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Overview on maturity of AI innovations in manufacturing

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Executive Summary

This report describing the situation of digitalisation and AI maturity among small and medium sized enterprises (SME) from manufacturing and food industries, is the EI Digital input to work package 1 of the end-to-end digitalised production testbed cross-KIC project. It was created in close collaboration between EIT Digital and FBK, providing the necessary insights into the topic of digitalised food and beverage manufacturing processes.

The report contains sections featuring the results of online and literature research activities. Furthermore, results from online surveys among SMEs from manufacturing and food industries were analysed and are featured in this report. The survey design was developed as part of the work package activities as well and aims at providing sound information about the respondents, their situation concerning data governance and management activities, as well as their approach towards integrating into their business processes.

Finally, based on online and literature research but also interviews conducted by the KICs and KIC members with industry experts, a collection of AI use-cases was established, and two types of categorisation systems implemented, to demonstrate which areas are currently benefitting from AI applications.

The report shows that digitalisation and AI maturity among SMEs from manufacturing industries is far more advanced than among food SMEs. These results demonstrate that the testbed cross-KIC initiative meets existing demands and will provide valuable assistance to producers of food and beverage items on their way to applying digitalisation and AI solutions.

1. Introduction

Expectations about the impact of Artificial Intelligence on business and society is now very high. Ambitious programmes are worldwide launched by governments to support AI development. The European Parliament has recently analyzed the AI framework in Europe[1]. Main findings emerged were:

- *A market in rapid evolution.* Although**,** AI is not a new technology, AI is still at a relatively early stage of development, so that the range of potential applications, and the quality of most existing applications, have ample margins left for further development and improvement;

- *A limited number of strong AI global players.* The EU AI ecosystem is still too reliant upon technologies developed in non-EU countries.

[1] European Parliament (2018), STUDY Requested by the ITRE committee*, European Artificial Intelligence (AI) leadership, the path for an integrated vision*, Policy Department for Economic, Scientific and Quality of Life Policies Directorate-General for Internal Policies Author: Laura DELPONTE (CSIL) PE 626.074- September 2018

- *A combination of political, legal and technical factors* can positively or negatively affect the uptake of AI in Europe.

- AI benefits from *strong political support worldwide*.

- *The amount of resources required* to keep up with the latest AI *developments cannot be met by a single Member State*, creating a clear rationale for EU intervention

- *The deployment of AI creates several pressing policy* (legal, societal and ethical) *challenges at the global and European level.*

- *There is not yet robust evidence of AI applications used for addressing significant real-life problems or societal challenges.*

- *In Europe, AI research resources are abundant* but scattered and skewed *in academia* and *public research organisations.*

Starting from this context, the present study is aimed at identifying the present state of the art of the use of Artificial Intelligence in manufacturing from its possible definition to the identification of the implementation gaps, passing through the analysis of possible use cases of interest.

The first part of the study - ***Premise: AI - a common definition*** - will be dedicated to share a possible shared definition of Artificial Intelligence and framework of reference, with specific attention for aspects that affect safety, transparency and accountability of AI applications, such as *ethics* (interactions with humans, possible opacity of data and actions), *technologies* used (that then will be of reference in the construction of the state of the art), *data* (as necessary premise for AI), and related *cybersecurity* issues.

The identification of systems and technologies of reference and in line with FBK AI vision will be part of the paragraph ***AI: systems and technologies***. First point will be the definition of the main AI approaches and techniques (machine learning, machine reasoning, robotics). Technologies of reference will be then identified (*Cognitive Computing*, *5G*, *Edge Computing*, *Cloud Computing*, *IoT*, *Computer Vision*, *Blockchain*) also as necessary to the development of solution improving production and work environment using systems such as: *Safety-Critical Systems*, *Adaptive and Autonomous Systems*, *Advanced Perception Systems*, *Diagnostic and Predictive Systems.*

Core part of the study will be a possible catalogue of best practices in terms of successful AI applications and projects in manufacturing with attention also for the *agritech* applications (***AI and manufacturing best practices***). AI applications in Industry 4.0 make working environments places where machines are able to work and interact with people more productively in various ways that will be identified and considered in the study (devices and platforms for the design, implementation and certification of production processes, real-time control of robots and drones, autonomous robotic applications, greater-time monitoring of the workplace, etc.). Case studies will be described considering systems and technologies deployed, use, best practices.

Implementing AI solutions in manufacturing is a complex process that involve not only technological issues but influence the well-being in the company of workers. The fourth part of the study - ***AI implementation*** *gaps* – will introduce main present difficulties and gaps emerging in the introduction and deployment of AI in manufacturing, such as: human-machine new relationship (trustworthy, opacity, etc.), skill gaps (digital divide, job changes, etc.), internal data management and cybersecurity issues, disruptive changes in value chains and business models, green deal and digital transformation related issues, COVID-19.

2. Premise: AI - a common definition

Talking and doing Artificial Intelligence is becoming more and more actual, due to the availability of big data generated by the availability of devices and applications that collect and generate data; to improved and more reliable machine- learning algorithms; and to more and more cheaper cloud and high-performance computer systems. The evolution of technologies is now changing our lives in various ways. In fact – as introduced also in the European Commission White Paper on AI – “it will change our lives by improving healthcare (e.g. making diagnosis more precise, enabling better prevention of diseases), increasing the efficiency of farming, contributing to climate change mitigation and adaptation, improving the efficiency of production systems through predictive maintenance, increasing the security of Europeans, and in many other ways that we can only begin to imagine. At the same time, Artificial Intelligence (AI) entails a number of potential risks, such as opaque decision-making, gender-based or other kinds of discrimination, intrusion in our private lives or being used for criminal purposes.” [2]

Before focusing on how Artificial Intelligence is applied and is changing manufacturing, It is important to introduce a possible shared definition.

The first time that the term Artificial Intelligence appears was in 1956, when *John McCarthy*[3] invited a group of researchers from a variety of disciplines (language simulation, neuron nets, complexity theory, etc.) to the workshop “Dartmouth Summer Research Project on Artificial Intelligence” to discuss about “**thinking machines**” that included cybernetics, automata theory and complex information processing. His definition was: “The science and engineering of making intelligent machines, especially intelligent computer programs”.

After more than 70 years, the *English Oxford Living Dictionary*[4] defines Artificial Intelligence: “The theory and development of **computer systems able to perform tasks normally requiring human intelligence**, such as visual perception, speech recognition, decision-making, and translation between languages.”

The *Encyclopedia Britannica*[5] states, “artificial intelligence (AI), the ability of a digital computer or computer-controlled robot to **perform tasks commonly associated with intelligent beings**.” Intelligent beings are those that can adapt to changing circumstances.

Various are the AI definitions focused on the capacities of machine to work and think like human. Implementing Artificial Intelligence in manufacturing needs to consider also its risks and therefore a definition that consider to face potential negative impacts on human activities.

“Artificial intelligence (AI) systems are ***software*** *(and possibly also* ***hardware****) systems designed by humans that, given a complex goal,* ***act in the physical or digital dimension*** *by perceiving their environment through* ***data acquisition****, interpreting the collected structured or unstructured data,* ***reasoning*** *on the knowledge, or*

[2] European Commission (2020) *White Paper on Artificial Intelligence. A European approach to excellence and trust*, Brussels, 19.2.2020 COM(2020) 65 final.

[3] http://www-formal.stanford.edu/jmc/

[4] https://www.lexico.com/definition/artificial_intelligence

[5] https://www.britannica.com/technology/artificial-intelligence

processing *the information, derived from this data and* ***deciding*** *the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions."*[6]

This common understanding of Artificial (AI) comes from the *Independent High-level Expert Group on Artificial Intelligence set up by the European Commission* to face AI advent in the present complex context of digital transformation. This definition highlights AI main technical components: digital technology, data and decision processes that are necessary but not sufficient to assure that AI can improve human welfare and freedom. So, the Group has further worked on the recognized need of a human-centric AI embedding socio-technical environments, defining a new concept of ***Trustworthy A*****I**, maximising the benefits of AI systems while at the same time preventing and minimizing their risks. Three are the components of this innovative concept being: **Lawful** (ensuring respect of all applicable laws and regulations), **Ethical** (ensuring adherence to ethical principles and values), and **Robust** both from a technical and social perspective (do not cause any unintentional harm).

OECD is in line with this vision of a trustworthy AI respectful of human rights and democratic values with ***OECD Principles on Artificial Intelligence***[7] promote artificial intelligence (AI) adopted in May 2019 by OECD member countries. Principles identified are:

1. *AI should* ***benefit people and the planet*** *by driving inclusive growth, sustainable development and well-being.*

2. *AI systems should be designed in a way that* ***respects the rule of law, human rights, democratic values and diversity,*** *and they should include appropriate safeguards – for example, enabling human intervention where necessary – to ensure a fair and just society.*

3. *There should be* ***transparency and responsible disclosure around AI*** *systems to ensure that people understand AI-based outcomes and can challenge them.*

4. *AI systems must function in a* ***robust, secure and safe*** *way throughout their life cycles and potential risks should be continually assessed and managed.*

5. *Organisations and individuals developing, deploying or operating AI systems should be held* ***accountable for their proper functioning*** *in line with the above principles*[8]*.*

In line with these principles, definition of reference for this study is the one of Trustworthy Artificial intelligence – as defined by the EC Expert groups and validated by OECD – that allows to take into account also potential risks and possible contingency measures and consider potential implementation gaps of AI in manufacturing.

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[6] Independent High-level Expert Group on Artificial Intelligence set up by the European Commission (April 2019), *A Definition of AI: Main Capabilities and Disciplines*, European Commission, p.6

[7] OECD (2019), *Recommendation of the Council on Artificial Intelligence*, https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0449

[8] https://www.oecd.org/going-digital/ai/principles/

3. AI: systems and technologies

Bernard Marr affirms - in his Forbes article on AI definitions[9] – that the goals that are trying to be achieved with an AI system are now the focus for its definition and categorisation. Generally, "people invest in AI development for one of these three objectives:

1. build systems that think exactly like humans do ("strong AI")

2. just get systems to work without figuring out how human reasoning works ("weak AI")

3. use human reasoning as a model but not necessarily the end goal."[10]

Accenture follows a similar approach in their ExplAIned – A guide for Executives[11], defining four possible level of use of AI, i.e.:

1. "**Weak AI**. This describes **"simulated" thinking**. That is, a system that appears to behave intelligently, but doesn't have any kind of consciousness about what it's doing. For example, a chatbot might appear to hold a natural conversation, but it has no sense of who it is or why it's talking to you.

2. **Narrow AI.** This describes an AI that is **limited to a single task or a set number of tasks**. For example, the capabilities of IBM's Deep Blue, the chess-playing computer that beat world champion Gary Kasparov in 1997, were limited to playing chess. It wouldn't have been able to win a game of tic-tac-toe – or even know how to play.

3. **Strong AI.** This describes **"actual" thinking**. That is, behaving intelligently, thinking as a human does, with a conscious, subjective mind. For example, when two humans converse, they most likely know exactly who they are, what they're doing, and why.

4. **General AI.** This describes an AI which can be **used to complete a wide range of tasks in a wide range of environments**. As such, it's much closer to human intelligence. Google DeepMind used reinforcement learning to develop an AI that learned to play a whole range of different games requiring different skills. The AI achieved human-like levels of performance at 29 classic Atari video games using only the on-screen pixels as its data input."[12]

If we can use the AI at different levels, AI is by no means a technology in its own right but rather is a combination of different technologies, all rapidly evolving, which put together, allow the machines to act with intelligence levels apparently similar to human ones. We can define AI as a constellation of

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[9] Bernard Marr (2018) *The Key Definitions of Artificial Intelligence (AI) That Explain Its Importance,* https://www.forbes.com/sites/bernardmarr/2018/02/14/the-key-definitions-of-artificial-intelligence-ai-that-explain-its-importance/#27dfef874f5d

[10] Ibidem

[11] Ray Eitel-Porter (2018), *ExplAIned – A guide for Executives*, Accenture Applied Intelligence Lead UKI https://view.pagetiger.com/AI-Explained-A-Guide-for-Executives/2018

[12] Ibidem

technologies organized in systems as introduced also in FBK vision on Artificial Intelligence[13] (Figure A). This AI vision and the definition given by the Independent High-level Expert Group on Artificial Intelligence introduce the main features of Artificial Intelligence, i.e.:

1. Approaches and techniques
2. Technologies
3. Systems

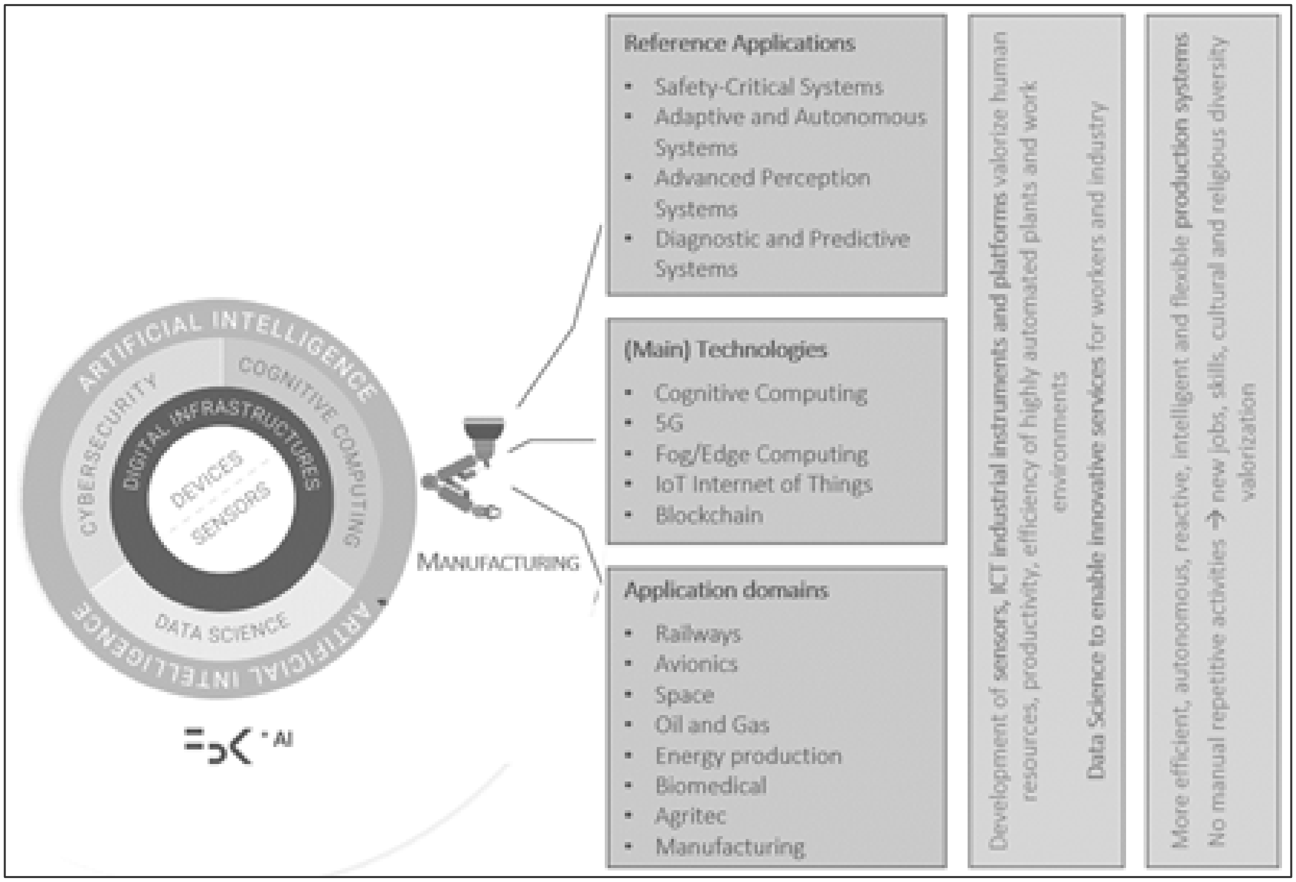

Figure A. FBK vision

3.1 Artificial Intelligence approaches and techniques

*As a scientific discipline, AI includes several approaches and techniques, such as **machine learning** (of which deep learning and reinforcement learning are specific examples), **machine reasoning** (which includes planning, scheduling, knowledge representation and reasoning, search, and optimization), and **robotics***

[13] https://ict.fbk.eu/areas/ai/

(which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems).[14]

Machine Learning: techniques that allow to AI systems to learn how to solve problems (such as the ones involved in perception capabilities: speech and language understating, computer vision, behavior prediction; or the production of numeric model supporting the decision-making starting from data) that cannot be precisely specified, or whose solution method cannot be described by symbolic reasoning rules. These techniques allow computers to learn automatically without human intervention or assistance and adjust actions accordingly. They include machine learning, neural networks, deep learning, decision trees, and many other learning techniques.

Machine Reasoning: techniques that allow to perform the reasoning on the data coming from the sensors, transforming data to knowledge (*knowledge representation*), reasoning with it (*knowledge reasoning*) and making inferences through symbolic rules, *planning* and *scheduling* activities, *searching* through a large solution set, and *optimizing* among all possible solutions to a problem. All this process allows to decide what action to take. They include knowledge representation and reasoning, planning, scheduling, search, and optimization

Robotics: "AI in action in the physical world" (also called *embodied AI*)[15]. A robot is a physical machine that deals with a dynamic, uncertain, and complex physical context. Various techniques and technologies are combined to its functionality, such as: perception, reasoning, action, learning, as well as interaction capabilities with other systems, mechanical engineering and control theory. Examples of robots include robotic manipulators, autonomous vehicles (e.g. cars, drones, flying taxis), humanoid robots, robotic vacuum cleaners, etc.

3.2 Artificial Intelligence technologies

The *Gartner Hype Cycle for Artificial Intelligence* (2019) well introduces technologies and techniques of reference for this study, considering the most mature ones (such as Cognitive Computer and Computer Vision) and the new ones introduced (such as: AI Cloud Services, Edge AI as AI techniques embedded in IoT, AI Marketplaces).

[14] Independent High-level Expert Group on Artificial Intelligence set up by the European Commission (April 2019), *A Definition of AI: Main Capabilities and Disciplines*, European Commission, p.6

[15] Ibidem, p. 4

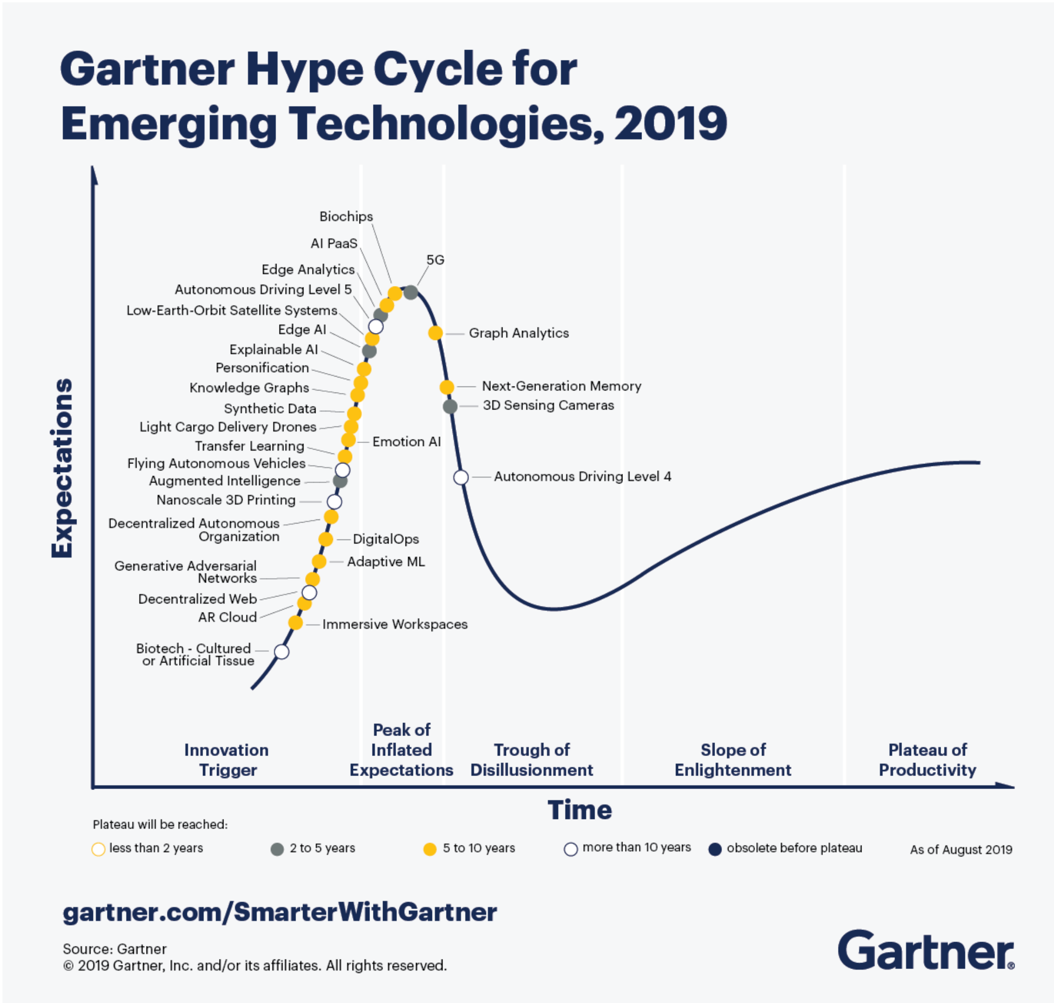

Figure B. Gartner Hyoe Cycle for Merging Technologies 2019

In particular, most interesting technologies involved in the application of AI in manufacturing are: **Cognitive Computing**, **5G**, **Cloud/Edge Computing**, **IoT**, **vision technologies**, and **Blockchain**.

Cognitive Computing: as defined by Bernard Marr[16], Cognitive Computing combines the study of the human brain and how its functions – *cognitive science* – and *computer science* "to simulate human thought processes in a computerized model. Using self-learning algorithms that use data mining, pattern recognition and natural language processing, the computer can mimic the way the human brain works. Another interesting definition is the one given by Dharmendra Modha: "Cognitive computing goes well beyond artificial intelligence and human-computer interaction as we know it – it explores the concepts of perception, memory, attention, language, intelligence, and consciousness. Typically, in AI, one creates an algorithm to solve a particular problem. Cognitive computing seeks a universal algorithm for the brain. This

16 Bernard Marr (2016), *What Everyone Should Know About Cognitive Computing*, https://www.forbes.com/sites/bernardmarr/2016/03/23/what-everyone-should-know-about-cognitive-computing/#645bfa995088

algorithm would be able to solve a vast array of problems"[17] that will reach impacts on our private lives, healthcare, business, and more.

5G - 5th generation of mobile Internet connectivity that is offering super-fast download and upload speeds as well as more stable connections that will have business implications for companies in terms of enabling machines, robots, autonomous vehicles. New potential will be developed in terms of collection, transfer and elaboration of data, leading to advances in the area of the Internet of Things (IoT) and smart machinery. Starting from 2020, 5G will be the future of Internet connection, available for the first time in 2019 but mostly still expensive and limited to functioning in restricted areas.

Edge Computing is "topology where information processing and content collection and delivery are placed closer to the sources of the information, with the idea that keeping traffic local and distributed will reduce latency"[18], including all the technology on the *Internet of Things* (*IoT*). The use and potential of devices is increasing, allowing the formation of smart spaces where Edge Computing is moving key applications and services closer to the people and devices that use them. Gartner is foresees a stable increase in the embedding of sensor, storage, compute and advanced AI capabilities in edge devices, creating a complex and ongoing management and integration challenge.

Cloud Computing is "the delivery of computing services—including servers, storage, databases, networking, software, analytics, and intelligence—over the Internet ("the cloud") to offer faster innovation, flexible resources, and economies of scale."[19] Cloud computing offers many advantages, such as: cost reduction, productivity, performance, speed, reliability, security.

Internet of Things (IoT) is – as defined by Jacob Morgan – "the concept of basically connecting any device with an on and off switch to the Internet (and/or to each other). This includes everything from cellphones, coffee makers, washing machines, headphones, lamps, wearable devices and almost anything else you can think of."[20] It is a network of physical objects, 'things' that can be embedded with technologies, software and/or sensors, helping in connecting or exchanging data with other devices and/or systems via Internet and vice versa.

Computer Vision as "systems that are able to identify items, places, objects or people from visual images – those collected by a camera or sensor."[21] It has and will have different uses such as production lines monitoring, employing computer vision cameras to detect defective products or equipment failures, and security cameras to alert in case of anything out of the ordinary, without human presence.

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[17] Quoted in Charles Roe (2014), *A Brief History of Cognitive Computing*, https://www.dataversity.net/brief-history-cognitive-computing/

[18] Gartner (2020), *Top 10 Strategic Technology Trends for 2020*, Edited by David W. Cearley, Distinguished VP Analyst, Gartner, p.8

[19] Definition given by Microsoft Azure - https://azure.microsoft.com/en-us/overview/what-is-cloud-computing/

[20] Jacob Morgan (2014), *A Simple Explanation Of 'The Internet Of Things'*, https://www.forbes.com/sites/jacobmorgan/2014/05/13/simple-explanation-internet-things-that-anyone-can-understand/#5f64a7af1d09

[21] Bernard Marr (2019), *The 7 Biggest Technology Trends In 2020 Everyone Must Get Ready For Now*, https://www.forbes.com/sites/bernardmarr/2019/09/30/the-7-biggest-technology-trends-in-2020-everyone-must-get-ready-for-now/#7350158b2261

Blockchain can be defined as "a type of distributed ledger, an expanding chronologically ordered list of cryptographically signed, irrevocable transactional records shared by all participants in a network. This enables two (or more) parties who don't know each other to exchange value without a need for a centralized authority."[22]. The most known use is the crypto currency, but it can be used for the traceability of products, their certification, etc.

3.3 Artificial Intelligence systems

AI systems are defined by the EC Independent High-level Expert Group on Artificial Intelligence as "any AI-based component, software and/or hardware. Indeed, usually AI systems are *embedded* as components of larger systems, rather than stand-alone systems. […] perceiving the environment in which the system is immersed through some sensors, thus collecting and interpreting data, reasoning on what is perceived or processing the information derived from this data, deciding what the best action is, and then acting accordingly, through some actuators, thus possibly modifying the environment. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behavior by analyzing how the environment is affected by their previous actions." [23] Analyzing the use of Artificial Intelligence in manufacturing Systems of interest are:

Safety-Critical Systems used to monitor and reduce design flaws and runtime errors, supporting certification procedure. "Safety-critical systems are those systems whose failure could result in loss of life, significant property damage or damage to the environment. There are many well-known examples in application areas such as medical devices, aircraft flight control, weapons and nuclear systems."[24]

Adaptive and Autonomous Systems combine advanced technologies to realize *adaptivity* (the ability to improve performance by learning from experience) and *autonomy* (the ability to perform tasks in complex environments without constant guidance by a use). These systems allows machines "to **sense** (perceive and process), **comprehend** (understand recognizing patterns), **act** (take actions based on understanding) and **learn** (optimize its own performance based on success or failure of those actions) […] to take behavioural patterns from human's past experience and acts accordingly without having the human factor of circumstances changing due to external factors."[25] They are used to improve production efficiency thanks to their adaptability to changing environmental conditions, autonomous planning and execution of suitable course of actions to achieve run-time objective.

Advanced Perception Systems are systems that not only collect data but create actionable information through an active and adaptive process to sense, react, respond, adapt, and predict events in the environment. Advanced perception systems combine sensor technologies, signal processing, classifiers, state filters, and environmental models to create context-driven smart sensing. Advanced Perception

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[22] Gartner (2020), *Top 10 Strategic Technology Trends for 2020*, Edited by David W. Cearley, Distinguished VP Analyst, Gartner, p.11

[23] Independent High-level Expert Group on Artificial Intelligence set up by the European Commission (April 2019), *A Definition of AI: Main Capabilities and Disciplines*, European Commission, p.6

[24] J.C. Knight (2002), *Safety critical systems: challenges and directions*, **Published in:** Proceedings of the 24th International Conference on Software Engineering. ICSE 2002

[25] Fiamma Panerai (2018), *Artificial intelligence needs human ingenuity and moral,* https://medium.com/@FiPanerai/artificial-intelligence-needs-human-ingenuity-and-moral-a6f0bcad8ca0

Systems support industrial process operations with leading-edge research techniques (DSP, vision, model-predictive control…).

Diagnostic and Predictive Systems combine the potential of *Diagnostic analytics*[26] ("process of gathering and interpreting different data sets to identify anomalies, detect patters, and determine relationships."[27]) and *Predictive analytics*[28] ("uses descriptive and predictive variables from the past to analyze and identify the likelihood of an unknown future outcome"[29]) to reduce downtime and improving production efficiency thanks to integrated platforms for big data analytics for diagnosis, prognosis, and predictive maintenance.

[26] Alerts, drill-down, data discovery, data mining and correlations can be based on diagnostic analytics.
[27] Eric Wilson (2020), *The Differences Between Descriptive, Diagnostic, Predictive & Cognitive Analytics*, https://demand-planning.com/2020/01/20/the-differences-between-descriptive-diagnostic-predictive-cognitive-analytics/
[28] Predictions on the possible future are made combine data mining methodologies, forecasting methods, predictive models and analytical techniques to analyze current data, assess risk and opportunities, and capture relationships.
[29] Ibidem

4. AI and manufacturing best practices

4.1 Introduction

The manufacturing industries represent a vast and extremely heterogeneous sector. Some domains (i.e. agriculture) are very ancient and approached lately the innovations of the industrial revolution, some (i.e. railways) have been one of the industrial revolution assets, and some others (i.e. space) are new and under rapid evolution. What are the most interesting domains connected to the AI ongoing revolution?

As FBK working on AI in manufacturing, means to introduce innovative solutions in sectors such as:

- Railways
- Avionics
- Space
- Oil and Gas
- Energy production
- Biomedical
- Agritech
- Manufacturing

This chapter will focus on best practices in Agritech and in Manufacturing more in general.

4.2 AI in AgriFood industry

4.2.1 AI technology and systems in AgriFood industry

Agritech could be considered a sub-section of the manufacturing domain. Agritech is the latest domain approaching technical revolution, with excellent results and a promising future. Furthermore, agritech is the most relevant primary sector, well connected to our earth, climate, and our primary needs. For this, after the technology and systems focus on Agritech we will now focus first on Agritech best practices.

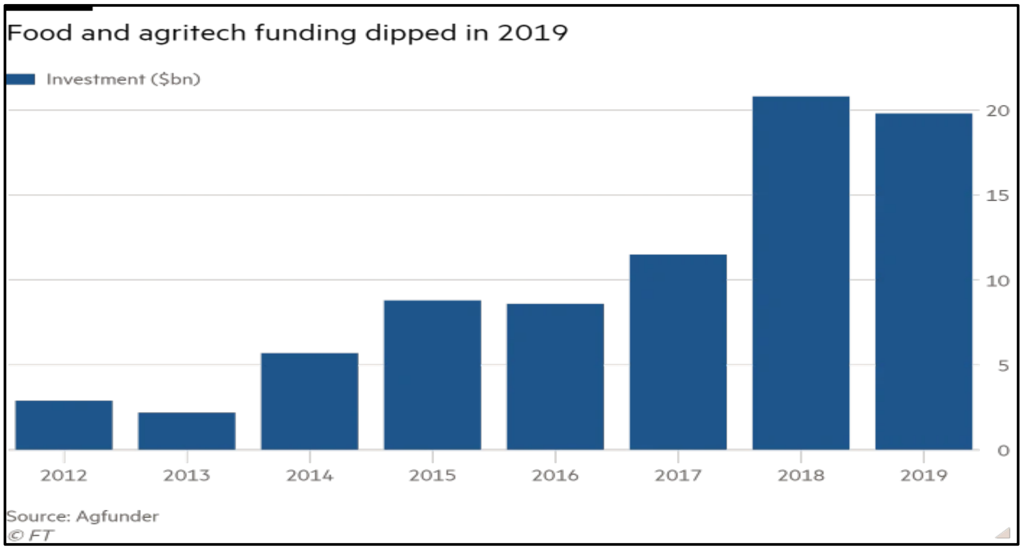

Figure C. Agrifood technology innovation investments [Source: Financial Times, 25 February 2020]

The Agrifood sector is one of the main, faster growing through AI innovation[30] (albeit with a slight slowdown in 2019, see Figure C), and for sure the most strategic - especially under pandemic circumstances -, sectors of the manufacturing industry.

AI innovation in AgriFood generates AgriTech, the use of technology in agriculture, and FoodTech, the technology innovation along the entire food supply chain. Of course technologies have been adopted in the agrifood sector before the AI revolution, but with AI technology this sector is nowadays experiencing a paradigmatic change. Then how to categorize and understand AI applications for the agrifood sector? First of all we should consider the subsegments separately.

4.2.2 AgriTech technologies

Even if not exposed to the amount of innovation investments of the food supply chain, agriculture is being revolutionised by AI technologies, startups and high-level investments worldwide. Just to mention a couple of cases, in the 2019 Basf invested 900M€ for the development of innovative solutions in agriculture, and the sales for the first half of 2019 of Bayer Agricultural Solutions increased the 38% the ones of the 2018 first half[31].

Relevant factors of agritech innovation are[32]:

- a new generation of farmers able to cope with AI innovation,
- the growing technology,
- efforts for agriculture sustainability,

[30] https://www.ft.com/content/88360cd4-5731-11ea-abe5-8e03987b7b20
[31] https://www.wired.it/economia/business/2019/11/08/basf-agricoltura/
[32] https://agritechtalk.com/2019/01/11/2019-agritech-trends/

- industrial alliances moving agriculture to a digital decentralized business setting.

With high simplification, AI technologies adopted in agritech may be grouped in four categories[33]:

- IoT and Sensors;
- Machine Learning and Analytics;
- Drones Technology;
- Blockchain (with little adoption in agriculture, mostly connected to , mostly used in the food supply chain).

More in detail, agritech technologies may be further understood in detail as part of interconnected the services including AI, specifying the "what" and the "how"[34]:

AGRITECH SERVICES	WHAT	HOW
Internet of Things	Sensor technologies and monitoring solutions integrate into the existing farming process (mechanization) to generate precision data for daily decision-making.	- optimize processes without spending unnecessary resources; - up-to-date information on irrigation equipment, soil moisture, crop growth and fertilizers consumption.
Smart Farming	Also called 3rd Green Revolution, it is a holistic approach to agricultural innovation by adopting and combining smart tech.	- software solutions, optimization devices, and process automation tools to reduce costs; - cloud based software solutions integrate with wireless sensors and IoT to increase yield; - Big Data and AI analysis of data from Drones and Satellites.
Precision Farming	Also called Site Specific Crop Management (SSCM), it adopts satellite or drone imagery to optimize strategies for best crop efficiency.	- uses various data and imagery gathered by satellites/drones to optimize farm management; - multispectral imagery help determine the best fit for crops and terrain types; - multi-year simulation helps to mitigate risks.
Vertical Farming	By adopting controlled environment agriculture, it stacks layers of plants vertically to produce food/medicine in spaces such as shipping containers and rooftops.	- uses sensor solutions and management software to optimize growth environment; - optimal use of space, energy and other resources.
BioTech	Adopting various BioTech, such as gene	- technologies and biological algorithms

[33] http://www.businessworld.in/article/Top-4-Agritech-Trends-To-Watch-In-2019/15-01-2019-166159/
[34] https://www.startus-insights.com/innovators-guide/agritech-innovation-map-reveals-rising-technologies-startups/

	editing and 3D Bioprinting to improve the adaptability of seeds and the fertility of soil.	build crops capable of battling weeds and insects; - soil, brownfield and dredging material remediation; - more effective ways to battle pests.
Big Data and AI	Use sensor-recorded weather conditions, changes in soil structure and crop efficiency, it can optimize almost every aspect of crop management.	- automates suggestions and recommendations to improve efficiency and business operations; - stores information, controls, observes and tracks livestocks and/or crops.
Drones and Satellites	Measure and monitor fields, create terrain maps, control the quality of tillage & sowing works, and provide a large amount of phyto-geo-morphological data for optimal farming management.	- hyperspectral cameras mounted on drones show water and fertilizer use, crop yield, and the emergence of pets; - presents biological parameters of plants or the maps of fertilizer application.

The previous table is incomplete. One of the latest trends in agritech - not adequately considered by the source - is the emerging adoption of the **Blockchain** technology[35,36]. Blockchain is one application of the Distributed Ledger Technology (DLT), an innovation that enables the various cryptocurrencies in circulation today. A DLT is a decentralized system for recording transactions with mechanisms for processing, validating and authorizing transactions that are then recorded on an immutable ledger. For this, Blockchain is extensively under adoption for the traceability of the supply chain, with the first step in agriculture. This technology allows every actor of the supply chain to insert its specific data, starting from soil and production data, with the result that customers will be soon able to reach that certified information in full transparency. "The blockchain technology enables the traceability of information in the food supply chain and thus helps improve food safety. It provides a secure way of storing and managing data, which facilitates the development and use of data-driven innovations for smart farming and smart index-based agriculture insurance."[37]

Another relevant AI technology that is not adequately considered in the previous table are **Farmbots**[38] or **Agribots**[39] or simply **Self-Driving Tractors**[40]: autonomous or semi-autonomous robots applied to agriculture, both in open fields and in greenhouse. Farmbots integrate many technologies with the ability to range in the fields. Robots are generally used in order to reduce the human component of fieldwork, with a growing level of perception and intelligence, constituting a possible revolution for agriculture from the large estate - where farmbots are already well applied - to small plots.

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35 http://www.fao.org/3/CA2906EN/ca2906en.pdf
36 https://www.wired.it/economia/business/2019/11/08/basf-agricoltura/
37 Blockchain Technology for Agriculture: Applications and Rationale, https://www.frontiersin.org/articles/10.3389/fbloc.2020.00007/full
38 https://www.ai4business.it/robotica/i-farmbot-e-la-diffusione-dei-robot-in-agricoltura/
39 https://www.economist.com/science-and-technology/2020/02/06/using-artificial-intelligence-agricultural-robots-are-on-the-rise
40 https://www.forbes.com/sites/lanabandoim/2019/04/27/how-self-driving-tractors-and-ai-are-changing-agriculture/#3f90b8467fa1

Apart of BioTech, that constitutes a specific innovation field, AI conjugates many interconnected technologies, allowing added value services and gathering data from a multiplicity of possible resources:

- **Satellite services**: satellite data for agriculture are one of the many services, providing high level added value, offered by the rapidly growing (with top level investments) satellite sector;
- **Weather services**: apart from satellites, weather data may be offered by weather stations agencies;
- **Drones**: drones with several kind of sensors may be used for providing data;
- **On Tractor devices**: devices with several sensors may be used on tractors for providing data;
- **Robots**: several kind of data may be gathered from robots with sensors;
- **Crop sensors**: sensors may also be installed directly in the field, on plants or stand alone stations.

4.2.3 FoodTech technologies

As anticipated, the food supply chain side after Agriculture is particularly under the interest of investors, and the "AgFunder Agri-FoodTech Investing Report - 2019" shows it in Figure D[41]:

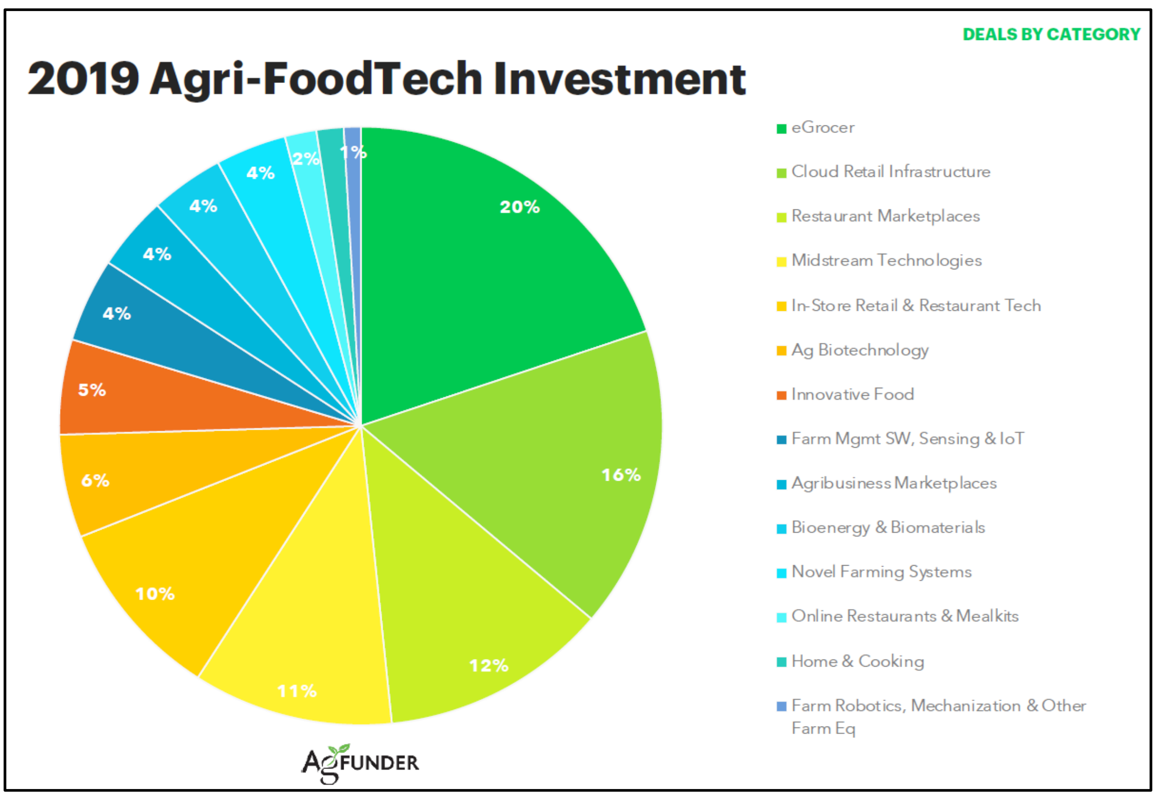

Figure D. Distribution of Agri-FoodTech investments in 2019 (Source: AgFunder)

FoodTech leading services, summarizing the 82% of 2019 AgriFood tech investment, are:

[41] https://agfunder.com/research/agfunder-agrifood-tech-investing-report-2019/

- **eGrocery**: online stores and marketplaces for sale and delivery of processed and unprocessed agricultural products to consumer;
- **Cloud Retain Infrastructure**: on-demand enabling technologies, ghost Kitchens, last minute delivery robots and services;
- **Restaurant Marketplaces**: online tech platforms delivering food from a wide range of vendors;
- **Midstream technologies**: food safety and traceability technologies, logistics and transport, processing tech;
- **In-Store Retail & Restaurant Tech**: self-stacking robots, 3D food printers, POS systems, food waste monitoring IoT;
- **Innovative Food**: cultured meat, novel ingredients, plant-based proteins;
- **Bioenergy and Biomaterials**: non-food extraction & processing, feedstock technology, cannabis pharmaceuticals;
- **Online Restaurants and Meal Kits**: startup offering culinary meals and sending pre-portioned ingredients to cook at home;
- **Home and Cooking tech**: smart kitchen appliances, nutrition technologies, food testing devices.

Beside the hype of online platforms, food delivery and BioTech, under FoodTech innovative services are applied various AI technologies:

- **Machine Learning and Analytics**: for high level food data management connecting marketing and sales, service customization, innovative cooking tools;
- **Robotics**: for food transformation and sale, reducing costs and time;
- **Blockchain**: for transparent certified information from food production to the end of the supply chain.

4.2.4 Best practices in the Agritech domain

As introduced in Section 3.2.1, Agritech is a fast growing sector in AI adoption with relevant investments. Technologies are being adopted and integrated in various ways inside an ecosystem that - not considering policymakers and other relevant stakeholders that could not find place in this reflection - could be described at two levels:

1. **Integrated SERVICES to farmers**: the fast growing offer of agritech integrated services, composed by projects, startups, consolidated companies, multinational companies.
2. **FARMERS adopting and/or integrating services**: the request on the agriculture domain side, composed by an heterogeneous base (by size, crops, …) of entities (from family-based to multinational entities) that find added value investing on AI for their business.

This report will focus on the first level. For approaching the AI services side, it is convenient to go further the services typologies considered in section 2. Business entities offering AI solutions for agriculture do not differentiate themselves only by adopting specific technologies (drones, IoT, analytics, robots …) or offering generic services (precision farming, …), but connecting services to one or more technology, finding a specific value proposition to attach the agritech market.

Following a categorization that takes into account solutions actually on the market answering to farmers' needs, we will consider the specific best practices listed below:

Best practice	Description	Use cases
Analytics and suggestions - with field sensors	Services offering suggestions based on field sensors. No need for tractors or other devices	CropX Arable xFarm
Analytics and suggestions - with tech on tractors	Services offering suggestions based on intelligence and data on tractors. Farmers may prefer to focus on one or more specific AI services, leveraging on tractors as base technology layer for AI devices.	Augmenta Karnott
Analytics and suggestions - with aerial and space tech	Services offering suggestions based on intelligence and gathering data from drones and/or satellites.	Taranis Gamaya Agricolus
One stop shop connected agriculture	Services offering a unique contact point for the farmers' digital needs.	Sencrop
Specialised on water management		WaterBit SWIIM System Vandersat Saturas
High tech tools for specific issues	Innovative tools for solving very specific needs like spot weeds and fruit manipulation.	Xarvio Rootwave Agrobot SabiAgr
Safer products for specific issues	Services offering ecologic and healthier solutions to specific needs.	Indigo AgroSustain
Financial and market services	Services for the supply chain mostly based on blockchain and online platforms	ProducePay NinjaCart

Ecosystems facilitators	Emerging services for helping agriculture ecosystems reach their goals (i.e. on green and climatic issues), based on blockchain and IoT.	SAPIENCE project

Analytics and suggestions - with field sensors

Name: CropX	
Country: Israel	**Web site:** www.cropx.com
Nr. rounds / Total funding: 8 / 22.9M$	**Founded date:** August 2013
Description: CropX develops cloud-based software solutions integrated with wireless sensors, which boost crop yield while saving water and energy. CropX offers an integrated hardware and software system for measuring soil moisture, temperature, and electrical conductivity and sending this data to the cloud where it can be accessed from any mobile or fixed device.	
AI / Technologies / Systems of reference: SW: soil sensors (moisture, temperature, electric conductivity) geo-tagged based on GPS, weather data services, aerial imagery (satellite services), topography maps, soil mapping, hydraulic modules, crop models, user input.	
Success factors: Opened a market with its sensors combined to external services, user friendly, focused on a precise service, present worldwide, good marketing.	
Acquired: CropMetrics on Jan 2020	
Relevance for the x-KIC Digitalized Test Beds project: One of the first and most successful hardware and software agritech solutions based on in-field sensors.	

Name: Arable	
Country: US	**Web site:** www.arable.com/
Nr. rounds / Total funding: 4 / 9.8M$	**Founded date:** 2013
Description: Arable is an agricultural business intelligence solution founded on in-field measurements. It enables data-driven decisions in agriculture and natural resource management with Measurements that Matter. The platform uses machine-learning to continuously update weather forecasts for individual	

fields using in-field observations and weather models. All that data feeds into the startup's platform to provide various insights including yield forecasts.
AI / Technologies / Systems of reference: The IoT station (Arable Mark) multi-sensors (40 kinds of data) and functions: precipitation, evapotranspiration, radiation, plant health, weather, event timing, integrations and accessories (soil moisture probes, wind speed and direction, pressure switch/transducer, …), cellular connectivity.
Success factors: Its user friendly IoT station, focused on a precise service, mostly adopted in the US. The sensor is reputedly the only one on the market that combines weather and plant measurements. Reduction of yield forecast uncertainty from 20% to 5%, good marketing.
Acquisitions: -
Relevance for the x-KIC Digitalized Test Beds project: Very complete and user friendly on-field IoT station, providing Yield forecast.

Name: xFarm	
Country: Italy	**Web site:** xfarm.ag
Nr. rounds / Total funding: 1 / 3M€	**Founded date:** Jan 2017
Description: xFarm is a startup that aims at the digitization of agriculture, providing innovative tools that can support farmers and food supply chain's stakeholders in the management of their companies. Created by farmers and tailored to the agricultural sector, its main focus is on ease of use, intuitiveness and complete adaptability to agricultural realities. The digital ecosystem includes a free agricultural application, available on both mobile and desktop and integrated with advanced premium modules, a dashboard Analytics dedicated to professionals and a line of IoT sensors selected, optimized and connected by xFarm.	
AI / Technologies / Systems of reference: Easy to use mobile app as the center of a system composed of field sensors and analytics with decision support. Precision farming and others (logistics, administration, …) integrated modules.	
Success factors: User friendliness (generated by farmers) and adaptability to farmer needs, specific modules, free app.	
Acquisitions: -	
Relevance for the x-KIC Digitalized Test Beds project: Innovative, user friendly and modular system for precision farming via - mostly - field sensors, looking for completeness.	

Analytics and suggestions - with tech on tractors

Name: Augmenta	
Country: Greece	**Web site:** www.augmenta.ag
Nr. rounds / Total funding: 2 / 3.1M$	**Founded date:** Nov 2016

Description:

Augmenta generates precision agriculture out of farm inputs in real-time, boosting yield, enhancing quality & reducing input spend using deep learning. It uses a robotic system, to assist farmers to accurately fertilize and spray their fields. The system combines a piece of hardware that joins to field equipment and automates the amount and timing of field treatments. By using Augmenta's web platform, the farmer monitors progress from a table. Additionally, it claims that its technology can improve crop yields by up to 12%, enhance crop quality by up to 20% and reduce fertilizer use by 15%.

AI / Technologies / Systems of reference:

Augmenta's "Field Analyzer", is a plug and play smart robotic system that can be attached to any tractor and can determine the amount of fertilizers, fungicides and pesticides that every inch of the farm needs to reach to its full potential, all in real-time. It is capable of controlling agricultural machinery. The farmer can use Augmenta's field-viewer, the company's easy to use web platform, to observe the progression of his field through visual data analytics which help him keep track of the results of Augmenta's real time operation but also assist him on making data-driven, customized decisions for the future, in a farm level scale and not in a generic geographical (county or even state/country) level scale which is the norm today

Success factors:

Created by farmers and engineers experts in AI, plug and play easy-to-use robots on tractors, successful precision farming.

Acquisitions: -

Relevance for the x-KIC Digitalized Test Beds project:

Plug-and-play and easy-to-use precision farming with on-tractors technology.

Name: Karnott	
Country: France	**Web site:** www.karnott.fr
Nr. rounds/Total funding: 2 / 3.6M€	**Founded date:** 2016

Description:

Karnott combines an autonomous connected meter with a simple and innovative application for the monitoring of materials and interventions, mostly used in France.

AI / Technologies / Systems of reference:

Karnott offers a tracking software coupled with a connected device that tracks agricultural equipment. It places an automatic, autonomous, mobile, real-time device in tractors, trailers, or seeders to collect data, and then their software automatically calculates, analyzes, and archives it.
Success factors: Karnott won a Sima Innovation Award in 2018 for meeting the performance needs of the agricultural world. Extremely fast data collection, calculation, analysis and archiviation, generate time savings.
Acquisitions: -
Relevance for the x-KIC Digitalized Test Beds project: Efficient and fast AI technology for tractors.

Analytics and suggestions - with aerial and space tech

Name: Teranis	
Country: Israel	**Web site:** taranis.ag
Nr. rounds / Total funding: 4 / 29.6M$	**Founded date:** May 2014
Description: Taranis is a leading precision agriculture intelligence platform. The system enables farmers to make informed decisions by detecting early symptoms of weeds, uneven emergence, nutrient deficiencies, disease or insect infestations, water damage and machinery problems.	
AI / Technologies / Systems of reference: Teranis uses sophisticated computer vision, data science and deep learning algorithms to effectively monitor fields. Data are gathered from Drones (0.3mm/pixel resolution; Leaf level accuracy;Up to 120mph / 200km/h; Scouting >7000 hectares/day), Airplanes (8cm/pixel resolution), and Satellites (1.2M/pixel resolution).	
Success factors: Overseeing millions of acres of farmland in Argentina, Brazil, Russia, Ukraine and the United States, Taranis gives farmers the tools to address issues in real-time, increasing yields and cutting costs. employs over 100 people worldwide and is headquartered in San Francisco with subsidiaries in Israel, Argentina and Brazil.	
Acquired: Mavrx (imagery agric.) on May 2018	
Relevance for the x-KIC Digitalized Test Beds project: Complete and sophisticated computer vision (sat, planes, drones) for agriculture.	

Name: Gamaya

Country: Switzerland	**Web site:** gamaya.com
Nr. rounds / Total funding: 7 / 20M CHF	**Founded date:** 2014
Description: Gamaya improves efficiency & sustainability of farming by offering compelling agronomy solutions, enabled by hyperspectral imaging and AI. Farmers are then armed with more accurate diagnostics of issues affecting their farms like crop diseases, invasive species and environmental stresses of the land they are farming.	
AI / Technologies / Systems of reference: Gamaya has created a small and light hyperspectral imaging system (HSI) in a camera for drones. HSI is used to collect and process information from the electromagnetic spectrum and lets farmers more easily identify materials, detect processes and find objects, producing a survey of the land.	
Success factors: High level identification of diseases affecting crops, rapidity, no need to touch the field for analysis.	
Acquisitions: -	
Relevance for the x-KIC Digitalized Test Beds project: Efficient use of drones in agriculture.	

Name: Agricolus	
Country: Italy	**Web site:**
Nr. rounds / Total funding: -	**Founded date:** Feb 2017
Description: Agricolus is a cloud applications ecosystem for precision farming with multiple purposes: disease awareness and forecasts, crop monitoring, decision support system for treatments and fertilizers, farm management and end to end traceability bringing valuable information to final users.	
AI / Technologies / Systems of reference: Agricolus is based on satellite images to consult the indices of vigor and water stress of crops. It integrates provisional models, decision support systems, agronomic management systems, traceability and integration with agricultural machinery.	
Success factors: Easy precision farming. The adoption of FIWARE has allowed Agricolus to advance into the market quickly and successfully with a product-ready application. FIWARE - an emerging European framework - can be a valuable way to standardize the adoption of common interfaces for IoT and Big Data analytics.	
Acquisitions: -	

Relevance for the x-KIC Digitalized Test Beds project: Successful and easy precision farming with satellite imagery in South Europe.

One stop shop connected agriculture

Name: SENCROP	
Country: France	**Web site:** sencrop.com
Nr. rounds / Total funding: 2 / 11.5M$	**Founded date:** Jan 2016
Description: Sencrop is an agritech startup that offers an in-field data-based platform to empower farmers to make better decisions in their daily agricultural activities.	
AI / Technologies / Systems of reference: In-field IoT sensors, cloud platform, satellite imagery, provisional models, decision support, agronomic management, traceability and integration with machinery.	
Success factors: Completeness, positioning itself as a unique point of contact for innovative farmers. Highly configurable, modular services with a marketplace. Positioned at the cutting edge of innovation in connected agriculture, Sencrop won the top award for its high-precision agrometeorological station and platform at the 2017 SIMA Innovation Awards ceremony. For every farm size, rich marketing offers.	
Acquired: Visio-Green Agriculture (IoT) on Feb 2020	
Relevance for the x-KIC Digitalized Test Beds project: The first startup looking for - and partially providing - a flexible, modular and complete one-stop-shop for connected agriculture.	

Specialised on Water Management

Name: WaterBit	
Country: US	**Web site:** www.waterbit.com
Nr. rounds / Total funding: 1 / 11.4M$	**Founded date:** May 2015
Description: WaterBit is an automated irrigation solution that enables remote control of local irrigation taking into account growth stage and soil conditions at a level of granularity and accuracy that is not possible with other current methods.	

AI / Technologies / Systems of reference: The key component is Carbon, a ready-to-use solar-powered node that fits in the palm of a hand. It connects to sensors, probes and valves–doing the hard work of collecting and sending data. Data is then sent to the entire farm and to the cloud, allowing remote control and executing irrigation. Configurations, reports and analysis via simple dashboard.
Success factors: Water management with granularity and accuracy level that is not possible with other current methods. Configurability and user-friendliness.
Acquisitions: -
Relevance for the x-KIC Digitalized Test Beds project: Provides specific and high level sensors for water management.

Name: SWIIM System	
Country: US	**Web site:** swiim.com
Nr. rounds / Total funding: 5 / 10.7M$	**Founded date:** Jan 2009
Description: SWIIM System is a software suite and technology system designed to enhance a farm's operation and conserve applied agricultural water while increasing the overall potential income of a farming operation. It enables agricultural water users to optimize water rights, conserve water, and increase net incomes of farm and ranch operations.	
AI / Technologies / Systems of reference: SWIIM includes a comprehensive administration/management tool that - connected to equipment, see success factors below - verifies water use and related conservation against a specified baseline, along with the resulting newly-projected crop production output.	
Success factors: SWIIM is "hardware agnostic" and compatible with many commercially available equipment, including flow meters, gate meters, tail water sensors, climatic sensors, groundwater instrumentation and supporting infrastructure such as weirs, flumes, stilling wells, and similar technologies.	
Acquired: OnFarm on Jun 2018	
Relevance for the x-KIC Digitalized Test Beds project: Water management solution not providing sensors, working with farmers' ones.	

Name: Vandersat

Country: The Netherlands	**Web site:** www.vandersat.com
Nr. rounds / Total funding: 1 / 1.3M€	**Founded date:** 2015
Description: Vandersat observes water data - globally, daily, without cloud obstruction - at field scale across the globe using satellites, providing services for insurance, agriculture and science sectors.	
AI / Technologies / Systems of reference: Satellites monitor soil moisture (water availability), vegetation optical depth (biomass) and land temperature. Data may be integrated in farmers' applications.	
Success factors: Specific geospatial service to be integrated in other ones.	
Acquisitions: -	
Relevance for the x-KIC Digitalized Test Beds project: Specific via satellite services to be integrated in water management systems.	

Name: Saturas	
Country: Israel	**Web site:** saturas-ag.com
Nr. rounds / Total funding:	**Founded date:**
Description: Saturas provide accurate Stem Water Potential systems to monitor water waste. The farmer receives information in an easy-to-read report. The Saturas technology tailors irrigation to real-time needs, resulting in more efficient water use while increasing yields, fruit size, and sugar content (e.g., vineyards).	
AI / Technologies / Systems of reference: Saturas' automatic and miniature Stem Water Potential sensing system collects accurate data using a minimal number of sensors per hectare, and transmits the data to a central control system connected to irrigation controllers for automated irrigation. The Saturas precision agriculture sensing system components: miniature implanted sensors, in-orchard communications and transponders, and control unit.	
Success factors: Most accurate measurement of water status in plants, to be integrated in other water management systems.	
Acquisitions: -	
Relevance for the x-KIC Digitalized Test Beds project:	

Specific and accurate device to detect water waste and help improving production saving money.

High tech tools for specific issues

Name: Xarvio	
Country: Germany	**Web site:** www.xarvio.com/global/en.html
Nr. rounds / Total funding: -	**Founded date:** ('90s)
Description: Xarvio Digital Farming Solutions offers digital products, based on a global leading crop model platform, which delivers independent field-zone-specific agronomic advice enabling farmers to produce their crops most efficiently. Xarvio developed services for agriculture like the "Field Manager", a satellite monitoring system with spray manager. There are other interesting tools by Xarvio (only for winter wheat at May 2020): SCOUTING: simple detection of in-field stress and estimations with a simple photo. HEALTHY FIELDS: Xarvio may decide whether a single, double or a triple strategy will be best to protect fields, enabling a contractor to manage farmer's fields in the best way possible.	
AI / Technologies / Systems of reference: SCOUTING has many functions: identification of multi-weed and in growth stages, diseases recognition, insect monitoring, nutrient estimation, estimation of nr of plants per m^2, leaf damage. HEALTHY FIELDS service is based on millions of data points and models, offering an intelligent monitoring and decision support system.	
Success factors: SCOUTING: simplicity with a smartphone app. HEALTHY FIELDS: specific for the farmer-contractor chain, suggesting Basf trusted contractors if needed.	
Acquired: by Basf Agricultural Solutions in 2018	
Relevance for the x-KIC Digitalized Test Beds project: Very specific and powerful tools for easy-to-manage solutions to solve farmers needs.	

Name: Rootwave	
Country: UK	**Web site:** rootwave.com
Nr. rounds / Total funding: 3 / 9.7M$	**Founded date:** 2012
Description:	

Pesticides and the risks they pose on both the environment and consumers have been a point of discussion in science for years. Rootwave offers a highly innovative product to kill weeds avoiding the use of pesticides. The product eliminates the need for noxious chemicals and is currently aimed at small-scale farmers and gardeners.
AI / Technologies / Systems of reference: Rootwave manufactures a device that zaps weeds from the roots up using an electrical pulse.
Success factors: Very innovative, avoid pesticides.
Acquisitions: -
Relevance for the x-KIC Digitalized Test Beds project: No pesticides needed with an electrical pulsing system.

Name: Agrobot	
Country: Spain	**Web site:** www.agrobot.com
Nr. rounds / Total funding:	**Founded date:** 2009
Description: Agrobot is a start-up company engaged in the business of agricultural robots, specialized in strawberries.	
AI / Technologies / Systems of reference: Agrobot has developed the first pre-commercial agricultural robot for gently harvest strawberries, no matter where and how they are grown.	
Success factors: Strawberry specific automation. Through this innovative approach, Agrobot has managed to align traditional farming culture and cutting-edge technology to face the most pressing difficulties that global primary industry is suffering.	
Acquisitions: -	
Relevance for the x-KIC Digitalized Test Beds project: Strawberry specific automation.	

Name: SabiAgri	
Country: France	**Web site:** www.sabi-agri.com
Nr. rounds / Total funding: ?	**Founded date:** 2017

Description: SabiAgri is a French startup which designs and manufactures electric tractors.
AI / Technologies / Systems of reference: Their flagship product, ALPO, is a robotable electric tractor which performs the same operations as a thermal tractor of comparable power, lasting up to eight hours, with operating costs 6 times cheaper than thermal tractors. Sabi Agri currently offers three versions: Basic, 4×4 and Enjambeur to market gardeners, grape growers, arboriculturists, to simplify their daily operations.
Success factors: Electric tractors with batteries that can last up to eight hours, it recharges in less than two hours, a full charge costs around 1€ (in France). The operating cost is 10 times cheaper than a thermal tractor.
Acquisitions: -
Relevance for the x-KIC Digitalized Test Beds project: Advanced and very convenient electric tractors.

Safer products for specific issues

Name: Indigo AG	
Country: US	**Web site:** www.indigoag.com
Nr. rounds / Total funding: 9 /809M$	**Founded date:** 2014
Description: Indigo believes there is a better, safer way to grow the grains that a large percentage of the world population considers their staple food. They offer an array of agricultural services.	
AI / Technologies / Systems of reference: The most notable services offered by Indigo are technologies focused on microbes that have been helping plants grow healthy for billions of years. Indigo's products offer growers an effective and low-risk means of growing crops, as well as healthy food sources for consumers.	
Success factors: For farmers, the yield benefits help improve grower profitability while increasing the capacity to feed a growing population. For consumers, Indigo makes fundamental changes in how our food is grown: more efficient with water, and reducing the use of nitrogen fertilizer and pesticides over time.	
Acquired: TellusLabs (Sat imagery and Machine learning) on Dec 2018	
Relevance for the x-KIC Digitalized Test Beds project: Successful and innovative bio-technology, microbes helping agriculture.	

Name: AgroSustain	
Country: Switzerland	**Web site:** agrosustain.ch
Nr. rounds / Total funding: 8 / 4.6M$	**Founded date:** 2018
Description: The spin-off from the University of Lausanne has developed a technology that prevents the development of fungal pathogens in fruits and vegetables by up to 80%.	
AI / Technologies / Systems of reference: Their product, AgroShelf+, is an efficient, non-toxic, plant-inspired solution, which is sprayed onto the crop and is able to extend the life of fruit and vegetables by a minimum of one week.	
Success factors: AgTech startup has already won numerous awards and grants in Switzerland and Europe for its solution to fight food waste.	
Acquisitions: -	
Relevance for the x-KIC Digitalized Test Beds project: Natural solutions for food pest management.	

Financial and market services

Name: ProducePay	
Country: US	**Web site:** producepay.com
Nr. rounds / Total funding: 8 / 299.9M$	**Founded date:** 2014
Description: ProducePay provides a wide array of payment solutions to the fresh-produce industry and its agents. Their goal is to help parties involved in agriculture to build networks that will help them expand their business and increase their revenue.	
AI / Technologies / Systems of reference: ProducePay offers comprehensive financial services to growers, shippers, distributors, and marketers. They also offer payment solutions, as well as a one-stop platform where interested parties can find pricing, weather, trend, movement, and seasonal information.	
Success factors: Specific and trusted financial services for the fresh-produce industry.	
Acquisitions: -	

Relevance for the x-KIC Digitalized Test Beds project: High level financial services and payment solutions for producers and the supply chain.

Name: NinjaCart	
Country: India	**Web site:** ninjacart.in
Nr. rounds / Total funding: 10 / 164.2M$	**Founded date:** 2015
Description: NinjaCart aims to solve two problems: the low quality of food in groceries and supermarkets, and the low income that farmers generate from their produce. NinjaCart connects farmers directly with retailers, skipping several steps – and middlemen – along the way. As a result, farmers are able to quickly sell and get up to 20 percent more revenue from their products, while retailers obtain high-quality produce at more competitive prices. The absence of middlemen also means products are now traceable to farmers, which benefits consumers in the long run.	
AI / Technologies / Systems of reference: Supply chain platform.	
Success factors: Shorten the supply chain,	
Acquisitions: -	
Relevance for the x-KIC Digitalized Test Beds project: Shortens the supply chain of fresh food with benefits for farmers, retailers and customers. The India case.	

Ecosystems facilitators

Name: SAPIENCE	
Country: Italy	**Web site:** sapience.fbk.eu
Nr. rounds / Total funding: 1 /	**Founded date:** 2019
Description: SAPIENCE project is a EIT Climate-KIC funded activity aiming to find ways for incentivising sustainable practices in agriculture, actually reflecting on horticulture and vineyards and water management.	
AI / Technologies / Systems of reference: Through the deployment of Internet of Things (IoT) technologies in the fields to monitor agricultural practices, it creates a system that incentivises and rewards virtuous behaviours. For 2020 it focuses on	

efficient and sustainable use of irrigation water between different pilot sites, dedicated to the production of wine and horticultural products. Besides monitoring and actuating purposes, quite common in many agritech use-cases, IoT devices will also serve relevant data to a distributed ledger using blockchain technologies to manage rewards and share profits amongst those farmers whose virtuous behaviour contributed to achieving them.
Success factors: Work-in-progress. It is a promising project, cutting differently the AI in agritech understanding aiming to improve the ecosystems' capacity to solve better and together specific issues.
Acquisitions: -
Relevance for the x-KIC Digitalized Test Beds project: Pioneristic initiative for improving agriculture sustainability by working on its ecosystem with AI.

5. AI adoption in industry 4.0

5.1 Best practices in the Manufacturing domain

Artificial Intelligence has the cards to become the greatest technological revolution in history. AI is a completely new production factor, which will determine an important growth of the business, bringing automation in areas that were the exclusive domain of man, bringing our work to new levels of decision-making ability, and spreading innovation to exponential levels in organizations and beyond.[42]Considering Industry 4.0, AI offers innovative opportunities such as devices and platforms for the design, implementation and certification of production processes, real-time control of robots and drones, autonomous robotic applications, greater-time monitoring of the workplace. AI is proposing solutions to make working environments places where machines are able to work and interact with people more productively that needs new attention for well-being in the company, with forms of artificial intelligence which contribute to the new managerial, co-decision, enhancing cultural and religious diversity. But there is no AI if there is not availability of *big data* related to processes, operations, products, etc., to be processed by advanced analytics methods to improve quality and efficiency of production processes, supply chain management, risk management, prediction models (both in production and in business: prediction of sale volumes, product quality, recall issues, etc.).

Analyzing the status of the deployment of AI potential in manufacturing some features need to be considered, i.e.:

- AI is considered *no-accessible* to all companies because of its high costs and work-organizational changes introduced (technology expenses, necessary changes in workflows, need of workers' digital skills , …). The evolution of AI is demonstrating that it is becoming cheaper and more accessible for all thanks to its diffusion;
- AI permits *rapid, data-drive decisions* allowed also by algorithms more and more efficient and near to the user thanks to the use of low-power devices and cloud/edge solutions;
- AI introduces important and new *cybersecurity open issues* related not only to the IT solutions present in the plant but also to the OT (Operational Technology)[43];
- AI solves, optimizes, improves the efficiency of processes, increasing the availability of time to work on business aspects;
- AI introduces new work paradigms that need to consider Human-Machine interactions as a central issue for increasing collaboration.

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[42] Massimo Morielli, Leonardo Galimberti (2018), *Intelligenza Artificiale: Istruzioni per L'uso,* Accenture Digital in Italia, https://www.accenture.com/it-it/insights/artificial-intelligence/artificial-intelligence-explained-executives

[43] If in IT the traditional CIA parameter on data is emphasized in the order in which the letters of the acronym are reported (Confidentiality-Integrity-Availability), in operational networks (OT) the order is exactly reversed, giving absolute priority to the Availability of data necessary to implement solid and effective event management, as well as in real time. (Igor Serraino, Andrea Maggipinto (2018), *Cybersecurity ai tempi delle Reti OT: come e perché gestire le vulnerabilità di dati e processi nell'interconnessione con reti IT*, ICT Security Magazine - https://www.ictsecuritymagazine.com/articoli/cybersecurity-ai-tempi-delle-reti-ot-come-e-perche-gestire-le-vulnerabilita-di-dati-e-processi-nellinterconnessione-con-reti-it/)

The *McKinsey Global Institute* well summarizes the present role of AI in industry: "Advances in AI technologies will enable the industry to leverage rapid growth in the volume of data to optimize processes in real time. They can shorten development cycles, improve engineering efficiency, prevent faults, increase safety by automating risky activities, reduce inventory costs with better supply and demand planning, and increase revenue with better sales lead identification and price optimization."[44]

[44] McKinsey Global Institute (2017), *Discussion paper: ARTIFICIAL INTELLIGENCETHE NEXT DIGITAL FRONTIER?,* McKinsey & Company, p.24

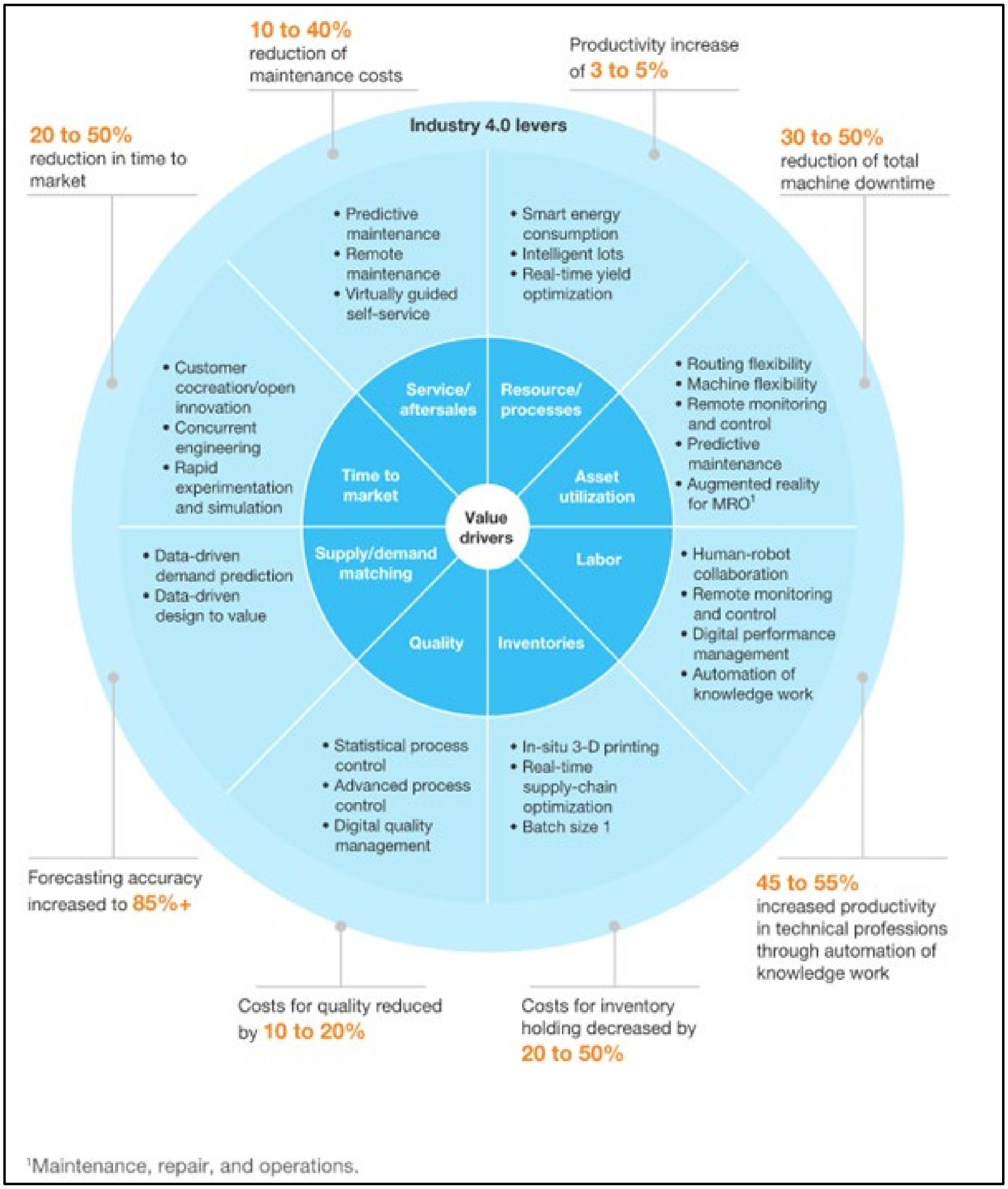

Figure E. Digitalization in industry 4.0: value drivers, functions and benefits (McKinsey 2015)[45]

The same Company identifies value drivers, functions, and benefits of digitalization in industry 4.0, as represented in Figure E. AI – in analogy with what is happening with Industry 4.0 - is applied in manufacturing in various areas, well identified by the value drivers represented by McKinsey, i.e.:

[45] Paul-Louis Caylar, Kedar Naik, and Olivier Noterdaeme (2016), *Digital in industry: From buzzword to value creation*, McKinsey - https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/digital-in-industry-from-buzzword-to-value-creation

Resource/processes, Asset utilization, Labor, Inventories, Quality, Supply/demand matching, Time to Market, Service/post-sales. Working on these areas mean offering various functionalities to improve production and work. Various studies collect and analyses use cases of AI in industry categorize them considering these functionalities.

IoT Analytics in their recent Industrial AI Market Report 2020-2025 has grouped the 33 use cases employing AI tools and techniques on (predominantly) IoT-connected data sources and assets of industrial enterprises into 10 broader use case categories which make up the majority of the almost $15B Industrial AI market in 2019 (Figure F)[46].

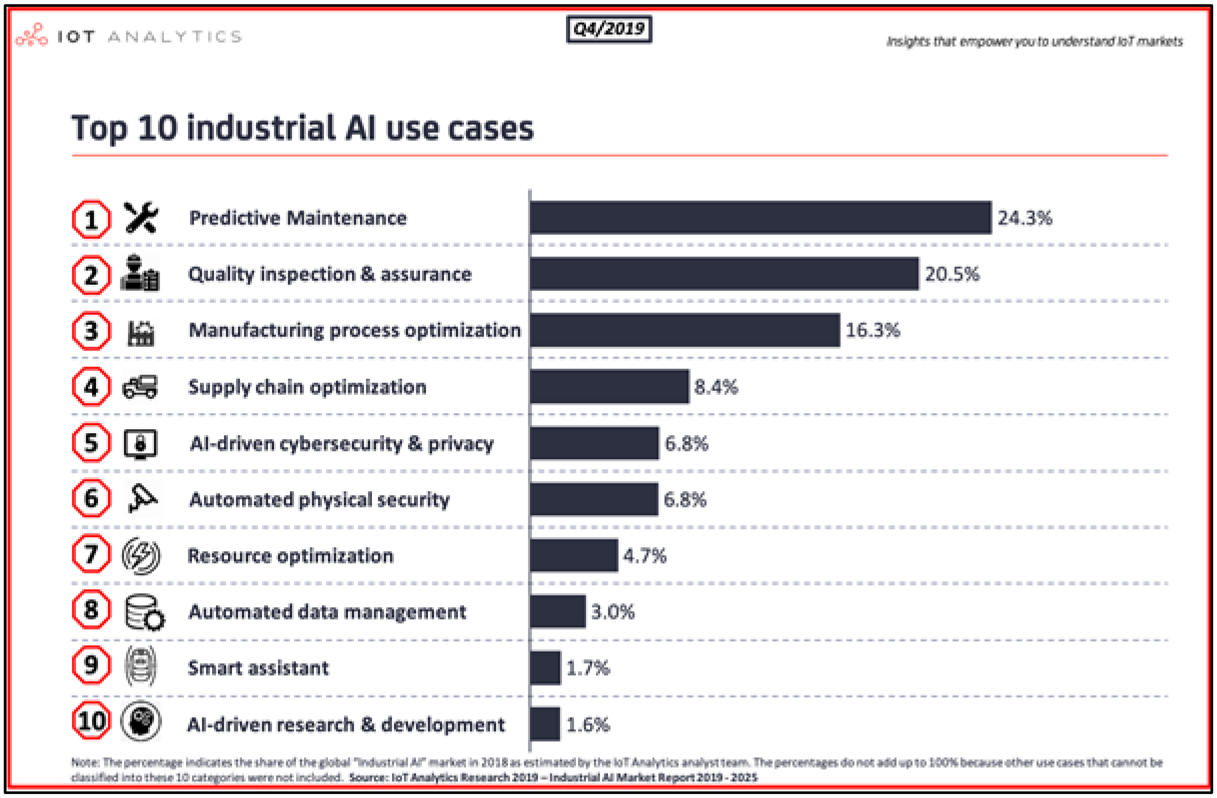

Figure F. IoT Analytics – Top 10 industrial AI use cases

Considering the Italian context, the *Artificial Intelligence Observatory of School of Management of the Milan Polytechnic*[47] analyzed 721 companies and mapped 469 AI use cases, referable to 337 international and Italian companies. To take the photograph, 8 classes of solutions have been identified, very heterogeneous among them, within which the analyzed cases have been placed, highlighting that the projects we are talking about most are not necessarily those to which companies invest the most investments.[48] These categories are: Autonomous Vehicle, Autonomous Robot, Intelligent Object, Virtual Assistant e Chatbot,

[46] IoT Analytics (2019), *The Top 10 Industrial AI use cases*, https://iot-analytics.com/the-top-10-industrial-ai-use-cases/
[47] https://www.osservatori.net/it_it/osservatori/artificial-intelligence
[48] Manuela Gianni (2020), *AI, cos'è l'intelligenza artificiale e come può aiutare le imprese*, Digital4Executive, NetworkDigital360 - https://www.digital4.biz/executive/ai-cos-e-l-intelligenza-artificiale-e-come-puo-aiutare-le-imprese/

Recommendation, Image Processing, Language Processing, Intelligent Data Processing. *Giovanni Miragliotta* [49] – presenting the analysis of the Italian industrial context of Industrial IoT & Artificial Intelligence[50] – identified application scenarios such as: Production tracking, Materials handling, Energy Management, Quality control, Predictive maintenance, Workers safety, Smart Lifecycle.

As reported, various are the classifications to analyze the status, use cases and possible best practices of the implementation and deployment of AI solutions in manufacturing. Combining these different approaches and considering FBK expertise, the present study will consider the following categories:

1. Predictive maintenance
2. Business processes – Supply Chain
3. Production and Quality Control
4. Robotics and production
5. Digital Twin

Predictive maintenance

“The largest use case for industrial AI is “*Predictive Maintenance*” (estimated to make up over 24% of the total market in 2018). Predictive Maintenance makes use of advanced analytics (e.g., Machine Learning) to determine the condition of a single asset or an entire set of assets (e.g., a factory). The goal: Predict when maintenance should be performed. Predictive maintenance usually combines various sensor readings, sometimes external data sources, and performs predictive analytics on thousands of logged events. Predicting the remaining useful life of an asset using supervised ML is the most common technique in Predictive maintenance.“[51]

Another interesting and complete definition is: “*Predictive maintenance: the power of machine learning to detect anomalies*. Deep learning’s capacity to analyze very large amounts of high dimensional data can take existing preventive maintenance systems to a new level. Layering in additional data, such as audio and image data, from other sensors—including relatively cheap ones such as microphones and cameras—neural networks can enhance and possibly replace more traditional methods. AI’s ability to predict failures and allow planned interventions can be used to reduce downtime and operating costs while improving production yield. For example, AI can extend the life of a cargo plane beyond what is possible using traditional analytic techniques by combining plane model data, maintenance history, IoT sensor data such as anomaly detection on engine vibration data, and images and video of engine condition.”[52]

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[49] Giovanni Miragliotta is Professor of Advanced Supply Chain Planning at Politecnico di Milano and Senior director at Osservatori.net.

[50] https://www.este.it/images/Presentazioni-Relatori/2019/Presentazione_Giovanni_Miragliotta_Poli_Mi_FabbricaBrescia.pdf

[51] IoT Analytics (2019), *The Top 10 Industrial AI use cases*, https://iot-analytics.com/the-top-10-industrial-ai-use-cases/

[52] Michael Chui, James Manyika, Mehdi Miremadi, Nicolaus Henke, Rita Chung, Pieter Nel, and Sankalp Malhotra (2018), *Notes from the AI frontier: Applications and value of deep learning*, Mckinsey Globa Institute, Discussion Paper,

The realization of a data-driven maintenance enables the transformation of maintenance in manufacturing from reactive to preventive maintenance powered by AI enabled predictive capability, driving the regime towards enhanced uptime reducing downtime via different possibilities, among which they can be mentioned:

- "Real-Time Alert of Wear, Tear, Fault, or Breakdown - Warning signals of potential breakdown by AI, it could even look ahead for fatigue;
- Lifetime Prediction: Using AI to accurately predict Time to Live for Assets like Machinery improving overall life of machinery and assets;
- AI to enable more informed asset maintenance schedule triggering a focused repair and MRO schedule optimizing overall effort, cost, and quality across assets."[53]

The main <u>*technologies*</u> used in Predictive maintenance are the ones related to *IoT* to enable real-time information feed to AI engines. Applying sensors in an industrial setting often termed as *IIOT* Industrial IOT. *Could and edge computing* supporting IoT in the efficiency of the proposed solution, offering data elaboration close to the machines. *Machine learning and cognitive computing* supporting all the data processing.

Main <u>*systems*</u> realized in Predictive Maintenance solutions are:

- Adaptive and Autonomous Systems,
- Advanced Perception Systems,
- Diagnostic and Predictive Systems

<u>*Use cases:*</u>

Title: Predictive maintenance in Nissan	
Type of project: Industrial	**Web site:** https://www.impomag.com/maintenance/article/13245332/how-ai-can-fill-maintenance-skills-gaps-boost-productivity https://info.senseye.io/nissan-case-study https://iot-analytics.com/the-top-10-industrial-ai-use-cases/
Owner: Nissan, Senseye	
Description: Nissan runs an AI Predictive maintenance platform to do RUL prognostication on 7,500 assets. The company claims an unplanned downtime reduction of 50% and a payback period of < 3 months. Nissan scaled the solution from 20 critical assets to thousands without increasing the workload of the on-site PdM team	
AI / Technologies / Systems of reference:	

Aoril 17 2018, https://www.mckinsey.com/featured-insights/artificial-intelligence/notes-from-the-ai-frontier-applications-and-value-of-deep-learning

[53] Mahesh Kumar (2019), The Role of Artificial Intelligence in Manufacturing: 15 High Impact AI Use Cases, posted on https://www.datasciencecentral.com/profiles/blogs/the-role-of-artificial-intelligence-in-manufacturing-15-high on February 25, 2019

AI Predictive maintenance platform
Relevance for the x-KIC Digitalized Test Beds project: Interesting and successful case of predictive maintenance.

Title: Predictive maintenance in Nissan	
Type of project: Industrial	**Web site:** https://www.bestpractice.ai/studies/deutsche_bahn_reduces_maintenance_cost_by_25_and_delay_causing_failures_using_machine_learning# https://iot-analytics.com/the-top-10-industrial-ai-use-cases/
Owner: Deutsche Bahn, Konux	
Description: Deutsche Bahn leverages smart sensor and advanced machine learning analytics from Konux to reduce maintenance costs and avoid infrastructure failure. With predictive maintenance, the rail network company has achieved a cost reduction of 25%, through minimisation of downtime and maximisation of performance.	
AI / Technologies / Systems of reference: Smart sensor and advanced machine learning analytic	
Relevance for the x-KIC Digitalized Test Beds project: Interesting and successful case of predictive maintenance.	

Business processes – Supply Chain

AI can support industry in various *business processes* at various levels of operativity (supply chain management, risk management, price forecast, customer care and services, customization of product and offer, etc.), but "8% of all industrial AI implementations are improvements to industrial *supply chains*. Using AI tools to improve inventory management is one of the key applications. Predictive inventory management leverages predictive analytics for a variety of inventory-related tasks including to reduce inventory planning time, minimize inventory cost, optimize repairments, and find optimal reorder points. For these tasks, techniques such as time-series analysis, probabilistic modeling (Markov and Bayesian models) as well as simulations (e.g., Monte-Carlo simulation) are most commonly used."[54]

The overall manufacturing industry is heavily dependent upon the accompanying supply chain effectiveness for overall productivity and efficiency. AI combined with IOT has tremendous potential. Some identifiable use cases are as below:

- "Real-time tracking of supply vehicles helps in better utilization of logistics fleet thereby optimizing overall production schedule

[54] IoT Analytics (2019), *The Top 10 Industrial AI use cases*, https://iot-analytics.com/the-top-10-industrial-ai-use-cases/

- Better data-driven AI-based approach to analyzing inventory and thereby using it to lower inventory costs can be a great cost saver for manufacturers.
- Shipping and Delivery Lead Time can not only be accurately predicted, but it is also optimized via application of AI algorithm."[55]

The main *technologies* used are the ones related to the elaboration of big data to better organize processes, analyze customer satisfaction and expectations. Cognitive computing are the most used ones.

Main *systems* realized are:

- Adaptive and Autonomous Systems,
- Advanced Perception Systems,
- Predictive Systems

Use cases:

Title: Continental Supply chain optimization	
Type of project: commercial solution	**Web site:** https://www.continental.com/resource/blob/134300/88a8628fbd62e465f5306b90c93c8dd6/the-seamless-supply-chain-data.pdf
Owner: Continental	
Description: Continental has built software to predict the optimal points for tire changes on its fleet. The underlying model predicts the overall running mileage and compares it to the baseline, to generate actions. By that, Continental is reducing its stock of tires, also improving safety on the road. IBM developed the technological solution.	
AI / Technologies / Systems of reference: Predictive Systems	
Relevance for the x-KIC Digitalized Test Beds project: Interesting and successful case of internal organization.	

Title: Retailers' shopper analysis	
Type of project: analysis	**Web site:** https://www.mckinsey.com/~/media/mckinsey/industries/advanced%20electronics/our%20insights/how%20artificial%20intelligence%20can%20deliver%20real%20value%20to%20companies/mgi-artificial-intelligence-discussion-paper.ashx

[55] Mahesh Kumar (2019), The Role of Artificial Intelligence in Manufacturing: 15 High Impact AI Use Cases, posted on https://www.datasciencecentral.com/profiles/blogs/the-role-of-artificial-intelligence-in-manufacturing-15-high on February 25, 2019

Owner: MCKinsey
Description: use of AI in retailers' activities: • to improve its earnings before interest and taxes (EBIT) by 1-2 % by using a machine learning algorithm to anticipate fruit and vegetable sales. The company automatically orders more produce based on this forecast to maximize turnover and minimize waste: • to cut surplus stock by 20 % and reduced product returns by more than two million items a year, using deep learning to analyze billions of transactions and predict what customers will buy before they place an order; • to predict future store performance when expanding their physical footprints; • autonomous robots can work alongside people to increase productivity and reduce injuries; • to optimize merchandising, with opportunities to improve assortment efficiency by 50 %; • to reach hyperconnected consumers who continuously redefine value by comparing prices online—even, and particularly, when browsing in a non-digital store; • to optimize, update, and tailor it to each shopper in real time; • to enhance user experience is the area that offers probably the most futuristic perspectives for AI in retail.
AI / Technologies / Systems of reference: Various
Relevance for the x-KIC Digitalized Test Beds project: Combination of various technologies and systems to improve the customer experience and optimising retailer work.

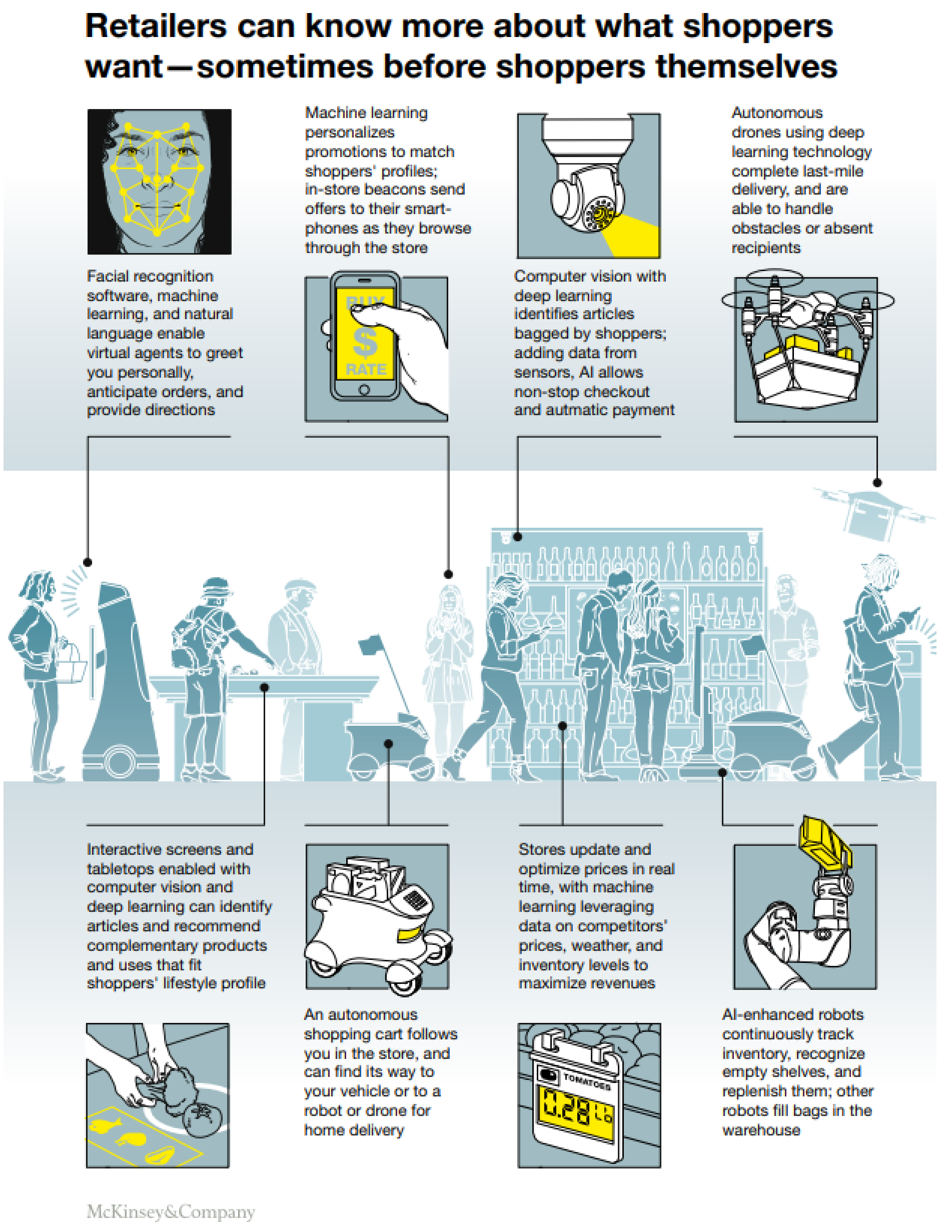

Figure G. Possible use of AI in retailer activities[56]

Title: KAOS - Knowledge-Aware Operational Support	
Type of project: funded project	**Web site:** http://kaos.inf.unibz.it/
Owner: Interregional Project Network (IPN) funded by the European Region Tyrol-South Tyrol-Trentino (EGTC) through the Euregio Science Fund	

[56] McKinsey Global Institute (2017), *Discussion paper: ARTIFICIAL INTELLIGENCETHE NEXT DIGITAL FRONTIER?,* McKinsey & Company, p.42

Description: The main goal of the *KAOS: Knowledge-Aware Operational Support* project is to overcome issues by empowering Operational Support (OS) with domain knowledge. In particular, KAOS will develop a foundational framework of concepts covering organizations, processes, participants and information as relevant for Knowledge-empowered OS (KOS).
AI / Technologies / Systems of reference: Business Process Management (BPM)
Relevance for the x-KIC Digitalized Test Beds project: Interesting example of use of Business Process Management (BPM) combined with digital technologies.

Production and Quality Control

"Quality inspection and quality assurance is the second largest industrial AI use case category at 20.5%. While there are various ways to do AI-based quality inspection, automated optical inspection is by far the largest sub-category. [...] The main benefit of this use case is cost reduction, and the main potential beneficiaries are large manufacturing facilities, where a small reduction in scrap or test time can yield very large savings."[57]

Several data-driven solutions are now becoming mainstream in manufacturing processes to be used for certification, product quality check and flaw avoiding. Some identifiable use cases are as below:

- "Quality process improvement. AI can enable understand limitations, shortcomings, or deficiencies of current as manufacturing quality processes and using AI applied on quality data several improvement opportunities can be harnessed.
- Using complex AI like computer vision to explore defects in produced items can be a great way to ensure product quality."[58]

The main *technologies* used are the ones related to the monitoring of production processes both with sensors and IoT technologies, and with computer vision. These technologies allow optical and not only inspection, testing catastrophic failure (e.g. missing component) and/or quality defects (e.g. fillet size or shape or component skew). Edge and cloud computing supporting data collection and elaboration using machine learning and cognitive computing technologies.

Main *systems* realized are:

- Advanced Perception Systems,
- Safety-Critical Systems

[57] IoT Analytics (2019), *The Top 10 Industrial AI use cases*, https://iot-analytics.com/the-top-10-industrial-ai-use-cases/

[58] Mahesh Kumar (2019), The Role of Artificial Intelligence in Manufacturing: 15 High Impact AI Use Cases, posted on https://www.datasciencecentral.com/profiles/blogs/the-role-of-artificial-intelligence-in-manufacturing-15-high on February 25, 2019

Use cases:

Title: ViPAS - Visual inspection assistant	
Type of project: industrial	**Web site:** https://www.bosch.com/research/know-how/success-stories/vipas-ai-in-automated-optical-inspection/
Owner: Bosch	
Description: In industrial manufacturing, product quality control is essential in order to fulfill the highest quality demands of customers. Automated production lines accomplish this in part with highly customized optical inspection systems. Such systems usually comprise cameras that capture images of parts to be checked and a task-specific software for automatically detecting defects on those products. Automated inspection is nothing new, but in a digital age, the flexibility of automation is reaching new heights.	
AI / Technologies / Systems of reference: Automated optical inspection systems	
Relevance for the x-KIC Digitalized Test Beds project: After implementing optical inspection on one of its plants, BOSCH claimed to achieve $1.3M savings due to 45% of total test time reduction.	

Robotics and production

"Perhaps the most obvious but still one of the most difficult to implement AI use cases is automated manufacturing process optimization. One implementation of this optimization is through Autonomous machines or robots. The idea behind those autonomous assets is that they replicate monotonous human tasks in the manufacturing process, thus saving costs. Before being put into production, the autonomous machines/robots perform the same task over and over again, learning each time until they achieve sufficient accuracy. The reinforcement learning technique is often used to train robots and autonomous machinery. Under this technique, a robot can relatively quickly teach itself to do a task under the supervision of a human. The "brains" of such a robot/machine are usually neural networks."[59]

While currently, robots are quite mainstream in automating manufacturing shop floors presence of AI can enhance the role of robots by better task handling. Some identifiable use cases are as below:

- "Enhanced effectiveness of robots in form of powerful software to enable robots to take on complex tasks. Not just complexity but also the versatility of tasks enhanced by AI.

[59] IoT Analytics (2019), *The Top 10 Industrial AI use cases*, https://iot-analytics.com/the-top-10-industrial-ai-use-cases/

- Role of AI in better human-robot interaction to enable more effective utilization of robots is key. Cobots are emerging as potential enablers in this area."[60]

Robotics uses a wide range of *technologies*: vision, sound, touch and perception technologies, sensors, IoT. These technologies allow robots to move and work on production. Edge and cloud computing supporting data collection and elaboration using machine learning and cognitive computing technologies.

Main *systems* realized are:

- Safety-Critical Systems
- Adaptive and Autonomous Systems
- Advanced Perception Systems
- Diagnostic and Predictive Systems

Use cases:

Title: ABB Digital factory of the future in Shanghai	
Type of project: industrial	**Web site:** https://new.abb.com/news/detail/56130/digital-factory-of-the-future-in-shanghai
Owner: ABB	
Description: ABB is investing $150M to build an "advanced, automated and flexible" robotics factory in Shanghai. In this plant, ABB will manufacture robots using robots. According to ABB, these robots will have autonomous and collaborative elements. The robots' autonomy is built with the use of AI and digital twin	
AI / Technologies / Systems of reference: AI and digital twin	
Relevance for the x-KIC Digitalized Test Beds project: One of the most advanced use of robotics in factory	

Digital Twin

Digital twins are virtual representation of factors/products/services and their physical attributes in the real world using sensors, cameras and other data collection and elaboration methods to predict behaviors. They are used in manufacturing to simulate various production processes.

"Since digital twins can give a real-time view of what's happening with equipment or other physical assets, they have been very helpful in manufacturing to reduce maintenance issues and ensure optimal production

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[60] Mahesh Kumar (2019), The Role of Artificial Intelligence in Manufacturing: 15 High Impact AI Use Cases, posted on https://www.datasciencecentral.com/profiles/blogs/the-role-of-artificial-intelligence-in-manufacturing-15-high on February 25, 2019

output. Chevron expects to save millions of dollars in maintenance costs from the digital twin technology they will have deployed on equipment by 2024 in oil fields and refineries."[61]

A recent initiative spanning several sectors of manufacturing is the idea of digital twin where there is an equivalent mapped equivalent of a process in reality. Some identifiable use cases are as below:

- "Idea of such a digital twin is to understand and simulate how the process flows occur and identify what if scenarios via AI. AI thus enables the realization of potential implications of the process.
- Exception Management: In conventional workflows, exceptions are usually routed to humans to take care of the same. In an AI wired process such processes could be automated and straight through actions could be taken by programs rather than humans.
- Testing of design and manufacturing feasibility of items can be carried out intelligent simulations."[62]

Technologies used are the ones related to IoT and for collecting data, cloud/edge computing to transmit and collect data, machine learning/cognitive computing to elaborate data. 5G – as in many cases of working on manufacturing – is not so necessary working into plants without many data exchange outwards.

Main *systems* realized are:

- Safety-Critical Systems
- Adaptive and Autonomous Systems
- Advanced Perception Systems
- Diagnostic and Predictive Systems

Use cases:

Title: POLARIS	
Type of project: industrial	**Web site:** https://www.ptc.com/en/windchill-blog/digital-transformation-making-industrial-innovation-reality
Owner: POLARIS	
Description: Polaris leverages its design data as part of a broader digital thread with feedback loops throughout the manufacturing process and product life-cycle. This real-world customer and	

[61] Bernard Marr (2019), *7 Amazing Examples of Digital Twin Technology In Practice*, https://www.forbes.com/sites/bernardmarr/2019/04/23/7-amazing-examples-of-digital-twin-technology-in-practice/#77f6cbf16443 on April 23 2019

[62] Mahesh Kumar (2019), The Role of Artificial Intelligence in Manufacturing: 15 High Impact AI Use Cases, posted on https://www.datasciencecentral.com/profiles/blogs/the-role-of-artificial-intelligence-in-manufacturing-15-high on February 25, 2019

performance data bolsters a product lens of Polaris' vehicles while enabling the manufacturer to utilize cutting-edge design capabilities such as simulation and additive manufacturing.
AI / Technologies / Systems of reference: Digital Product Traceability Product Design Optimization Usage-Based Requirements
Relevance for the x-KIC Digitalized Test Beds project: Reducing design and validation process time hastens time-to-market for new products. Better customer experience through improved product performance and fit to customer requirements.

Title: Volvo Virtual Twin Plant	
Type of project: EC project	**Web site:** https://www.volvogroup.com/en-en/news/2017/mar/virtual-twin-plant-shorten-lead-times.html https://entoc.eu/
Owner: Volvo Group Cab Plant in Umeå collaborating with, the Simulation Company Algoryx, the Components Company Schneider Electric and Chalmers University of Technology	
Description: Volvo created a virtual twin factory to significantly shorten lead times to market. With a digital twin of their factory, they can test "the entire functionality in product quality, resource use, maintenance, process stability and cost."	
AI / Technologies / Systems of reference: The approach involves development of extensions on existing engineering tools (like CAD, ECAD and control programming tools), simulation tools and the development of server-based model distribution systems.	
Relevance for the x-KIC Digitalized Test Beds project: An example of digital twin used for the whole production process.	

6. AI implementation gaps

Several are the studies that analyze the gaps to be faced in the implementation of Artificial Intelligence in industry and agrifood.

In general – as reminded by *Accenture* in a recent study[63] - it is therefore advisable to start the adventure in the world of AI with a clear vision of what risks it could pose for a company. Those to be considered immediately concern the following four areas:

1. **Confidence**. How do we prove to the public that AI is safe? How do we avoid the prejudices, unconscious or not, that have been there since the beginning?
2. **Responsibility**. What happens when an AI makes a mistake or breaks the law? Who is legally responsible?
3. **Security**. How can we prevent unauthorized or malicious manipulation of an AI?
4. **Control**. What happens when a machine takes control of a process? How does man regain possession of it, if he needs it?

McKinsey&Company - analyzing the first results in Industry 4.064 - represented in the following Figure the barriers met by companies in implementing Industry 4.0. Barriers met by six out of ten in 2016. These implementation barriers are very similar to the same that industries are now facing in implementing Artificial Intelligence solutions.

[63] Massimo Morielli, Leonardo Galimberti (2018), *Intelligenza Artificiale: Istruzioni per L'uso,* Accenture Digital in Italia, https://www.accenture.com/it-it/insights/artificial-intelligence/artificial-intelligence-explained-executives

[64] McKinsey&Company (2016), *Industry 4.0 after the initial hype Where manufacturers are finding value and how they can best capture it*, McKinsey Digital, https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/getting%20the%20most%20out%20of%20industry%204%200/mckinsey_industry_40_2016.ashx

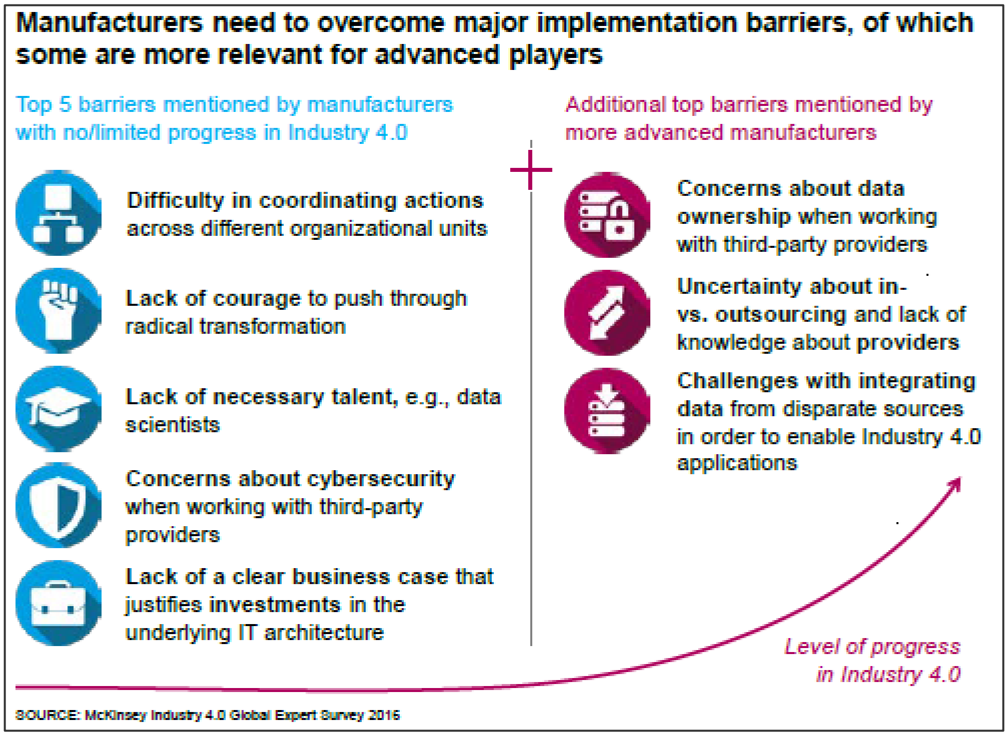

Figure H. Industry 4.0 implementation gap

A recent Forbes Insights survey of 313 executives from both medium- and large-sized companies highligts "a strange paradox surrounding the feverish embrace of artificial intelligence in recent years: The vast majority of companies talk a big game, but when it comes to putting AI into practice, most are still sitting on the sidelines. […], nearly 90% of executives say AI is either important or very important to the future of their company, yet just 25% have adopted AI into their business plans and processes."[65] Main challenges identified in this study to successfully implementing AI in the company are:

"1. Building a Talent Pipeline One key finding from the Forbes Insights survey is that executives see assembling a team of skilled talent as a major challenge to implementing a robust AI strategy. And for many of them, it's not just an IT staffing problem, but also a company-wide issue. […]

2. Managing Data Another major challenge to AI adoption is data management, which 60% of executives in the Forbes Insights survey say is an obstacle. […] Data governance, data cleaning, the difficulties of integrating datasets when your company acquires or merges with another firm—these are all crucial factors executives must consider in formulating a forward-thinking AI strategy.

3. Insourcing vs. Outsourcing When it comes to strategizing around AI, companies are faced with a stark choice: to invest in outside expertise or internal solutions? Many executives seeking to build out their companies' AI capabilities are looking outward, partnering with third-party vendors with huge AI talent pools and expertise, the Forbes Insights survey reveals. Between one third and one half of executives say

[65] Forbes Insight (2018), *Closing the Corporate Gap On AI,* Insights Team Insights Contributor, Intel AI, FORBES INSIGHTS Paid Program, https://www.forbes.com/sites/insights-intelai/2018/09/21/closing-the-corporate-gap-on-ai/#38b03b276034

their companies are currently partnering with Google, Facebook and other tech giants in their initial forays into AI adoption. Partnering with an outside vendor, rather than building up an internal AI team through direct hiring or retraining, can have obvious short-term benefits: Your company enjoys fast access to a robust talent pool as well as cutting-edge innovations. But is that kind of partnering a sustainable long-term strategy? Some companies, particularly larger ones, are pursuing another path: acquisition."[66]

A Deloitte survey on AI adoption in manufacturing in China, 2019[67] highlights that the 91% of the AI projects failed to meet expectations, and that the delta between expectations and implementation is due to:

- **Obstacles from EXISTING EXPERIENCE and ORGANIZATIONAL STRUCTURE**: the inertia of the existing patterns, embedded in employees experiences and organizational structure, limitates the innovation process.
- **INFRASTRUCTURE limitations**: most AI innovations require high level - or reformulated - infrastructures and this change strongly impacts on innovation plans.
- **DATA collection and quality**: even with qualified infrastructures and complete automation equipment, often the data collected or data utilisation do not provide key information.
- **Lack of ENGINEERING EXPERIENCE**: some AI innovations require engineering experience inside companies in order to adequately plan, managing SW and HW resources, and create reliable products.
- **Excessively large scale and COMPLEXITY**: AI is more applicable to specific concrete problems, while large projects often involve multiple factors and decisions that are beyond the capabilities of AI at the current stage.

The "Research for AGRI Committee - Impacts of the digital economy on the food chain and the CAP", 2019, requested by the European Parliament's Committee on Agriculture and Rural Development, focuses on the agrifood sector identifying the main accelerators as positive pushing factors for adaptation with new technologies[68]:

- "**The COSTUMERS' changing preferences and their request** for access to more information concerning food products.
- **The presence of well-developed INFRASTRUCTURE (broadband networks) and support by legislation** that encourage use and uptake of new technologies.
- **DATA availability and open access to information** to facilitate the development of new products, services and business models across the entire value chain.

[66] Ibidem
[67] https://www2.deloitte.com/cn/en/pages/consumer-industrial-products/articles/ai-manufacturing-application-survey.html
[68] https://www.europarl.europa.eu/RegData/etudes/STUD/2019/629192/IPOL_STU(2019)629192_EN.pdf

- **Enough INVESTMENTS IN RESEARCH AND DEVELOPMENT** to support technology advancements in the agricultural sector in Europe."

This perspective on agrifood in the EU, compared to the previous detection of AI application gaps in the manufacturing sector in China, highlights how AI adoption issues may be understood differently. Costumers and their market push potential are identified, the adequate legislation support on infrastructures is underlined, open-access information of data is well identified, and finally adequate investments in R&D is required.

Considering the vastity of AI adoption examples in the manufacturing and agritech sectors, and also the large number of reflections on technological innovation in the production and transformation sectors, <u>some specific factors may be highlighted as implementation gaps</u>:

- **RELATIONAL: human-machine new relationship.** Every technological revolution challenges in practice the consolidated relationship between humans and machines and its understanding. Optimists and pessimists visions are rapidly generated with claims regarding risks and opportunities in terms of power, control, etc. with experts trying to understand the present and predict the future. In any case also the AI adoption in the manufacturing sector has the characteristics of a black-box with its opacity (it is hard to see what itr is and what it generates immediately) involving trust complications (on the technical infrastructure, on the ability of the humans to manage it, on possible side effects…). The new relationship between the two core production resources needs time to be understood in every practical situation of AI adoption, while in some cases it may be problematic and in others no. This adoption should be understood as a trajectory to be accurately monitored to generate knowledge and trust.

- **LABOUR CHANGE: skill gap and digital divide, job changes, etc.** A specific dimension of the human-machine relational factor is the set of possible effects on labour. Workers skills, capacities and in general the work structuration are challenged in many possible ways: new characteristics are required, new attentions are needed, the ability to cope with new technologies and a renewed organizational life are often welcomed. This may generate also stress at the many work levels, and this may corrode the innovation process. Also here, management should take care of workers issues and of possible processes (training) and the needed time to successfully apply AI in manufacturing.

- **SPECIFICITY: concrete needs, resources and tailoring adoption.** As results evident from the former factors, there is not an easy-to-go model to adopt AI in manufacturing. There may be simplified services created in order to facilitate the firm side, but plug-and-play is the kind of narrative that should be looked at with suspictuness. In any case the manager interested in driving a small/big organization in the 4.0 era should deeply understand the concrete needs, considering the resources already presents and the new one needed, trying to specifically tailor the adoption of AI technologies and services leveraging on a solid plan. Small trials and experimentations may be strategic to better figure out the next steps reducing the risk.

- **DATA: internal data management and cybersecurity issues.** AI involves the generation of large quantities of data, and in the manufacturing sector (especially in agritech) many firms are not used to data management. Data needs to be accurately managed, from the gathering to the use, visualization sides, also considering the possible need to use data outside the organization in the value chain, and - finally - the cybersecurity side needs to be accurately considered. Bad data management is highly risky and managers may be worried when reflecting on the necessary resources to adequately manage AI data. Specific competences may be required inside the organization or an external consultant may be needed. Some AI services are comprehensives of some levels of external data management (cloud, security, visualization tricks, …), simplifying it on the organizational side.

- INTERORGANIZATIONAL CHANGE: disruptive changes in value chains and business models. Introducing AI innovation in an organization may affect the interorganizational side, depending on the kind of relationships ongoing. In many cases this may positively influence the entire value chain, if the innovation provides new resources for its improvement and the value chain agrees to follow that change. This is the case of blockchain applied to the value chain for trust and quality improvements, but the positive effects should not be taken for granted. Managers may have solid reasons for considering certain AI innovation as risky for the interorganizational dimension, in any case also this dimension should be adequately considered when reflecting and planning new business models in 4.0 mode.

- INNOVATIVENESS: mindset, digital transformation, green deal. Changes are reasonably taken by owners and/or managers with a clear vision and capacity. Like for general digitalization, introducing new technologies is first of all a challenge for the decision makers and who should monitor and manage an organization. AI may be introduced for reducing costs, following the green deal - which consists itself of an innovative idea -, surviving in a rapidly changing market, anticipating problems, finding a specific market destination and marketing. Traditionally new generations may help solve this step, but some agencies are offering AI services on the market taking in account the solution of this gap. However, at the end managers will need to change mentality, but this is a process that may be facilitated[69].

- SUSTAINABILITY: resource/capacity balance and circular economy. Complementary to the general innovativeness capacity required to managers approaching an introduction of AI systems in an organization, there is the sustainability plan. Manufacturing 4.0 may involve a substantial change in resources and capacities, that might be better approached with a circular economy mindset. As already suggested, managers should be able to consider this factor, and this could represent a specific gap in AI adoption when this change challenges specific organizational balances.

- FACTS COPING: unexpected events and opportunities. Finally, the inability to cope with unexpected events might represent a disadvantage when considering (also) AI adoption. Taking the example of the Covid-19 pandemia, for some organizations it represents a critical point with no easy solution, while in other cases there could be resources (and willingness) enough to catch the occasion for a paradigmatic organizational change.

[69] https://www.gartner.com/smarterwithgartner/how-to-build-a-business-case-for-artificial-intelligence/