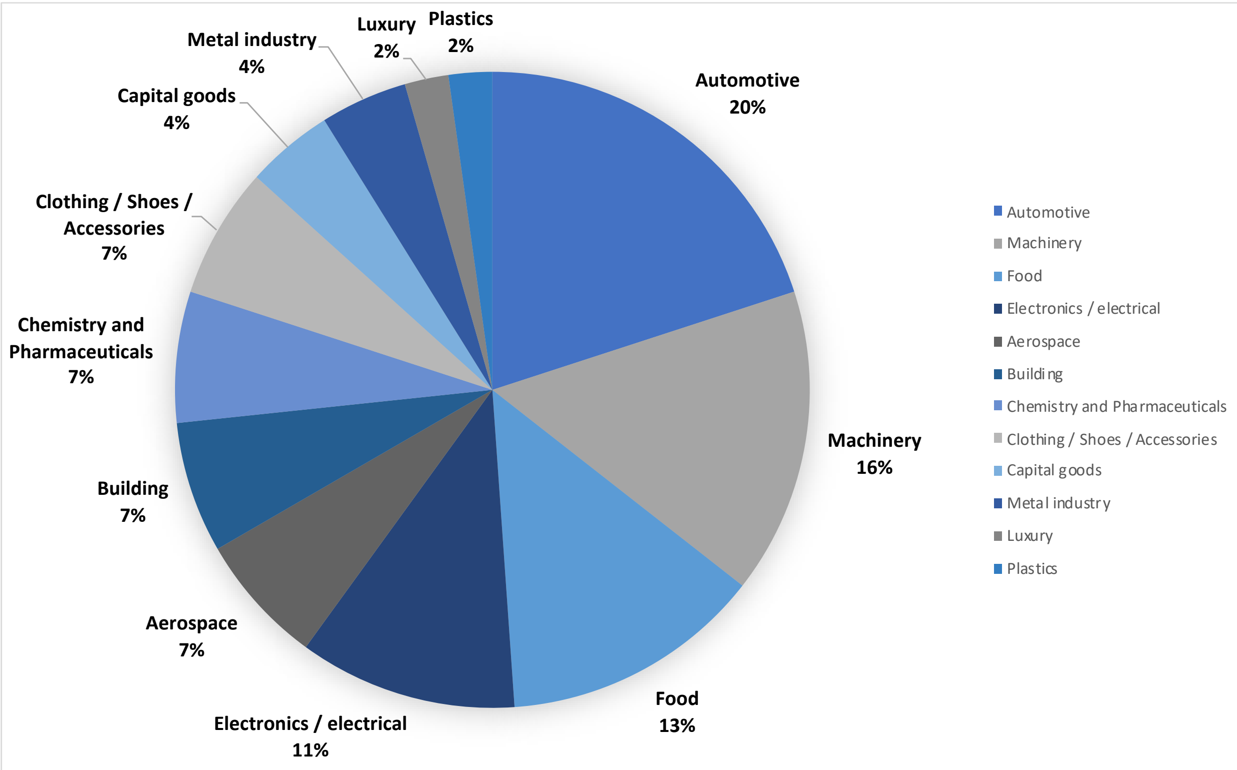


Figure 10 shows the number of collected case studies per each Industry 4.0 enabling technology.

Figure 11: Technology Details

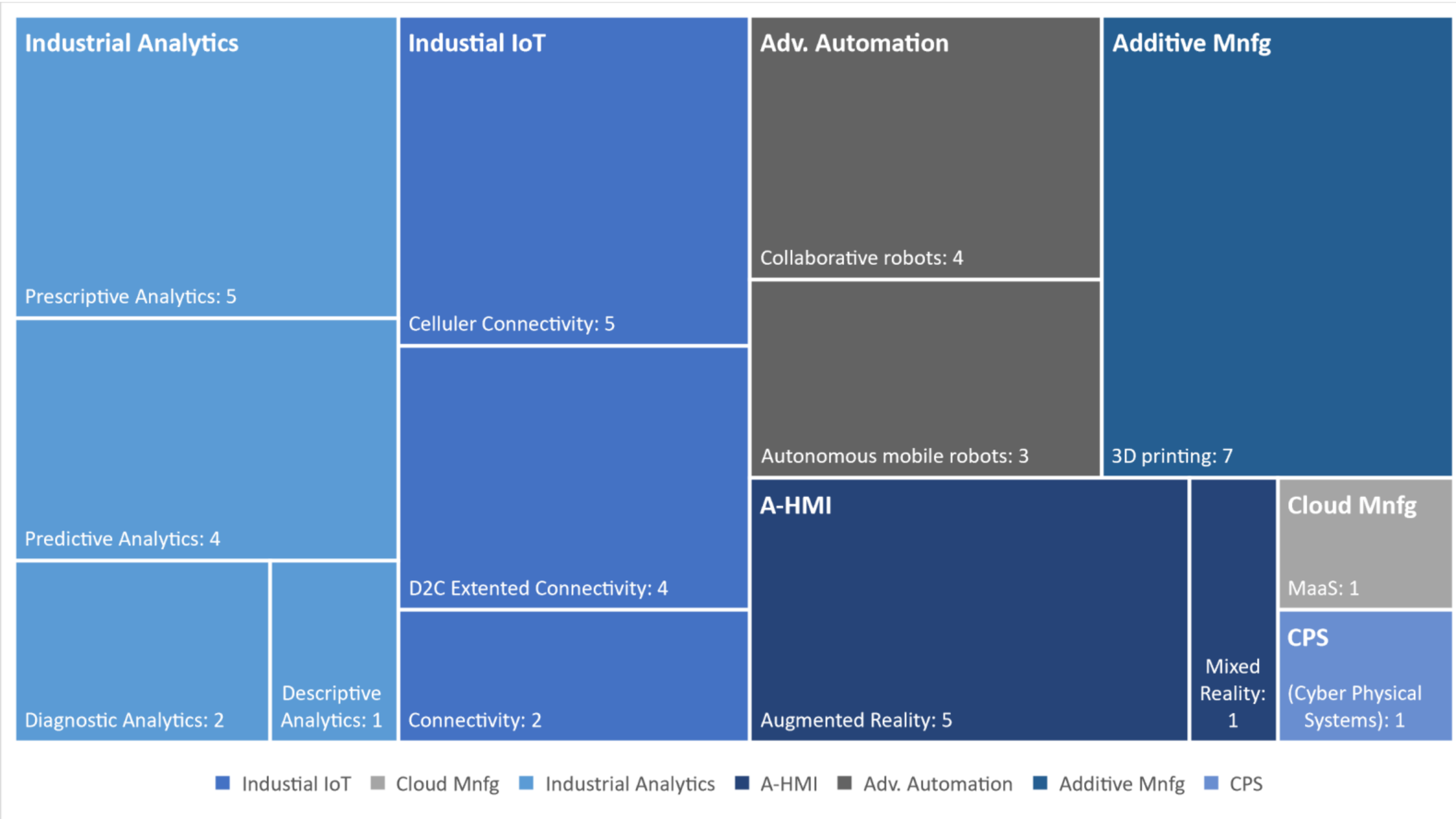


Figure 11 shows the number of collected case studies per each subcategory of Industry 4.0 enabling technologies.

Table 6: Manufacturing Processes

Macro Process	Process	Num. of cases
Smart Life Cycle	Product Development	5
	Product Lifecycle management	2
Smart Factory	Production	26
	Maintenance	7
	Logistics	3
	Safety & Compliance	1
	Training	1

Table 6 shows the number of collected case studies per each organizational process.

Figure 12: Application Areas

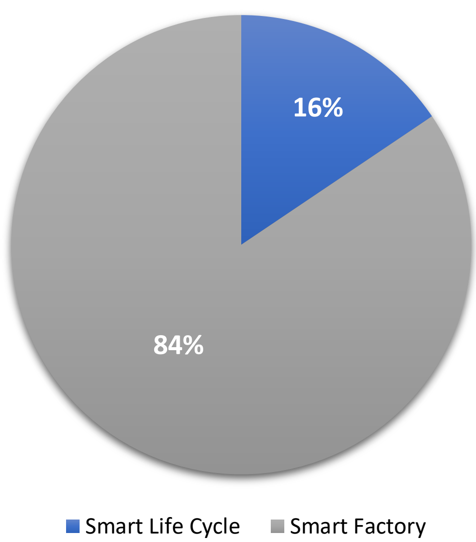
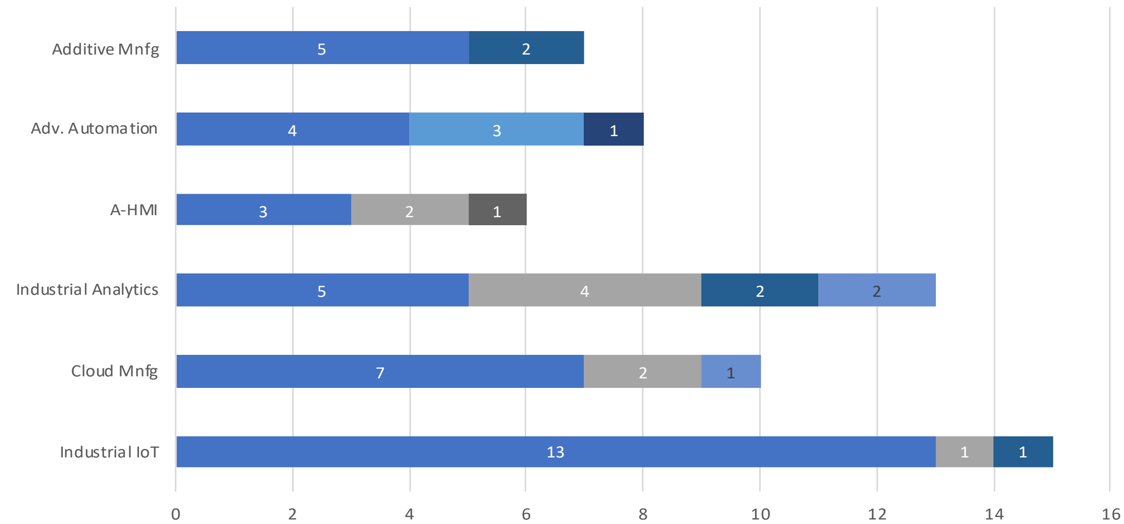


Figure 12 shows the percentage of cases per each application area (macro-process)

Table 7: Enabling technologies and Processes



	Industrial IoT	Cloud Mnfg	Industrial Analytics	A-HMI	Adv. Automation	Additive Mnfg
Production	13	7	5	3	4	5
Maintenance	1	2	4	2		
Logistics					3	
Safety & Compliance					1	
Training				1		
Product Development	1		2			2
Product Lifecycle management		1	2			

Table 7 shows a cross-table view for the enabling technologies and in which processes they were implemented.

Final Remarks

- The case collection resulted in forty-five projects representing companies in various industrial sectors, sizes, and regions, thus providing a clear picture of the Industry 4.0 adoption worldwide, at the same time, considering different needs, technological advancements, and processes.
- The introduction of Industry 4.0 technologies or applications can initiate big changes in individual companies, but also in entire industries. The most affected industry sectors by the

fourth industrial revolution based on the number of collected cases are: Automotive sector (9 cases) and Machinery sector (7 cases)

- Additive manufacturing as an enabling technology with its 3D printing applications provides SME companies with a fast, cost-effective solution to produce personalized spare parts and prototypes by internalizing the process and freeing them from third-party suppliers. Which can be observed in the collected cases, more than half of the projects belonging to additive manufacturing technology were implemented by small or medium enterprises.
- When implementing any of the enabling technologies, the primary focus of many organizations is to enhance overall equipment efficiency (OEE) and improve the productivity of manufacturing processes resulting in most cases belonging to the *Production* process (26 cases).
- IIoT-connected equipment provides the foundational first stage to adopt Industry 4.0, but merely establishing a network of physical objects has little to no business benefit. That's why companies always implement with it computing resources to store and process data accompanied with advanced analytical tools to monitor manufacturing processes and support decision making.
- Companies mainly adopt augmented reality (A-HMI) to provide visualized assistance to workers during product assembly or machine repair processes, in addition to enabling more interactive training sessions.
- Advanced automation machines have revolutionized the way manufacturing activities were once performed, the most extensively used types of automation machines are cobots and AMRs. These robots are going to work alongside humans on the shop floor in a more efficient and sophisticated than their predecessors; which had to be kept isolated from humans by the

building of fences or safety cells, in addition, these advanced robots now have the cognitive abilities to take decisions independently. Companies adopted this technology in application areas containing repetitive or dangerous activities.

- Connected machines and digitized processes expose the company to a massive amount of data. In most cases, companies convert the data collected from various sources into actionable insights through industrial analytics tools that range from real-time monitoring, root-cause analysis, and condition-based maintenance to reach more intelligent analysis that does not just predict but react autonomously utilizing artificial intelligence and machine learning. Accordingly, industrial analytics is the essence of any smart factory.

Conclusion

The relevance of Industry 4.0 has been highly demonstrated in the course of this paper. Enabling technologies are evolving quickly, making it fundamental to keep constant track of the new signs of progress and applications.

This report is therefore fundamental in this fast-evolving context. It provides a literature review on Industry 4.0 main topics to explain its enabling technologies and application areas. Moreover, it contains a database of forty-five case studies of companies that across the world successfully implemented Industry 4.0, which is particularly relevant for two main reasons. Firstly, tracking the new ways Industry 4.0 is applied across the globe allows us to understand how its limits are constantly pushed. Secondly, case studies are fundamental to comprehend the actual implications of Industry 4.0 fully.

Possible limitations of the report include the methodology with which the cases were selected. The author applied subjective criteria to be sure to include the most relevant applications of

Industry 4.0. The methodology had to be subjective, ensuring geographic inclusiveness and covering all the enabling technologies.

The aim of Industry 4.0 is to utilize cutting-edge technologies to enhance the manufacturing system's agility, flexibility, and responsiveness to unpredictable events. It sets a Smart Factory where the Internet, sensors, software, and other advanced technologies work collectively to optimize manufacturing practices and improve operational processes. As a result, I4.0 empowers a company to react swiftly and efficiently to the current turbulent market changes by offering more personalized products and increasing operational productivity in a ceaseless growth manner.

In conclusion, this report provides an essential milestone for businesses and research. Further research can be carried based on the collection of cases that provides a well-structured database with a comprehensive and multidimensional view of Industry 4.0 applications in the manufacturing context.

Concerning business, the results of this report can prove valuable for practitioners who want to implement one or more I4.0 technologies, providing them with solutions for applications in manufacturing.

Appendix

Appendix 1: Partners (I4.0 Technology Providers)

Partners	Description	Num. of cases	Source
ABB robotics	ABB Robotics is a pioneer in robotics, machine automation, and digital services, providing innovative solutions for a diverse range of industries, from automotive to electronics to logistics.	1	(ABB robotics, cases)
Advantech	provides value-added products and solutions helping customers to embrace Industry 4.0.	1	(Advantech, cases)
Altizon	A global industrial IoT company powers digital revolutions by helping enterprises leverage machine data to drive business decisions.	4	(Altizon, cases)
BCN3D	one of the leading developers and manufacturers of 3D printing solutions in the world.	3	(BCN3D, cases)
Desktop Metal	Is a metal 3D printing and carbon fiber 3D printing provider for all engineers, designers, and manufacturers.	1	(Desktop Metal, cases)
Ericsson	One of the leading providers of Information and Communication Technology (ICT) and help customers.	4	(Ericsson, cases)
Fraunhofer IPT	Develops system solutions for networked, adaptive production for clients and cooperation partners come from the entire manufacturing industry	1	(Fraunhofer IPT, cases)
GeekPlus	Offers smart logistic solutions for factories to improve automation, intelligence, and flexibility while reducing costs and increasing efficiency.	1	(GeekPlus, cases)
IBM	A global information technology company that offers a mix of products, including industry 4.0 solutions	1	(IBM, cases)
Markforged	produces the leading additive manufacturing platform for manufacturing and factory floors.	1	(Markforged, cases)
Microsoft Azure	Microsoft offers a cloud computing platform (Azure). It provides a range of cloud services (Iaas, PaaS, SaaS). Including analytics, storage, networking and other computing sources.	5	(Microsoft Azure, cases)
Mobile Industrial Robots	is a leading manufacturer of collaborative mobile robots	1	(Mobile Industrial Robots, cases)

Nokia	is a technology company providing private LTE/4.9G and 5G wireless networking solutions to enable the true potential of Industry 4.0 technologies.	2	(Nokia, cases)
PTC	helps industrial companies to create value for themselves through a combination of our Augmented Reality, Industrial IoT, PLM, and CAD solutions.	2	(PTC, cases)
Re-flekt	is an AR software company that offers visual guidance, real-time information, and remote collaboration for the industrial manufacturing sector.	2	(Re-flekt, cases)
Senseye	the leading machine health management offers Industry 4.0 best practices and implementation, such as predictive maintenance solutions	2	(Senseye, cases)
Siemens	Is a technology company focused on industry, infrastructure, mobility, and healthcare. Creating technologies for more resource-efficient factories and resilient supply chains	5	(Siemens, cases)
SierraWireless	is an IoT pioneer, empowering businesses and industries to transform and thrive in the connected economy.	1	(SierraWireless, cases)
Telefónica Deutschland	Is a telecommunications company that offers a mix of products and services, including digital products and services in the fields of Internet of Things (IoT) and advanced data analytics.	1	(Telefónica Deutschland, cases)
Ultimaker	is a 3D printer-manufacturing company offering additive manufacturing products and services	2	(Ultimaker, cases)
Universal Robots	Is a manufacturer of collaborative robots enabling companies to use robotic automation	2	(Universal Robots, cases)
Upskill	Deliver higher productivity, higher quality, and reduced costs with wearable computing and augmented reality solutions.	2	(Upskill, cases)
Vodafone UK	Is a telecommunications company that offers a mix of products and services, including digital technologies such as 5G wireless connectivity solutions	1	(Vodafone UK, cases)

Appendix 2: Database Attributes

Attribute	Description	Data Type
Company Name	The owner of the implemented Industry 4.0 project	Free text
Elements	The name is hyperlinked to a website containing the company's preliminary information.	

Sector	The industrial sector that the company belongs to	List
Elements	Aerospace – Automotive – Building – Capital goods – Chemistry and Pharmaceuticals – Clothing/Shoes/Accessories – Electronics/electrical – Food – Luxury – Machinery – Metal industry – Plastics	
Dimension	The size of the company based on its revenue.	List
Elements	Big (Revenue > 50 million €) – SME (Revenue < 50 million €)	
Revenue	The company's sales when the case was collected. The primary source for this information is the "Dun & Bradstreet Data Cloud" website.	Number
Elements	The value was converted to euro and represented in millions.	
HQ Country	The location of the headquarter company under study.	Free text
Elements	Country name	
Factory Country	The site of the factory, plant, or facility under study.	Free text
Elements	Country name	
Geographical area	The region of the factory, plant, or facility under study.	List
Elements	Region names based on United Nations Country Grouping	
Count	The number of technologies adopted through the implemented project.	Number
Elements	The sum of enabled technologies included in the project implementation	
Technology	Industry 4.0 enabling technologies (listed in Table 2).	Number
Elements	Given the number (1) if the technology was included in the implemented project, otherwise left empty.	
Project Description	A summary of the project implementation.	Structured text
Elements	Introduction – Issue – Solution – Result	
Technology Detail	The subcategory of Industry 4.0 enabling technologies.	List

Elements	Refer to Table 3	
Macro process	The major process under development consists of a group of processes.	List
Elements	Smart Factory – Smart Life Cycle	
Process	The process under development consists of a group of sub-processes.	List
Elements	Smart Factory List: Production – Maintenance – Logistics – Training – Safety Smart Life Cycle List: Product Development – Product Lifecycle management	
Sub-process	The specific activity under development.	Free text
Elements	Deduced from the case study	
Benefits Description	The benefits realized by the company after implementing the project.	Free text
Elements	Deduced from the case study	
Partner	I4.0 Technology providers (listed in Appindex 1)	Free text
Elements	Deduced from the case study	
Source	The source (Link address) of the selected case study	Free text
Elements	Hyperlink	

Appendix 3: Cases collection

Company	Project Description

Hirotec America	Hirotec is a global auto parts manufacturer, HIROTEC sought to eliminate the trend of reactive maintenance and lost opportunities by utilizing the information and systems it had on hand to gain deeper insight into its operations and processes. Issue: The machinery involved, runs until a failure occurs without a condition-based monitoring system. Even though, HIROTEC had long collected industrial data from sensors and machines to support its decisions and track business progress, however, volumes of this data were manually separated and stored across multiple sources, making it inaccessible to collective and systematic analysis. Solutions: HIROTEC chose the (ThingWorx IoT Platform) and (Kepware's KEPServerEX) -both solutions from PTC- to enable company-wide device-to-cloud connectivity through one overarching toolset. (ThingWorx IoT Platform) provides analytics and the ability to rapidly develop role-based applications for data visualizations, where the Kepware's IoT Gateway for (KEPServerEX) collects data from the CNC machines and streams it in real-time to the Cloud. Result: The solution gave HIROTEC labor-free access to a customized visualization of both the operations and conditions of its industrial devices and systems. Justin Hester Senior Researcher HIROTEC, says, "In just six short weeks, we've gained more visibility into our operations than ever before, reinforcing our investment and belief in the power of the IoT."
Griffin's Food Company	The Griffin's Food Company focuses on speed and scale to achieve digital transformation Issue: Paper-based processes slowed down their operations and created opportunities for human error and lack of real time data. Solution: Griffin's partnered with PTC to implement a flexible IoT solution that fueled connectivity and visibility, digitizing the production lines by connecting machinery to capture key performance data and displaying it in a unified view. Result: Data collected through sensors and presented on dashboards that gave factory workers, operators, and managers access to production data. Griffin's built on the initial Manufacturing Apps initiative and scaled the IoT Platform to three full lines. The remaining four were planned for implementation.
Nissan	Nissan was keen to expand the benefits of using data to influence maintenance. Issue: Abundance of data and insufficient skilled resources to perform analysis, and the lack of efficient condition Based maintenance programme. Solution: Senseye is providing Predictive Maintenance capability across multiple global Nissan production sites. 9,000 connected assets and more than 30 different machine types including robots, conveyors, drop lifters, pumps, motors and press/stamping machines are remotely monitored using Senseye's proprietary machine learning algorithms. More than 400 maintenance users actively use Senseye to optimize maintenance activities and make repairs months before predicted machine failure. Result: Damian Wheeler, Nissan UK Engineering Director, says, "Senseye is supporting our Predictive Maintenance programme across multiple production facilities and has helped us lower overall downtime and increase OEE."

Alcoa	Alcoa Corp. has the most significant bauxite mining operations globally, an alumina refining system, and aluminum smelting plants. The team was looking for a robust specialized solution delivering Predictive Maintenance; as a product capable of efficiently leveraging existing machine and maintenance data feeds and without installing thousands of new sensors. Issue: difficult margins in the global aluminum market and increasing operational and production efficiency target, arises the need for a new system to lower cost and increase efficiency. Solution: Partnered with "Senseye" to enable Predictive Maintenance at this site, the Predictive Maintenance product from Senseye was connected to Alcoa's existing machine and maintenance systems, which allowed Alco's engineers to monitor operational and critical machinery processes. The Senseye software analyzes machine condition indicators against historical information using proprietary and mechanical engineering-focused ML algorithms that automatically provide maintenance engineers with alerts and diagnostics before any functional failures. Result: The company's managers were satisfied with the partnership with Senseye and the benefits gained from the new Predictive Maintenance system. The solution enabled Alcoa to leverage existing data and infrastructure, obtain a unified view of machinery conditions, reduce maintenance costs and machines downtime.
Honda	Honda R&D is the research and development wing of Honda, one of the world's largest manufacturers of automobiles and motorcycles, and a pioneer in robotics and other advanced technologies. In the automotive space, Honda R&D's mission is to develop technologies that maximize the joy of driving. Issue: Honda R&D recognized the potentials of data-driven insights and wanted to equip its engineers with advanced analytic tools to uncover the hidden opportunities within massive and chaotic data sets. These analytical tools will help the company explore Big data, gain a better understanding of how to satisfy the market, and design better, more innovative, safer vehicles. Solution: The company decided to partner with IBM, providing the needed big data analytics tools, training and consultation. Honda R&D's big data analytics environment is based on: - IBM SPSS Modeler (organizing raw data into usable data-sets) - IBM Watson Content Analytics (Text mining), which runs on IBM's cloud platform Result: Kyoka Nakagawa concludes: "IBM Analytics is helping Honda R&D's engineers harness big data to explore valuable new areas of research – and ultimately design better, smarter, safer automobiles." For example, the company is using vehicle sensor data to monitor drivers' steering maneuvers and gain a better understanding of customers' preferences. This real-world insight feeds into engineering projects that aim to design a steering experience that can be personalized for each driver. The scalability of IBM Cloud infrastructure also means that it is easy to add new users, so if other departments decide to adopt IBM Watson Content Analytics in the future, Honda will be able to support them seamlessly.

GE Aviation	GE sought to find a solution that could improve how mechanics perform engine maintenance tasks, and believed AR technology might be the answer. Issue: GE Aviation loses millions of dollars each year to errors made at key points during the assembly and overhaul of its engines. Or example; B-nuts are one such key manufacturing point. They play acritical role in aircraft engine fluid lines and hoses, providing a sturdy, reliable seal—but only if tightened and torqued properly. Solution: GE Aviation initiated a deployment of AR that combined three technologies: Skylight from Upskill, Glass Enterprise Edition smart glasses, and a Wi-Fi-enabled Atlas-Copco Saltus MWR-85TA torque wrench. With Skylight, instructions are now provided via the smart glasses. So are guided videos, animations, and images—all configured and accessible at any time for the worker. it also track results and allow workers to upload those records immediately to be stored in the manufacturing systems of record in the plant and an engine's maintenance files for chain of custody. Result: Ted Robertson, Manager, GE Aviation, says, " We believe that Skylight with Glass has the potential to be a real game changer in terms of its ability to minimize errors, improve product quality, and increase mechanic efficiency.“ When GE reviewed and analyzed data from its initial deployment, the results were clear: its team could dramatically reduce development and production assembly errors, and consequently, also reduce downstream customer in-flight shut downs and unscheduled engine removals. Following the pilot, the 15 mechanics included in the study were surveyed on their impressions of the technology: 60% of the participants indicated that they preferred using the wearable technology to the traditional methods, and 85% of the mechanics agreed to the statements, “I believe that using this system will reduce manufacturing errors,” and, “I thought the system was easy to use.”

Boeing	An astounding 130 miles of wiring go into every new Boeing 747-8 Freighter. For Boeing, the world's leading manufacturer of commercial jetliners, that translates to thousand of miles of wiring and tens of thousands of hours of work. Issue: Wiring is a special challenge: Every Boeing aircraft, has multiple configurations, each with its own wiring scheme. In years past, technicians used manuals (huge amount of paper) to do their work. Laptops helped, but had the same basic problem: constant look-away interruptions as workers got directions and cross-checked diagrams and schematics. Solution: The company began a pilot program,with Skylight replacing those laptops with a smart wearable solution. Skylight gives Boeing's technicians the instructions they need right in their viewfinder. Bar code readers and the Glass cameras help identify and confirm wiring inventory. Workers can also stream and share their view with engineers or other remote experts. Technicians can also look at how-to videos right in their field of view. Result: "Rather than picking up seconds or minutes, a step function change gives us an opportunity to cut the build time by 25%," says Randall MacPherson, Senior Manager for Boeing's Electrical Strategic Fabrication Center. Now Boeing is looking at ways to use Skylight in other areas of its manufacturing and assembly. Randall MacPherson, adds "Wearable technology is helping us amplify the power of our workforce."
Tecalum Industrial	Tecalum Industrial specialize in manufacturing aluminum products for the industrial sector . In order to produce these parts, which they design from scratch according to the needs of each customer, they need some very specific jigs and fixtures, custom made for every mold they work with. Issue: The company commissions an external vendor to produce mechanized tooling, such as nylon clamps, for them. However, this was an expensive and slow process, involving waits of weeks at a time in order to receive the parts. Solution: Tecalum decided to internalize the production of their customized tooling through additive manufacturing. The company purchased 3D printers from BCN3D, at the end of the project, Tecalum owned four Sigmax 3D printers, all operating non-stop in order to keep their production moving. Results: Their attempt to maximize efficiency and reduce cost with additive manufacturing has been successful. As Marc Linares, the company's Production Management Deputy, confirms "The two main advantages of using BCN3D's printers are significant time-savings and cost reductions achieved. One of the other benefits of working with these 3D printers is their great versatility". Based on that huge success, they have also started to 3D print a number of tools for assembling and transporting pieces of aluminum.

PSA Peugeot Citroën	PSA Peugeot Citroen's objective is to have its range of vehicles completely electrified by 2025. For electric cars, the battery is a key component for enabling electrified vehicles to meet customer expectations. Issue: The team of battery system modeling and design, faced a lot of engineering and designing constraints. Greco the team leader said :"We used to assess battery thermal management using 3D battery modeling for both static evaluation and cell thermal flow modeling. This happened too late in the development cycle and didn't allow you to anticipate any change in the battery design. So, it has been fundamental to find a way to transcribe a 3D thermal and hydraulic model into a 1D model with the addition of the electrical part in order to evaluate the battery thermal management in a reliable way early in the development cycle." Solution: The team decided to use Simcenter Amesim (from Siemens), to perform battery design analysis and evaluation through simulation without integrating it into the complete vehicle architecture. Which equipped the team with needed tools to develop a methodology to create a 1D model of the battery from a 3D thermal model using a nodes network. He reached similar results to the 3D thermal-hydraulic modeling but in shorter runtimes. Result: Having access to simulation enables PSA Peugeot Citroen to rapidly analyze battery performance and its thermal management. Further, it enables the firm to investigate alternative battery designs, validate them virtually and to make sure they meet the required levels of performance without compromising safety. This improved methodology enables the team in charge of battery modeling to make decisions earlier in the development cycle and define a battery architecture that enables them to reach reliability and safety criteria for an optimal overall vehicle performance.
Lazer Helmets	Lazer Helmets philosophy is combining the best product design and engineering with the best material and technology available, with focused dedication to safety and innovative engineering. Issue: The development team needs to be aware of many aspects whole creating a new helmet (Material choice, market trends, consumer safety, style requirements,...). Which creates a hassle of working in different software systems, reducing efficiency and eventually increasing time-to-market. Solution: The company chose Siemens NX software, to enhance its development capabilities and develop an accurate digital twin of each helmet. Unlike previous solutions, NX allows Lazer Helmets to start the ideation and design phase digitally. Also, design sketches and mock-ups are kept to a minimum since this level of design work can also be completed in NX as well. Arnould, Head of development team, says "We use NX to make the design and to engineer all parts of the helmet." Result: The enhanced design capabilities of NX, combined with the platform integration, offers an optimum foundation to reduce time-to-market and meet market demand for more personalized and individualized products. Lazer Helmets is pleased with the results of the Siemens subscription model. This enabled Lazer Helmets to run an impactful digitalization initiative without any massive upfront investments.

ADG Mobility	ADG Mobility is an engineering company specializing in the development of high mobility protected military vehicles and associated systems. And wants to equip its' highly skilled employees with leading-edge systems and software. Issue: The company needs to manage data, configurations, design changes, and approval procedures in large design teams, in addition to providing clients with insight into evolving 3D designs, including non-engineering stakeholders. The previous approach was time-consuming and tedious, design changes were difficult and often required complete remodeling of the routed systems. Solution: Seeking a more streamlined workflow, the engineering team at ADGM used the integrated software solutions from Siemens to develop its armored vehicles. These include Teamcenter software for product lifecycle management (PLM), NX software for computer-aided design (CAD), and Simcenter software for computer-aided engineering (CAE) simulation. "The Siemens suite of products was chosen because it integrated multiple disciplines like CAD, CAE, and PLM, as well as the fact that almost all our engineers were already well versed in the software," says Nian Fuls, senior engineer and systems administrator at ADGM. Result: The integrated system in place now enabled ADGM to eliminate data export and transfer steps, in addition to accelerate design-analysis iterations and directly feed analysis results to the design process. Teamcenter automatically creates and updates visualization models from NX, allowing non-engineering stakeholders to open 3D assembly models to gain insight into evolving designs.
Dlimit (Tensabelt)	Dlimit (formerly known as Tensabelt) designs, produces and distributes devices for queue management systems such as barriers, cones, and roll-up belts. Currently distributing over 10,000 injected plastic units across all of Southern Europe. Issue: The production team at the company realized that they needed a quick and efficient solution for functional validation that would allow them to achieve better results in less time, to reduce their products' time to market while maintaining high-quality results. Dlimit's Global Production Manager, Clara Bazán, explains that they had a "more conservative approach" to producing the tooling they needed. They would work with aluminum tools, whose fabrication had to be externalized, a process that was slow and costly, with waiting times of several weeks for each new piece designed. Solution: Given the importance of counting on physical models, Dlimit decided to invest in in-house 3D printing and acquired a BCN3D printer. As additive manufacturing technology will be used to quickly fabricate new tools (such as; jigs and fixtures), and achieve more functional designs, leveraging on shorter waiting times and the lower cost of the materials used. Result: Dlimit workflow has been enhanced considerably since incorporating 3D printing in constructing functional customized tooling, which enables them to maximize efficiency and accelerate the iteration process, reducing a significant amount of time and costs in their production process of queue management systems.

NGNY Devices	NGNY Devices works on the design and construction of machinery and automated equipment for repetitive processes. Each NGNY machine serves a different purpose and has to be completely customized for the client. Issue: Before they started integrating additive manufacturing into their workflow, the staff at NGNY used to design each new iteration and send it to an external supplier for machining, then it has to be tested and if any changes needed to be made, a new piece would be machined. This was a slow and expensive process Solution: NGNY decided to use in-house 3D printing to fabricate end-use pieces for each machine they construct. They develop the parts, 3D print them, and start testing them, after going through the iteration process, they come up with a part that fulfills all mechanical requirements. The final step of this operation is to implement the new parts in the specific machine that is being constructed. Once they have found the optimal design, they fabricate many of the final pieces using their Sigma 3D printers. Result: Incorporating in-house 3D printing for the engineering and fabrication of end-use parts for its automated machines. CEO of the company, states, “with 3D printing we obtain perfect results every time”. 3D printing has saved a great amount of time and costs, also allowed them to accelerate their time to market.
HIL Limited	HIL had close to 20 manufacturing plants, each commissioned at different years. This came with different maturity levels and different problem statements. The team was keen to optimize productivity and identify opportunities for cost and energy saving. Issue: the company was facing many difficulties, mainly, absence of real-time visibility into process data, data was being captured on paper logbooks, inability to assess the energy expenditure, and they were also struggling with the lack of a real-time warning system for proactive and predictive process management. Solution: The HIL team wanted a digital road map for connecting shopfloors, to be a foundational layer that can lay the path for future digital transformations. As part of the ‘Connected Shopfloor’ project, Altizon’s Datonis suite was deployed at HIL across 4 locations for optimizing Productivity, CBM, Quality, and Energy. The solution targeted 4 Strategic Business Units (SBUs), each dealing with a different product and manufacturing process. The HIL team leveraged Datonis Edge for data acquisition from PLC/SCADA and built a manufacturing data lake on a multi-tenant cloud. They also made use of various modules for real-time analytics and dashboarding. Result: Digitally connected shopfloors, helped with timely availability and accuracy of data, enabling the plant operations team to take corrective actions in real-time. Also enabled batch traceability and provided operators with process deviation alerts.

Doosan	Doosan plays an important role in meeting the goals of South Korea's Green New Deal plan, as it is responsible for the manufacturing and construction of wind farms, to enhance the country's renewable energy generation. Issue: Doosan's wind farms will be operating remotely, which means, it is important to monitor operations, schedule predictive maintenance, and predict and control every output. However, the main challenge was to collect and process data from a huge number of sources, which made it difficult for operators to manage, consolidate, and convert the data into actionable insights to predict future behavior. Solution: Doosan realized that creating a digital twin of an existing wind farm would be the most cost-effective, efficient way to combine and analyze data from multiple sources. they turned to Microsoft (Azure Digital Twins and Azure IoT Hub) and Bentley (iTwin platform) for building 3D industrial digital twins. Result: Using its 3D model in iTwin combined with Azure Digital Twins and IoT Hub, Doosan implemented two solutions: - Performance Watchdog: provides real-time power generation data and compares it to two data models a physics-based model and the other is based on a machine-learning algorithm from available sensor data. - Power Prediction: to predict future power generation based on forecasted weather data and to improve operational planning.
TVS Motor	TVS Motor Company is a two and three-wheeler manufacturer, wants to enable IoT digital transformation by connecting machines on the assembly line. Issue: TVS data was spread across many heterogeneous machines and related information from other IT systems on the shop floor, which needs to be integrated into a centralized data lake, required more visibility and predictability into its manufacturing operations. The goal was to use this data in a more comprehensive and reliable analysis. Solution: The company has decided to partner with Altizon, and deploy the complete Datonis suite with customized integrations, analytics, and reports. The solution deployed was a hybrid in nature with Datonis Edge (distributed computing platform) deployed in a fail-safe configuration inside the customer's network. Altizon's IoT platform (repository for data) and Datonis Digital Factory (unified digital manufacturing platform for monitoring, measuring, analyzing, and predicting outcomes using AI) were deployed on the cloud. Result: TVS was able to leverage IoT to connect a complex and heterogeneous assembly line and gain deep insights into multiple aspects of their manufacturing process. General Manager of TVS Motor, says, "Altizon was able to take up all the challenges and was able to deliver targeted results. KPIs that saw improvement were OEE, MTTR, and utilization due to improved visibility and subsequent actions. The solution was designed and built in such a way that it can be horizontally deployed with minimum modifications in other vehicle assembly lines in all locations."

JK Tyre & Industries Ltd	JK Tyre & Industries Ltd provides a wide range of products to the automobile industry. With a global presence in 100 countries, JK Tyre has 12 manufacturing plants. JK Tyre wanted to deploy IoT-enabled digital transformation by connecting operational processes in tire manufacturing. Issue: The company needed to establish a data lack that can store and integrate manufacturing processes data from different IT systems and heterogeneous machines. As the company was facing problems concerning real-time data visibility and traceability, unable to improve operations efficiently or predict machine failures, caused by the complexity of manufacturing processes coupled with outdated and scattered data. Solution: The company has decided to partner with Altizon, and deploy the complete Datonis suite with customized integrations, analytics, and reports. The solution deployed was a hybrid in nature with Datonis Edge (distributed computing platform) deployed in a fail-safe configuration inside the customer’s network. Altizon’s IoT platform (repository for data) and Datonis Digital Factory (unified digital manufacturing platform for monitoring, measuring, analyzing, and predicting outcomes using AI) were deployed on the cloud. Result: JK Tyre was able to use the power of IoT and advanced analytics to understand their complex manufacturing process and unlock savings in energy and consumables. The resulting manufacturing process data lake was used for deeper analysis into improving process quality and predicting failure using machine condition monitoring. The process and manufacturing data were integrated with ERP to bring visibility and predictability into the manufacturing value chain.
SRF Limited	SRF Limited is a manufacturer of technical textiles, fluorochemicals, specialty chemicals, and packaging films. It has already adopted Industrial IoT (IIoT) by connecting a set of chemical manufacturing processes through Altizon’s Datonis IoT platform. This case will cover a new digital transformation initiative in four connected plants across India. Issue: SRF wanted to continue its digital transformation by connecting yet more processes (from polymerization to dipping) in the manufacturing of technical textiles. The team plans to use the captured data from the manufacturing processes to avoid rework or raw material wastage, enable predictive analysis and analyze fuel consumption. Solution: The company chose Altizon since it's an established industrial IoT partner with technical and capabilities to achieve the desired outcomes. Altizon’s Datonis IoT suite was deployed at SRF with Datonis Edge (distributed computing platform) operating in a fail-safe configuration inside the customer’s network. Datonis IoT platform and MInt (manufacturing data lake) were deployed on the cloud. The Datonis IoT API was leveraged to integrate with all dependent systems including ERP and QMS. Establishing a correlation on real-time data between process and quality defects while optimizing specific fuel consumption. Result: The team is now capable of conducting condition-based monitoring and productivity optimization through IIoT. They are also in the process of scaling this initiative to other BUs of SRF, such as fluorochemicals business and specialty chemicals business.

Tetra Pak	The Swedish company specializes in complete solutions for the processing, packaging, and distribution of food products in more than 175 countries. "We will take over a lot of risk on behalf of our customers. To do that, we need cutting-edge technologies to control and minimize these risks," says Johan Nilsson, vice president of Tetra Pak Services. Issue: One of the most important aspects for their customers is (shelf-Life) which is directly related to the aseptic process (Packaging) including maintaining its machines and equipment. But it remains a delicate task to predict when to maintain aseptic equipment and machinery. If done too soon, a plant may unnecessarily swap out expensive parts well before they're worn, adding costs. on the other hand, delayed maintenance will cause days of unplanned downtime. Solution: Tetra pack decided to partner with Microsoft by connecting packaging lines to the Microsoft Azure Cloud, to collect operational data from machines across multiple factories, allowing global experts to analyze real-time data patterns in those factories against data from more than 5,000 other packaging lines. Eventually, help predict informed maintenance timing. Result: Cloud-connected machines provided the ability to predict exactly when equipment needs repair, averting many breakdowns or unnecessary maintenance. During a six-month period involving 11 packaging lines, the company predicted future breakdowns in five of those lines, spurring preventive maintenance and saving those customers more than $30,000, Tetra Pak leaders say.
Tetra Pak	The Swedish company specializes in complete solutions for the processing, packaging, and distribution of food products in more than 175 countries. In addition, the company provides maintenance services for their deployed machines at different customers' sites. The company wants to improve its maintenance services, As part of their solution, Tetra pak has already implemented a cloud-connected machines solution, to predict when equipment needs maintenance. Issue: Some maintenance procedures require them to dispatch a service engineer to a customer's plant to assist in the repair, a journey that involves extra cost and resources, while prolonging the repair process, leading to an unsatisfied customer. Solution: To further streamline machine diagnostics and repair for customers, Tetra Pak is outfitting service engineers with hundreds of HoloLens devices, Microsoft's mixed reality technology. With those headsets, service engineers can make a Skype call to a Tetra Pak service center and speak to an expert with a deeper knowledge of a specific machine. The expert remotely guides the engineer through a repair. Result: Tetra Pak service engineers use HoloLens headsets to more quickly diagnose and fix machine issues, even in the most remote locations. "Customers have many pieces of equipment, so you have to know a lot about a lot. That's often difficult. This helps us to do that," he says. "This is how we take the global expertise that we have available somewhere in Tetra Pak and bring it to the fingertips of the engineer in the countryside in Chile or Pakistan," says Johan Nilsson, vice president of Tetra Pak Services.

PepsiCo	PepsiCo, whose Frito-Lay division makes Cheetos and other brands like Tostitos and Doritos. As part of the company's digital transformation efforts, PepsiCo began investigating how to apply the next generation of AI in its operations. Issue: For PepsiCo, an out-of-specification product can't be sold, which leads to wasted resources, time, and money. the company wanted a more efficient way to consistently manufacture Cheetos with the proper attributes while reducing waste, help them maintain high-quality products while maximizing throughput. Solution: PepsiCo developed an AI solution powered by Microsoft Project Bonsai that monitors and adjusts its extruders, the equipment that produces Cheetos. The complex extruder has: Several inputs and specifications, including the ratio of cornmeal to water and the speed of the cutting tool, interact to create the desired Cheetos Snack characteristics. PepsiCo built a computer vision system that continually monitors Cheetos attributes, then data about qualities such as density and length are fed to the Project Bonsai solution, which makes adjustments to bring the product within desired specifications. Result: The Project Bonsai solution has now proven itself at a pilot plant, where the technology does a good job of independently adjusting the extruder to maintain product quality and consistency. "This is the future for process controls," says Sean Eichenlaub, a senior principal engineer at PepsiCo. "We're using AI-based automation to improve the consistency of our products." PepsiCo is preparing to use the solution in a production plant and exploring how to use the solution with other products, including the tortilla chip manufacturing process.

Ericsson Panda	The Nanjing Ericsson Panda factory manufactures telecommunication equipment products. the company objective is to Improve daily operations with the use of cellular IoT and become the world's first cellular IoT-based smart factory. Issue: Screwdrivers -which are used massively in daily operations- require routine calibration and lubrication based on utilization times, but the lack of monitoring capabilities and absence of counters for individual screwdrivers led to a time-fixed maintenance schedule that is unrealistic and costly. This adds to other critical equipment's monitoring issues, which included manual and cost-intensive maintenance procedures performed periodically and relied on hand-written records. The alert system in place (Andon system) is rigid and requires continuous manual intervention. Solution: The company decided to use narrowband-IoT (NB-IoT) and LTE-M/Cat-M1 with low-cost and simplified devices, like ADI motion sensors. To enable real-time monitoring and indicate the utilization time. Data is then captured in the factory's private cloud system, making automatic calculations and analysis about the tools' utilization and condition status. A new wireless Andon system was installed with cellular IoT devices on its production lines, providing a more agile and automated alarm system. Result: With the wireless solution, the factory can enable flexible production lines, configured on-demand and with easy data collection, analysis, and optimization. Tomas Qvist, a manager, says: "Industry 4.0 and massive IoT over cellular networks increases operating efficiency and productivity. For instance, by connecting our high-precision screwdrivers, we see a significant reduction in maintenance material costs, and manual maintenance work costs have been cut in half, with return on investment in about 2 years."

Nokia Oulu	The Nokia Oulu factory is a new product introduction (NPI) factory that produces 4G and 5G radio base stations. Nokia recognized this factory as a perfect environment to test and prove the value of their digital transformation solutions. Issue: Traditionally, the Factory has managed machine and device telecommunications through ethernet cables. To meet weekly NPI requirements the factory needs to continuously change the production lines and relocate machines, which required a more flexible manufacturing floor free from cable connections. Solution: The factory decided to use Nokia's private (4.9G/LTE) wireless network to connect all assets within and outside the production floor, integrated with other industrial-grade technologies including Nokia's IoT analytics running on Nokia Digital Automation Cloud (DAC). The new network provides the security and bandwidth needed for critical operations and enables changes in floor layout without the need to reconfigure and rewire the cabled LAN network. The cloud provides a data architecture that captures and processes real-time production data at the cloud-edge (inside the factory) and historical data that is stored offsite in the public cloud, enabling a digital twin system to be designed that uses real-time manufacturing data as inputs to develop applications and perform process analytics. Result: The integration (4.9G/LTE) network provided a fully connected manufacturing floor with the needed latency and connection density to support smart factory Industrial IoT (IIoT) applications. The implementation of these industrial-grade solutions enabled the plant to locate and track assets in a more efficient way, to feed the digital twin models, and to deliver the statistical data needed to optimize the automated supply chain between the plant's different production lines and storage facilities.
Ericsson Tallinn	Ericsson Tallinn is one of Ericsson's largest manufacturing units. Tallinn factory is engaged in the development and launch of new digital and radio products. The manufacturing site has set out a digital transformation program to improve operational efficiency. Issue: Troubleshooting of circuit boards is a process that requires high competencies and consumes a lot of time. almost half of the processing time is typically spent searching for information from manuals, documents, and graphics. Solution: The factory developed an in-house proof of concept (PoC) to validate ideas using Augmented Reality that is connected to a Private wireless LTE/5G. In this PoC, AR is used to place instructions on top of what the operator or troubleshooter sees when inspecting circuit boards. Before, engineers had to look up instructions and manuals on the workstation PC, but now, instructions are shown as an overlay on a tablet screen or AR headset. Result: Testing results show that, with AR troubleshooting solution, there is a reduction in fault detection time, as well as, lower assembly time and effort due to the availability of quality assembly information. Additional value can be generated using the tool in other manufacturing sites.

Nokia Oulu	The Nokia Oulu factory is a new product introduction (NPI) factory that produces 4G and 5G radio base stations. Nokia recognized this factory as a perfect environment to test and prove the value of their digital transformation solutions. Issue: The plant had a material handling system in place that is made of automated guided vehicles (AGVs). But the factory noticed the increasing pressure to be more agile and flexible and recognized the limits of that system as AGVs work according to preset systems and processes, which can make rapid change difficult. Solution: The factory decided to leverage from its private wireless network (4.9G/LTE) and other industrial-grade solutions to address these challenges. Replacing AGVs with autonomous mobile robots (AMRs), that use stored layout maps, sensors, and SLAM (simultaneous location and mapping) software to autonomously navigate around obstacles delivering components and boards over the private 4.9G wireless network. Result: ARMs enhanced logistics productivity and eliminated the need for manual handling. The solution grants increased shop-floor flexibility allowing more agile layout changes, it also contributed to standardizing the material replenishment flow which leads to a lower setup time compared to the previous AGVs and manual material-handling processes.
Mercedes-Benz	Mercedes-Benz Cars company is implementing the world's first 5G mobile network for automobile production in its "Factory 56", as part of its innovative project, to introduce new production opportunities through industrial digital transformation. Issue: The main drivers for the implementation of a private 5G IoT Network are to enhance the efficiency and precision of the production process, connect factory machines and systems and introduce new features to optimize production such as; data linking or tracking products through the assembly line. Solution: Mercedes-Benz Cars decided to partner with both Telefonica and Ericsson to deploy the private network solution in the factory. Telecommunications company Telefónica Deutschland was in charge of implementing, integrating, and supporting the 5G network, while Ericsson was the network supplier is Ericsson, who has supported the project through network design and implementation. The "Factory 56" has been equipped with several 5G small-cell indoor antennas and a central 5G hub to reach the full potential of 5G. Result: Jörg Burzer, Member of the Divisional Board of Management of Mercedes-Benz Cars, Production and Supply Chain, says “As the inventor of the car, we are taking digitalization in production to a whole new level. With the installation of a local 5G network, the networking of all production systems and machines in the Mercedes-Benz Cars factories will become even smarter and more efficient in the future. This opens up completely new production opportunities”. An example of this is the development of an automated quality control system, where the product is tested on the assembly line removing the need for testing post-production, saving time and resources.

Atlas Copco	Atlas Copco provides products and services that enhance industrial productivity. Besides producing air compressors it also provides complimentary services for customers such as maintenance and repair. Issue: Atlas Copco had initially connected its industrial air compressors using 2G and 3G cellular communication to remotely monitor machines and collect data, but even though Altlas and its customers have gained great benefits from this solution (called SmartBox), the conventional 2G network did not harness the full potential of the solution in place, causing low indoor coverage and weak connectivity in addition to other technical and cost problems. The overall objective is to help customers avoid downtime. Solution: Atlas Copco partnered with Sierra to install the wireless' device-to-cloud solution, comprised of (FX30 programmable IoT gateways) which can be configured to support 2G, 3G, 4G, LTE-M, and NB-IoT connectivity, with Edge processing applications developed in the (Legato open-source Linux platform), all are tightly integrated with (AirVantage) where FX30s can be monitored, managed and controlled remotely. Result: This solution guarantees better indoor coverage, low-cost connectivity, longevity, and a solid foundation for future digital transformations. Preventive maintenance was enabled by enhancing the amount and quality of machine data collected, allowing the service team to deliver the right spare part at the right time, in addition to lowering the duration and cost of breakdowns. The data collected from air compressors also enables customers to manage their energy usage efficiently and further increases product reliability.
Ford Motor Company	The Ford Motor Company is an automotive producer and wishes to optimize vehicle manufacturing in one of its electric-vehicle factories in the United Kingdom by introducing a mobile private network. Issue: Initially The factory has highly standardized repetitive production processes but still encounters variations caused by uncontrollable factors (temperature, sunlight,..) that can negatively affect the efficiency of the production process and the quality of products. The previous network had a slow responsive connection causing a delay in receiving information, meaning that if conditions change the factory will not be able to change the settings on the machines at the right time impacting the whole production process. Solution: The company partnered with Vodafone UK to install a private network (5G MPN) at Ford's facility that will replace the older Wi-Fi networks to capture data from sensors installed throughout the plant. The new private mobile network with its low latency connectivity allows Ford to better detect changes in plant or machine conditions, enabling the factory to react quickly and change the settings on machines within milliseconds through the same network. Result: Ford is now able to more efficiently analyze and control the new laser welding machines which are used to manufacture batteries and electric motors for vehicles. Chris White of Ford, says "Connecting today's shop floor requires significant time and investment, Present technology can be the limiting factor in reconfiguring and deploying next-gen manufacturing systems. 5G presents the opportunity to transform the speed of launch and flexibility of present manufacturing facilities, moving us towards tomorrow's plants connected to remote expert support and artificial intelligence."

MTU Aero Engines	MTU Aero Engines manufactures turbines, turbine parts, and models. The parts focused on, so-called (BLISKs) are bladed disks which are high-tech components that are used for jet engines. These are milled out of solid pieces of metal, the production process is very complicated and important. Issue: BLISKs quality is directly linked to safety because a defective blade in the turbine will cause the engine to fail to lead to an extreme accident. Another pain point is the difficulty of monitoring and controlling the milling process (part of current BLISK production) meaning that defective parts cannot be spotted until milling finishes. Given the milling process can last for more than 20 hrs, and rework is often as high as 25 percent, leading to a high production time. Solution: Fraunhofer IPT and Ericsson have teamed up to research new methods for improving process control and damaged parts detection, the research has looked specifically at the manufacture of bladed disks (BLISKs) to uncover the value of using 5G technology in the metal processing industry. Fraunhofer IPT developed a vibration sensor to monitor the blade when it goes inside the milling machine, but the sensor's information needs to be processed and acted on within 1 millisecond to prevent rework, here comes the role of 5G network (Ericsson) capabilities as it provides very low, stable and predictable latency for real-time control. Result: Applying 5G in the manufacturing industry has many important benefits in terms of costs, quality, and flexibility. The ultra-low latency and very high bandwidth make it possible to control machines in real-time, reducing manufacturing costs and improving the quality of products.
PT Indolakto	PT Indolakto produces a wide range of dairy products, embracing digital transformation to achive competitave advantage in a highly competitive dairy market. Thier vision is to be a role model of the digital transformation in the dairy industry Issue: Recent studies made by the company show that dairy market is growing concluding the need for production expansion. Steven Tan, Deputy Division Head of PT Indolakto, says "The Covid-19 pandemic has boosted demand further. But as Indolakto grows, it must not be at the expense of quality: consumers are discerning and expect nothing less than the best." Solution: Given the need to expaned coupled with the companys vision of digtalization, Indolakto has decided to open a new plant and introduce industry 4.0 technologies from the start. Siemens provided the plant with three main digitalization building blocks inculding; MindSphere (cloud-based IIoT solution) collectes production data and prepare it for further analysis, Control Performance Analytics (cloud-based Analysis service) analyses collected data and calculate KPIs to support root cause analysis, Simatic PLCs (Siemens' flagship automation system) intelligently controls automated guided vehicles (AGV) and automated storage and removal systems (ASRS) to transport and store pallets. Result: The new plant is fully digital, this embracment of digtaliziagion has helped the company to expand successfuly, uphold quality, reduce operation cost, and improve its compitive advatage in the dairy market. Moving a step closer to fullfil the companies vision

TCI	Taiwanese company TCI provides different pharmaceutical services among which testing COVID-19 sample. Issue: Due to the pandemic situation the previous testing process contained many flaws, including human interventions which led to human errors and the risk of getting infected, shortage of trained staff, and a low sample testing capacity. The company wanted a COVID-19 detection system that is more rapid, accurate, and fully automated. Solution: TCI Gene developed with the help of ABB robotic arms a new COVID-19 detection system, the QVS-96S is a fully automatic and enclosed testing machine, consists of three stations, nucleic acid extraction, dispensing, and analysis, in which ABB IRB 1200 (compact, flexible, fast and functional small industrial robot) were installed in the first two stations. Result: Taiwan's first fully automated COVID testing system allows testing to proceed continuously (24/7) ensuring full monitoring and allowing a punctual response to the pandemic. Dr. Arvin Chen, a Supervisor for TCI Gene, says: "The robotic system replaces the manual operations which have previously been conducted by well-trained technicians. With skilled lab technicians in short supply, automating the process allows available staff to be re-deployed to apply their skills to handle other tasks, improving their productivity."
Hosokawa Micron	Hosokawa Micron Ltd. (HML) is a provider of machines and systems for powder and particle processing. Their goal is to gain a competitive advantage in the marketplace through the use of industry 4.0 technologies. Issue: The company knew that digital transformation is inevitable and necessary, looking for a new and digitally smart solution that can optimize productivity improve the efficiency of their machines, and add great value for customers, using data-driven insights and analytics. Solution: HML chose to implement the cloud-based Internet of Things (IoT) operating system (MindSphere) offered by Siemens. MindSphere connects the entire environment (products, plants, systems, and machines) to understand the data, monitor it, and control it. Enabling the company to set key performance indicators through powerful data analysis and visualization. Result: The implementation of this digital solution has provided HML with new data-driven insights and better presentation of KPIs. The company can now make more informed decisions to better satisfy customers with powder processing machines that provide higher uptime, lower energy consumption, and increased capacity.

Bischofszell Nahrungsmittel AG (BINA)	The food company Bischofszell Nahrungsmittel AG (BINA) provides fresh produce, minimally processed foods, and ready-to-eat meals to supermarkets around Switzerland. BINA sought to optimize its productivity by automating some aspects of its manufacturing process. Issue: In the order-picking station supplies for each supermarket are picked and placed in plastic containers, which are then labeled using unique barcodes. The critical task of applying labels is a complex and repetitive job, as each label must be slightly bent to fit into its corresponding slot. BINA understood that the only feasible way to complete this task is through an automated solution, a labeling machine was suggested as a solution but there wasn't enough space for it, creating the need for a faster, more reliable labeling solution. Solution: Moveline AG (ABB system partner) had the answer to BINA's issues by integrating and programming the YuMi cobot (YuMi IRB 14000 collaborative robot) into its production process. This collaborative and safe robot can fit in the small space provided for labeling, Moveline also designed a tool to hold and bent the labels just enough so that YuMi cobot can insert the labels into the container's slot. Result: YuMi cobot enhanced the labeling task providing a more rabid and relaible solution, which can process 1,200 containers every hour in a two-shift operation from Monday to Friday without needing any breaks. "I believe collaborative robots like YuMi offer new possibilities for us. Employees quickly got used to the idea that YuMi does not work hidden behind a protective grid, unlike other industrial robots installed on site." said Knoll, manger at BINA.
Allied Moulded	Allied Moulded manufactures non-metallic electrical boxes and enclosures. Like any other company, it was looking for a way to automate repetitive tasks to improve consistency in the production process. Issue: Allied firm wanted to automate the bin-picking operation which includes picking up parts one by one from a pin and placing the part in a specific orientation onto a narrow conveyor for further processing. Many pin-picking machines were considered but not deployed because of the restricted space available also it offered limited functionalities, as a result, the task was done manually causing inconsistent output and fluctuations in quality, with the COVID pandemic there were also unexpected shortages in labor leading to additional concerns. Solution: Allied Moulded found out that it can solve the production challenges by using collaborative robots and chose Universal Robots' ActiNav system. The deployment of UR ActiNav autonomous bin-picking kit provided a flexible, simple, automated bin-picking solution that combines intelligent vision and real-time autonomous motion control. Result: The implementation of cobots replaced the previuos manual repetitive bin-picking tasks while providing same output volume it also enabled Allied Moulded to reduce labour cost, deal with workers shortage, improve quality and enhance consistency in the manufacturing process. ActiNav's high-resolution sensor and CAD matching ensure consistent and high accuracy picks.

Albrecht Jung GmbH & Co. KG	JUNG is a premium supplier of modern building technology. With its commitment to made in Germany, JUNG focuses on sustainable development and manufacturing, processing precision, and high design quality. Issue: The company recognizes the increase in individual customer demands which means it needs to efficiently handle the production of parts in small batch sizes. While human intervention is essential because many of the products must be hand-crafted, it wants to relieve workers from repetitive dangerous tasks. JUNG is looking for a solution that can optimize its operations according to lean principles, guarantee flexibility and enable a safe working environment. Solution: Collaboritive robots presented the best solution for the company. JUNG installed a total of eight UR cobots offered by Universal Robots, which where deployed in the plant to work alongside the operators in multiple stations (Picking, Screw insertion, Packaging, Assemply). Spacificly, UR3e cobot was deployed to support operater in light assembly tasks with maximum precision, and UR5e cobot was used to tackle medium-duty applications with ultimate flexibility. Result: Cobots worked successfully in close collaboration with operators, providing a cost-effective, safe and flexible solution. “We are proud to be able to successfully optimize our production with this cutting-edge technology. Production costs and lead times are considerably reduced by the cobots – resulting in fast amortization.” says Mario, Head of Plant Production
Novo Nordisk	Novo Nordisk is a global pharmaceutical manufacturer, wishes to improve its competitiveness in the Chinese market by optimizing the productivity of its Tianjin plant, through advanced automation solutions. Issue: Even though the factory is considered highly automated, the warehouse acknowledged the need to automate its intralogistics system. Originally the internal transportation tasks were done manually using forklifts to move packaging material from and to the warehouse. Zhao Xin, warehouse supervisor, noted that the internal transportation process was monotonous, time-consuming, and the transportation path is narrow with a lot of obstacles. Solution: The company wanted to use Autonomous mobile robots (AMR) which offer an intelligent, flexible, and reliable transportation method. After examining various options, Novo Nordisk chose to partner with Mobile Industrial Robots and acquired five MiR500 autonomous mobile robots (AMRs). The robots are armed with sensors, cameras, and scanning devices all linked to intelligent software, allowing the five AMRs to analyze the environment, avoid obstacles and navigate autonomously between various destinations. Result: The MiR Fleet has successfully replaced the manual process of internal transportation freeing workers for more added-value activities. In addition, MiR’s Fleet software is considered easy to program and set up, offering technicians centralized control of all AMRs which can be easily programed and managed remotely.

Nike Inc.	Nike Inc. manufactures and supplies athletic equipment. With the rapid sales growth of shoes and clothes in Japan, the company sets a goal to optimize production and enhance operational efficiency through cutting-edge technology. Issue: Nike's warehouse relied on manual operations to transport material internally that were facing fluctuation in order volume and labor retention as a result of the COVID-19 pandemic. It hoped to digitally transform its Internal logistic operations, to reduce labor intensity and improve picking accuracy, eventually achieving same-day delivery in conjunction with a reduction in labor costs. Solution: Nike Inc. worked with Geekplus Technology Co. and implemented 202 picking robots and 6000 set racks to streamline Nike's warehouse operations in Japan. the solution uses P series robots to move the inventory shelves and pallets to the picking station, working safely and flexibly around humans. The system uses artificial intelligence for order optimization and inventory management. Result: The new internal transportation system has helped Nike's plant further improve the productivity of their ongoing operations eliminating the redundant walking to and from picking stations, enhancing the efficiency of picking tasks, and reducing human concentration leading to a safe and secure enviroment in regards to COVID infection.
Tien Kang Co., Ltd.	Tien Kang Co., Ltd. is concerned with the production of high-tech shoe manufacturing machines and triggered by the increasing competitiveness in the market, it decided to optimize machine efficiency and improve maintenance services for its clients by implementing a smart machinery management solution. Issue: The shoe-making machines endured problems in combining data coming from different communication protocols and different legacy equipment systems. The lack of a unified view of the manufacturing process and machinery led to low equipment utilization, unscheduled downtimes, and delays in troubleshooting production issues, as a result, a decision was made to digitally upgrade Tien Kang's shoe-making facilities. Solution: To meet the unique needs of Tien Kang, Advantech integrated iFactory RTM (Real-Time Monitoring) Gateway. The gateway solution consists of both hardware (IFS-RTM-UNO box computers) and software (WISE EdgeLink) that worked together to collect and aggregate data from various sensors, devices, and older legacy equipment while monitoring operations. With the smart machinery management solution, the plant can control the production of each machine through a visualized dashboard, analyze production statistics, and obtain a real-time alarm notification system. Result: Kang Co., Ltd. successfully implemented the first stage of Smart Machinery Management Solution (iFactory). The shoe machine manufacturer was able to increase assembly speed, integrate various equipment data, provide a visualized presentation of data, conduct preventative maintenance and remotely control different aspects of production across plants and lines. The company will continue its cooperation with Advantech to expand the smart functionalities of production in the future.

Volvo Group Trucks Central Europe GmbH	Volvo GmbH is part of the automobile industry, it was looking for a solution to deliver visual presentation of the complex vehicle information for its employees in automotive workshops and training centers. Issue: Originally, technical training was done through the use of complex 3D graphics and paper-based instructions, the information involved were considered complicated, incomplete and out-dated. Even though the purpose of using 3D graphics was to better understand vehicle functionalities,he information involved was considered unrelated to the actual workshop repair and maintenance scenarios, lower trainees technical engagment, and often require the existence of experts for further explanation. Solution: By introducing Reflekt One suite (modular Augmented Reality Platform) offered by Reflekt, the company replaced its traditional training manuals with AR- empowered visual representation of training content. The solution allowed Volvo GmbH to build training guide scenarios with their own teams using a no-code augmented work platform and visualize hidden truck components and part specifications directly onto the vehicle. In addition, it provided technical trainers with ability to instantly update instructions and maintenance scenarios. Result: The AR-solution offered a smart and innovative representation of training material and enhanced knowledge transfer through more realistic training sessions and better engagment of trainees.In addition, the solution could be used as reliable resource in the workstations to check part specifications, diagnosing vehicle errors and guiding customers through repair procedures to using augmented reality visualizations.
IDEAL-Werk	IDEAL manufactures machinery that ranges from modular standard models to tailor-made special solutions. Its vision stands for continuous innovation and high quality in machine and plant engineering, that’s why it decided to digitally upgrade its maintenance and repair services. Issue: For a machine manufacturer such as IDEAL-Werk, providing support and maintenance services for its customers is considered a critical task as equipment downtime negatively affects the productivity at the customer’s site, requiring the expertise of highly qualified engineers to repair the machines accurately as soon as possible. The problem resides in the scarcity of maintenance staff that has to do site visits to fix customers’ equipment, in addition, the main source of documentation for engineers is a set of outdated, text-based maintenance manuals, all of that compromised service quality. Solution: The company partnered with Re-flekt to create an Augmented Reality platform (REFLEKT ONE) replacing classic methods of text-based documentation with a digital format that combines real-time superimposed digital information with step-by-step instructions enabling service engineers to perform important maintenance procedures effectively and accurately. The AR guides are available on tablet devices ensuring that service engineers have instant access to repair procedures for any equipment at any time. Result: Re-flekt’s augmented reality solution will allow IDEAL to speeds up repair procedures, reduces errors, and saves costs. AR application assists technicians to perform their missions efficiently by providing real-time interaction and accurate 3D registration of virtual and real objects.

Ricoh	Ricoh is a media and office machines producer interested in using data and analytics to drive digital transformation and enhance the overall equipment efficiency for their Connected Factory system in their UK facilities, reaching a holistic view of processes across all manufacturing facilities. Issue: The company noticed some room for improvement in their factory facilities. There was an absence of methods and technologies that use data and analytics to improve real-time monitoring of machines, predict machine failures, track inventory and provide deep insights. Solution: Richo decided to introduce Microsoft Azure machine learning and AI applications in their connected factory system. Machine sensors will record and transmit real-time data to Microsoft Azure, after which live adjustments can be applied to the machine. Azure machine learning will use data collected by sensors to suggest actions to improve machine performance. Azure artificial intelligence can predict machine failures and provide maintenance schedules. Microsoft Azure tracks inventory at all stages of the production cycle using data from Ricoh cameras. Result: The successful implementation of machine learning and AI applications across all factory areas enabled Real-time machine optimization, predictive maintenance, intelligent production tracking, and automated cost reduction.
EAC Metal Ornaments	EAC Metal Ornaments designs and manufactures metal accessories for multiple sectors. The company focuses on providing innovative and customised metal accessories, jewellery, and luxury items to brands worldwide to personalise and sign their finished products. Issue: For luxury items, the quality and appearance of custom accessories are crucial. Reaching the required level of quality and customisation using traditional manufacturing methods is challenging, as each product requires custom tooling increasing cost and causing bottlenecks. The company wanted to replace these methods with machines capable of producing customised, low volume patches efficiently while keeping the cost-per-part low. Solution: EAC decided to invest in metal 3D printing to eliminates the root cause of their problems by installing Desktop Metal’s Shop System -an end-to-end, single-pass binder jetting solution delivering high-resolution 3D printed parts. This new additive manufacturing system allows tooling-free shopfloor, higher production throughput, and creating highly complex parts with a superior surface finish to laser-based systems, making it ideal for creating metal ornaments. Result: The Shop System solution has been a success. Using the system, EAC designers can produce more custom metal ornaments with more distinctive features, production rate increased drastically, time to market shrunk, and the company was able to reduce waste resulting in a greener manufacturing environment.

Průmyslová keramika	Prumyslova Keramika produces and supplies ceramic mixes and custom heat-resistant parts to central Europe. The company's focus on flexibility and customization of ceramic parts based on customers' requirements led their production team to consider additive manufacturing technology. Issue: Previously, the company produced ceramic parts using molds for external shape and core inserts for internal shape. These fittings are complex and differ based on customer specifications, including processes (manual carpentry or CNC machining) that were time-consuming and expensive. The company adopted 3d printing as a pilot project to speed up the mold production process, but it was unsuccessful. says Jakub Cvilinek, Managing Director. "Only about 30% of the prints were successful, and the rest was waste. Even after this experience, we believed in 3D printing. It was a great school for us. The technology was still good for us – we just chose the wrong printer." Solution: Ultimaker 3d printers provided the desired level of reliability and compatibility that Prumslova's team was looking for in the 3d printing solution; the company acquired two printers (Ultimaker 3 Extended and Ultimaker S5). Engineers design the core parts using Autodesk Inventor and AutoCAD, after which 3d printers use these designs to create the parts eliminating the need to use manual carpentry or CNC machining. Result: 3D printing has proven to be an excellent addition to the manufacturing process. The Ultimaker 3 Extended and S5 have led to massive savings and burst the speed of production, along with the ability to produce more complex shapes, eventually enhancing overall productivity and satisfying customer expectations.
Eriks N.V.	ERIKS is a specialized industrial service provider with a wide range of technical products, co-engineering, customization solutions, and related services. The company wishes to enhance its services using additive manufacturing. Issue: The common factor across all industrial services provided by ERIKS is providing a safe and clean solution. It also considers achieving safety goals as important as achieving production targets and profit margins. Driven by its slogan "Clean Manufacturing Facility" the company decided to include additive manufacturing in its workflow. The team understands the benefits of installing 3D printers, specifically in creating tools that enhance onsite safety. Solution: ERIKS implemented a new 3D printing hub in the Alkmaar facility containing multiple Ultimaker S5 printers, in which the printing process creates technical components and safety parts. One application of 3d printing enhancing onsite safety; is a 3D printed tool that allows for quick and safe replacement of a large roll of wrapping film. Result: Additive manufacturing guarantees a cleaner environment by reducing waste, in addition to providing "certified" parts – ensuring quality, duplicability, and reliability of printed parts. In all, ERIKS' slogan and vision are in alignment with the use of 3D printing. The process is automated, stabilized, and clean.

Wartsila Oyj Abp	Wartsila uses cutting-edge technologies and complete lifecycle solutions to maximize the environmental and economic performance of its customers' vessels and power plants. This case focuses on enhancing processes using additive manufacturing technology in the Finnish factory in Vaasa and the Italian factory in Trieste, which oversee the manufacturing of large engines that power a third of the world's largest cargo ships. Issue: During the manufacturing process, the team faces problems such as lifting pistons - cumbersome engine parts- that often require them to fabricate unique lifting tools for moving these parts safely and efficiently and assist engineers in performing maintenance tasks. Traditionally, the plant relied on third-party suppliers to manufacture these tools out of solid steel, but the resulting tools were expensive, time-consuming to manufacture, challenging to move and transport, with no possibility to iterate or make changes to the design. Solution: Engineers at Wärtsilä solved similar problems by fabricating tools using Markforged carbon fiber 3D printers. The Trieste and Vaasa teams acquired an Industrial Series X7 printer for their Italian facility, and by working with Markforged, they redesigned the lifting tool to be produced using additive manufacturing technology. The tool went through several tests and inspections to be certified. Result: The implementation of the additive manufacturing solution was a success for the company, the team estimates over €100,000 savings in just eight months for tooling alone. By Internalizing the tooling process and freeing the teams from third-party suppliers led to a faster, cheaper, and more efficient solution.

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