2017

What is the impact of the industry 4.0 in the process industry ?

MATEO JIMENEZ – MSC CONSTRUCTION MANAGEMENT AND ENGINEERING

TEBODIN | **TU DELFT**

Foreword

In September 2017 I started my Master Thesis research for Tebodin. With a vague idea of the industry 4.0, IoT and the new digital era. However, I have always been a futurist, and I consider myself thinking in the future and how things will be, quite often. In fact, my real interested with this thesis was to gather as much information about the cutting edge technologies and try to develop a method that can help companies to keep up with digital innovation. During my work at Tebodin, I met wonderful people that help me out during the entire process, consultants of environmental sciences, safety and asset management were always intrigued and enthusiastic with the outcome of my report. This enthusiasm made easier for me to find experts to interview and continue to gather information about the digital technologies and their applications. I am grateful that I meet also these wonderful engineers and I wish them the best.

I have to thank all the experts that I interviewed. They gave me a minute of their life to share with me their knowledge and insights about the technologies and the industry. With their help, I manage to collect their thoughts and type them into my master thesis. I wish that when they read this document, they could find their words and thoughts.

I will also like to thank my four committee members. Kas Oosterhuis, Sander van Nederveen, Maurice Houben and Argun Cecen, without all of you this process wouldn't been possible. Thank you for your patience and dedication towards my research. For being enthusiastic but also severe in the moments that I needed too. Please continue driving innovation and changing the world with your day by day work.

At last, I will like to thank, my family, friends, colleagues and other people that support me during the whole process. Thank you for helping me reach my graduation and to support me in my educational career.

I sincerely hope that everyone who reads this thesis will understand the ideas and thoughts I present and that they will see this thesis as a stepping stone for their own digital development. Finally, I will quote one of the books that I read while making my thesis (thanks to the Sander van Nederveen for the recommendation). This phrase summarizes what I have learned in this master research. Everything is becoming something else, everything is moving and unfinished. In order to apply technology in the industry. We need people that I continuously thinking, experimenting, shifting, searching and changing. The world is moving fast, and it requires professionals that are able to cope with the pace and keep updating their knowledge on daily basis.

"Because of technology everything we make is always in the process of becoming. Every kind of thing is becoming something else, while it churns from "might" to "is." All is flux. Nothing is finished. Nothing is done. This never-ending change is the pivotal axis of the modern world." Kevin Kelly, The Inevitable

Mateo Jimenez, May 22, 2017.

Summary

The industry 4.0 is a group of digital technologies that can create cyber-physical systems (CPS). These systems can redefine the rules of the industrial production, creating more wealth than ever before, while transforming the factory ecosystem (Schwab, 2016). In the car and aerospace industry different prototypes of CPS have been developed in factories and end products. However, in the process industry, in particular Oil and Gas, Food & Beverage, Construction or Chemicals, it is not clear yet what could be the impact of these digital technologies and what methodology should be used to design cyber-physical systems (PwC, 2016). For all these reasons, this thesis focus on analyzing the impact that the industry 4.0 might have in the process industry. In this analysis, a categorization of the i4.0 technologies was develop based on the phenomenological qualitative approach. It was determined that sensors, artificial intelligence(AI), cloud computing are in the category "KEY", which means they have a high impact and technological maturity. With the "KEY" technologies mentioned before, the next step was to make a design of a CPS based on a methodology called the 5C level architecture, following the special requirements and boundary conditions of the process industry. After this design and methodology, it is concluded that it is possible to build up and asses a CPS in the process industry, by following the criteria mentioned in the document. At last, based on the information gather in the previous steps, it was concluded that process factories will tend to shrink by reducing inventories and redundancies. This, by enhancing software and hardware elements in the structure and operation, embedding AI in their process, and shifting from pushing to pulling production processes.

Key words: *Industry 4.0, process industry, digital technologies, cyber-physical systems, validation board, factory of the future*

1. Introduction

Digitalization gap for the process industry

According to PwC "*2016 Global Industry 4.0 survey* "of the 600 process industry firms interviewed, 72% of them want to achieve digitalization and automation in the processes, within the next five years. However, only 33% of the respondents have already found out how to reach this digitalization and automation (PwC, 2016). This gap of 39% represents the fact that, even though companies in the process industry want to achieve digitalization, not all of them have a methodology on how to apply digital technologies to their processes and business cases. For this reason, the purpose of this report is to foresee the impact that the Fourth Industrial Revolution might have in the process industry in the next five years and propose a methodology to develop digitalization.

What is the Fourth Industrial Revolution?

Klaus Schwab, the CEO of the World Economic Forum, defines the Fourth Industrial Revolution as **"A range of new technologies that are fusing the physical, digital and biological worlds, impacting all disciplines, economies, and industries"** (Schwab, 2016). According to Schwab, the combination of internet, automation and human interactions will change the idea of factories, operations and society (Schwab, 2016). According to professor Erik Brynjolfsson, from the Massachusetts Institute of Technology (MIT), this revolution is all about connecting hardware like computers or 3D printers, software components, such as artificial intelligence or cloud computing, and humans at the level of interactions never done before (Erik Brynjolfsson, 2016). In his book *"The Second Machine Age"* the professor explains that digital devices are more useful and unpredictable that steam or automated machines (Erik Brynjolfsson, 2016). Moreover, while the last three industrial revolutions had a linear technological development, the fourth one is rather exponential, and this characteristic relies on the fact that our new society is fully interconnected and information take few hours to spread around the globe. According to Klaus Schwab, this revolution has the power to connect billions of people to the web, improve the efficiency of business and organizations, help to regenerate the natural environment through asset management and reduce the damage caused from the previous industrial revolutions (Schwab, 2016). In fact, the CEO of the World Economic Forum, states that companies should be able to apply these technologies to their processes to increase their competitiveness, cut the costs in all their operations without causing environmental damages (Schwab, 2016).

What is the Industry 4.0?

The Fourth Industrial Revolution, as described by Schwab, involves various types of digital technologies impacting different industries, services, and economies (Schwab, 2016). However, since the interest of this research is to foresee the incidence of the Fourth Industrial Revolution in the process industry, this research will focus on an aspect of the Fourth Industrial Revolution that deals with the industrial processes and end-products, so called the *"Industry 4.0"*. The concept "*Industry 4.0"* was first defined in the Hannover Fair in Germany in 2013 as ***"The establishment of intelligent products and production processes"*** (Malte Brettel, 2014). The Industry 4.0 has been on the top of mind of most manufacturer companies and consulting firms for the last four years; they have been selecting which technologies are profitable for their business and what is the path to develop them.

Additionally, there have been several articles and academic papers defining what the Industry 4.0 is and which are the possible implications, that these technologies might have on the whole manufacturing industry.

Inside the Industry 4.0 definition, there is a concept that is essential for this research called the cyber-physical systems (CPS). These systems, as explained by Schwab in his book, are the atom of the Fourth Industrial Revolution and the Industry 4.0 because they allow humans to fuse the physical and digital worlds in various ways (Schwab, 2016). In fact, a definition of a CPS according to the US National Science Foundation is: "***Cyber-physical systems are physical and software components that are deeply interconnected, each of them operating at different spatial and temporal scales, exhibiting multiple and distinct behavioral modalities, and interacting with each other in a myriad of ways that change with the context"*** (National Science Foundation, 2015). As explained by Bryonjolfsson, the real potential of the Industry 4.0 technologies is the ability to connect them in various ways to create powerful and robust cyber-physical systems (Erik Brynjolfsson, 2016). Herewith, each I4.0 technology, that will be explained later on, will not add value to a company if it is not connected properly with other I4.0 technologies in a network of components called CPS. Therefore, the scope of this research will be the impact that cyber-physical systems (combination of I4.0 technologies) might have in the process industry.

1.1 PROBLEM

The process industry has always been one of the engines of the global economy and labor creation. In 2016, according to the US Bureau of Economic Analysis, the Chemical, Oil and Gas, Food and Beverage and Construction represented 2.5%, 3%, 4% and 4.2% of all the GDP of the US, which means that about 13.7% of the GDP accounts to the process industry (Bureau of Economic Analysis, 2016). Regarding labor, according to the Bureau of Labor Statistics in 2017, the Chemical, Oil and Gas, Food and Beverage and Construction account for 812, 448, 1535 and 6734 thousand of employees directly, meaning the equivalent to 6.8% of all the workforce of the US and indirectly to approximately 12.6% (Bureau of Labor Statistics, 2017). Thus, the importance of keeping the industry updated with the latest technology is a must for the economy of develop countries.

Cyber-physical systems, as explained before, make possible for companies to run leaner, efficient and more sustainable production processes. However, even though there is a tremendous opportunity for businesses to make these systems, there is still a gap between what companies want to achieve and what they can achieve. According to the PwC "*2016 Global Industry 4.0 survey*", this difference is mainly caused by the lack of digital culture and training (53% of respondents), the unclear economic benefit of digital investments (41% respondents) and high financial investment requirements (35% of respondents) (PwC, 2016). Herewith, companies in the process industry have not a clear idea which i4.0 technologies they should focus their investments on, and which methodology should they use to develop cyber-physical systems in their factories.

1.2 RESEARCH OBJECTIVE

The manufacturing industry has already started to create cyber-physical systems into its processes since the Hannover Industrial Technology Fair in 2013 (VDI Nachrichten, 2013). On the one hand, leading manufacturing companies such as Bosch, Volkswagen Group and Siemens have developed, in collaboration with the German government, a path towards the construction of cyber-physical systems in their factories (GTAI, 2016). On the other hand, academics such as Brett (Malte Brettel, 2014), Wahister (GTAI, 2016), Zühlk (Zuhlk, 2016) or Weyer (Weyer, 2016) have already discussed the potential and challenges of the cyber-physical systems in the manufacturing industry. Herewith, for this industry, there is already enough information to select I4.0 technologies, combine them to create CPS and assess the impact of these systems in a factory. This existing knowledge makes easier for companies to focus their investment on these technologies and foresee the impact on their own business. However, as explained previously, the process industry has still a digitalization gap, and companies do not have a clear idea which technologies they should focus their investments on in the short term (5 years) or what methodology should they use to upgrade their factories. For that reason, the purpose of this research is to **explore the possible impact that combination of I4.0 technologies (proven in the manufacturing industry) can have in the context of the process industry in the next five years, and propose a methodology to tackle the digitalization gap.**

1.3 Research Question

Main question

Based on the problem of the knowledge gap and promising concept that has been identified, the following research question needs to be answered in the following study:

"What could be the impact of cyber-physical systems (combination of industry 4.0 technologies) in the process industry in the next five years?"

Sub-questions

The main research question is divided into several sub-questions, which need to be answered to solve the main issue. First, identify the i4.0 technologies that might create a higher impact on the process industry in the short term. Second, explain a methodology to design cyber physical systems (CPS) in the process industry with the technologies chosen in the previous step. Third, after showing the methodology and designing of a CPS, the company should be able to assess the CPS. Fourth, identify some aspects that might change in a process installation when CPS are included in their processes.

1. *Which I4.0 technologies could impact the process industry in the next five years?*
2. *How can a company design a cyber-physical system for a process installation?*
3. *What is the methodology to asses a cyber-physical system in the process installation?*
4. *How will the factory of the future look like in 5 years with cyber-physical systems on it?*

Sub question number 1 will be answered in chapter 3, sub question number 2 and 3 will be answered in chapter 4 and, finally, question number 4 will be answered in chapter 5. It is important to mention that chapter 2 does not respond to any sub question, because it explains the state of the art of the process industry, cyber physical systems, industry 4.0 and all the technologies that belong to it.

1.4 RESEARCH METHOD

In figure 1 a sketch is illustrated to show, step by step, how to go from the Fourth Industrial Revolution to the impact on the process installations.

Figure 1 – Research method

In chapter 2 there is a definition of the purpose and scope of the research, defining the concept of Fourth Industrial Revolution, Industry 4.0, cyber-physical systems and the process industry. In chapter 2 there will also be a more profound definition of each of the technologies that belong to the Industry 4.0. In figure 1, the blue square represents the content of that chapter, which implies the broad scope of the second chapter. It is important to mention that the technologies chosen in this chapter are those that have a high potential in the manufacturing industry and not for the process industry.

Chapter 3 will focus on assessing the technologies described in chapter 2. This assessment will be done by a *phenomenological qualitative approach* (John W. Creswell, 2013) based on the opinions of 32 experts. The outcome of this chapter will also give some hints about the possible impact of the Industry 4.0 in the process industry. In figure 1, this chapter is represented by the stars, which show the technologies that might have a big potential in the process industry in the short term, and the two green parentheses, that represent the context of the process industry.

Chapter 4 will focus on the design of a cyber-physical system for a particular process installation based on the *5C level architecture* (Jay Lee, 2014). This design methodology will be assessed with a *validation square* (Karolyn C. Seepersad, 2005) that will identify the impact of the CPS on the stakeholders and the boundary conditions identified, based on the paper "*Evaluation in Design-Oriented research*" (Hartog, 2005). In figure 1, this chapter is represented by the image of the factory.

Finally, chapter 5 will discuss the trends that factories might have in the next five years in the process industry. In this chapter, a focus will be given to the form and shape of the factories and the outcome of the *validation square*. (Karolyn C. Seepersad, 2005).

2. The process industry, CPS and the Industry 4.0

The goal of this chapter is to answer the questions: What are the characteristics of the process industry? Which are the trends and challenges of the process industry? What is a cyber-physical system? And What are the technologies that belong to the Industry 4.0. To solve these issues, there will be a definition of process industry, a description of the challenges and trends of four process industries, a selection of technologies that belong to the Industry 4.0, and finally, a profound description of each I4.0 technology specifying their potential and limitation. In the following section, there will be a definition of the process industry.

2.1 The Process Industry

According to the Institute of Industrial & Systems Engineers, the process industry is *"where the primary production processes are either continuous, or occur on a batch of materials that is indistinguishable* " (Institute of Industrial & Systems Engineers, 2008), which means that processes, are uninterrupted from the beginning till end of the production line. According to a managing director of a consultancy firm, various implications can be discussed under that definition. First, the production of independent units and batches is difficult. Second, the transformation time of the raw materials cannot be easily modified, and third, machinery and systems are physically connected with each other. Furthermore, academics such as Kadlec and Gabrys confirm that process factories cannot allow having extended downtime period because that translates into enormous costs compare to other industries (Petr Kadlec, 2009). In their report, they also suggest that most of the downtime in continuous production is caused by alterations in the product line, demand changes and unexpected failures (Petr Kadlec, 2009).

Another important characteristic of the process industry is bulk production. Liters of yogurt, tons of plastics, barrels of gasoline and tons of pharmaceuticals, are some of the most common finished products in this industry. Due to bulk production, companies tend to invest in extensive facilities that produce an enormous amount of material, rather than small factories in which the output is also low. This phenomenon is called by economists as the economy of scale. By definition, the economy of scale is "*an additional gain when the output of a production process increases*" (Sheffrin, 2003). Herewith, the more a company produces, the cheaper will be to produce an extra unit of material. E.g. In construction, prefabrication, which is a trend that has been used for the last decade to "industrialize" the civil works, have used the economy of scale in an outstanding way. This method that uses an offsite factory to produce constructive elements with high-quality standards at a low cost allow the contractor to make structures cheaper and faster. However, a negative effect of the economy of scale is that tend to make process industry leaders risk adverse in their way of thinking, only making them willing to change when technologies are proven and mature.

Finally, it is important to understand that there are various industries within the process industry. However, given the fact that this document was develop in collaboration with the consultancy and engineering firm called Tebodin. The focus of this paper will be on food and beverage, chemicals, oil and gas and construction, which are the areas of expertise of this company. In the next section, a general overview on each of the industries mentioned before will be presented, based on a compilation of experts' views and surveys made by consulting companies or governmental agencies in Europe.

FOOD AND BEVERAGE

Definition of Food and Beverage industry

According to US Commercial Service the food and beverages industry is - all companies involved in processing raw food materials, packaging, and distributing them. This includes fresh, prepared foods as well as packaged foods, and alcoholic and nonalcoholic beverages. Any product meant for human consumption, aside from pharmaceuticals, passes through this industry (US Commercial Service).

Trends of the Food and Beverage industry

According to the article "*Food and beverage trends in a transformative time"* by Tish Van Dyke, the global sector chair at Edelman Company, the trends of the food and beverage industry are a focus on the convergence of food, health and wealth, and food-tech development (Dyke, 2016). On the one hand, local food production will get more attractive and valuable to the customer, whereas, on the other hand, technology will be applied in the supply chain process for crop protection, water recycling, delivery on demand and meal solving. In the same study made by Van Dyke, there is also a trend towards gathering stakeholders from different nationalities to enrich the company, as well as, their social responsibility indicators (Dyke, 2016). Finally, with the combination of all these trends, customers will tend to look at food as an experience rather than as a need.

OIL AND GAS

Definition of oil and gas industry

According to Harvard Devold from ABB O&G business line, the oil and gas industry represents all the possible business related to the petroleum-gas based materials. Which includes the discovering, obtaining, producing, refining, and distributing oil and gas (ABB Norway, 2013).

Trends of the Oil and Gas industry

PwC strategic report on the O&G sector says that investments on asset integrity will get higher day by day in the O&G industry (PwC, 2016). In fact, according to the Vice President of Exxon Mobile Harry Longwell, their company is investing millions of euros in developing ways of checking the asset integrity, in particular on a vessel under soil and sea (Longwell, 2002). Longwell argues that by doing this, the connection between maintenance group and the asset will improve in such a way, that the extraction platforms or refineries will work 24/7, with fewer safety problems. Additionally, in the same PwC report, there was also identify that O&G companies are shifting their investments to new business lines such as renewable energy and clean oil and gas production. This change as a consequence of tighter government regulations and societal pressure to avoid contamination of the air, water, and soil (PwC, 2016). Finally, as a result of variability of oil prices, companies have a sense of urgency to redefine their revenue streams, and therefore, there will tend to adapt different innovations faster in their production facilities.

CONSTRUCTION

Definition of the construction industry

According to the divisions 41 to 43 of the UK Standard Industrial Classification of Economic Activities 2007 – SIC (2007). The concept of construction industry includes general construction and allied construction activities for buildings and civil engineering works. It includes new work, repair, additions and alterations, the erection of prefabricated buildings or structures on the site and also construction of a temporary nature. General construction is the construction of entire dwellings, office buildings, stores and other public and utility buildings, farm buildings etc., or the construction of civil engineering works such as motorways, streets, bridges, tunnels, railways, airfields, harbors and other water projects, irrigation systems, sewerage systems, industrial facilities, pipelines and electric lines, sports facilities etc. This work can be carried out on own account or on a fee or contract basis. Portions of the work and sometimes even the whole practical work can be subcontracted out. A unit that carries the overall responsibility for a construction project is classified here. The repair of buildings and civil engineering works is also included. The industry definition includes the complete construction of buildings, the complete construction of civil engineering works, as well as allied construction activities; if carried out only as a part of the construction process. The renting of construction equipment with operator is classified with the specific construction activity carried out with this equipment (Empire State College).

Trends of the construction industry

According to the book "*Automation in Construction*" (Bhargav Dave, 2016) digitalization is crucial in the construction industry, especially for asset management control. In this topic, there are different exploratory projects such as drone surveillance or the Pegasus project. This last project has the purpose of creating a CPS for the whole highway infrastructure in The Netherlands. Pegasus is a system that has automated detection systems, which gives real-time information about the condition of the road. The aim of this scheme is to help the maintenance teams predict failure, meaning from the government, savings in operational expenditures and better availability of the highway infrastructure. The second trending topic in construction is about BIM (Building Information Modelling), which is not a recent issue and it has been under investigation for years to make the collaboration of designers and contractors more efficient and especially more comfortable. However, within BIM there are still improvements that need to be done especially in the interface between design, execution and operation phase (Azhar, 2011).

CHEMICALS

Defining Chemical industry

According to the American chemical society, the chemical industry comprises the companies that produce industrial chemicals. Central to the modern world economy, it converts raw materials (oil, natural gas, air, water, metals, and minerals) into more than 70,000 different products. Polymers and plastics, especially polyethylene, polypropylene, polyvinylchloride, polystyrene and polycarbonate comprises about 80% of the industry's output worldwide (American Chemical Society, 2013).

Trends of the Chemical Industry

According to the report *"The Future of the European Chemical Industry*" by KPMG, the chemical industry is experimenting new challenges in particular for the European companies. The first challenge is to optimize facilities that are not profitable and cannot compete with the new and more efficient plants working outside Europe. A second hustle is to identify which products or chemical clusters will be needed in the future to focus resources and research on them. A third challenge is to capitalize on innovation to make a wider competitive advantage, especially regarding sustainability solutions (KPMG, 2010). Moreover, these companies need to leverage long-term relationships to develop higher quality and more specialized products. Finally, it is also important for the European chemicals companies to find allies with suppliers and other companies' especially in other markets overseas. For all the above reasons, the European chemical industry goals are to cut costs, increase innovation and produce specialized products.

After explaining the challenges and trends of each industry independently, the analysis of converging or diverging trends will be discussed in the next section. This study is important for the research because the result of this document can only be extrapolated if challenges and trends are converging between the industries mentioned. If challenges diverge, it won't be possible to found common ground for all sectors, hence the research needs to focus on each production independently and find a potential application for each industry.

2.2 CONVERGING OR DIVERGING TRENDS IN THE PROCESS INDUSTRY?

In the *"2016 Global Industry 4.0 Survey"* (PwC, 2016) developed by PwC, it is clear that all four industries, as mentioned before, are looking at what data analysis, automation, customer access, and connectivity have to offer. E.g. In Chemical and construction companies, the significance of data analysis in decision making will increase in the next five years from 60% to 88% in chemicals and 40% to 72% in construction. Herewith, companies are eager to invest in tools that allow them to have more data, because this, translates into the better decision-making process. In research and development (R&D) the situation is also convergent. In the same report by PwC both chemicals and construction are investing 5% of their annual gains in R&D for Industry 4.0 technologies, meaning that, the Board of Directors of most of the European companies in the process industry are looking at this topic on a strategic level and as a field that might differentiate them from the competitors (PwC, 2016). Finally, the report suggests that even though the industries and business models are different, there is a common tendency of digitalization in almost all industries. In the following paragraphs, the three leading causes of this quick evolution towards the digital era will be described.

In the first place, a rapidly changing environment makes companies be constantly looking for new product development and ways of satisfying their clients. This constant search is caused because if

companies stagnated with their business lines and products development, other competitors and startups would overpass them in short time. According to Klaus Schwab, dynamic environments require flexible and adaptive companies that are always willing to innovate (Schwab, 2016). Factories with flexible product lines, modular production, and organizations with innovation vision are some of the strategies that companies should apply in their business. However, the process industry is traditional, and their end products are not customer oriented, but B2B transactions instead. Hence, rapid changes in customer desires will make manufacture companies change and eventually hitting the entire supply chain, including process companies. Even though these changes won't be immediate, they will arrive sooner than expected.
Secondly, competition is getting tougher and tighter. It is well known that emerging markets have cheap labor cost and, in most cases, loose environmental regulations. These characteristics make chemicals, construction materials, food, and O&G final products more affordable outside Europe than inside, Even though the majority of the customers are still in the old continent (KPMG, 2010).
Finally, uncertainty in the markets is getting higher. According to Klaus Schwab, the leading cause of volatility in prices of commodities relies on the fact that our interconnected world is difficult to predict and new business models are shifting the way of purchasing goods at a tremendous pace. As an example, the implementation of fracking technology in the O&G industry made the price of petroleum barrel drop in such a way(from 60 to 34 USD per barrel in the last 18 months) that companies couldn't sustain anymore and some of them got bankrupt (Cooke, 2015).

After explaining the reasons why construction, chemicals, O&G, and food and beverage are moving towards digitalization at a fast pace, it can be concluded that this research could be extrapolated and adapted to other process industries previously mentioned.

2.3 THE MANUFACTURE INDUSTRY

According to the Economy Watch the manufacturing industry refers to those industries which involve in the manufacturing and processing of items and indulge in either creation of new commodities or in value addition. The manufacturing industry accounts for a significant share of the industrial sector in developed countries. The final products can either serve as a finished good for sale to customers or as intermediate goods used in the production process (The Economy watch, 2010).

The manufacturing industry refers to industries like automotive, aerospace, tooling, electronics, packaging and most products that arrive to the final user or consumer. This industry has a characteristic of having a discrete production process and several assembly lines of different materials. For example, a car is an end product of the manufacture industry that has several components from metallic, hardware, glass, foam and several materials that make a modern car useful for the driver.
The manufacturing industry is also the one

2.4 CPS IN THE MANUFACTURING INDUSTRY: INDUSTRY 4.0

As it was first defined in chapter 1, the cyber-physical systems are a network of components that are deeply interconnected living in both, virtual and physical space. The concept cyber-physical implies a multidisciplinary knowledge of Mechatronics, cybernetics, and design (Suh, 2014). In this section, these three fields will be described.

The Mechatronics is the area in charge of creating machines that develop specifics tasks. This area is widely known by engineers because they have already designed devices like car assembly arms, oil extraction machines and even space shuttles, which were unthinkable decades back. In fact, the sharp development of the mechatronic field was the primary cause for the third industrial revolution, in which automation and the relation between mechanical and electronic engineering produced machines that work on their own for plenty of time and are under control of only a couple of engineers.

The second field, cybernetics, is defined by Andrei Kolmogorov as *"The Science concerned with the study of systems of any nature which are capable of receiving, storing and processing information so as to use it for control"* (Umpleby, 2008). Cybernetics, belong nowadays to the field studied by computer science and electronic experts who try to understand how can technologies control a group of machines to fulfill different tasks, that cannot be done by just one machine. In cybernetics, the internet of things (IoT) has to be a key issue to understand how can elements of a physical environment interact with other items to report, fix, maintain and keep under control an entire system.

Finally, the last field is design and process engineering. For this topic, there are plenty of studies that have being done to link the machine-human-environment. One of the most important aspects of a CPS is that it combines computing power, machine strength and human creativity, to make an excellent human-machine relationship. This collaboration makes possible for machines and humans to work together in the same space, developing tasks together, in a completely safe environment.

Technologies in the Industry 4.0 for the manufacturing industry

In this section, the technologies that belong to the Industry 4.0 will be selected. This selection was made following the consultancy reports: *"How to navigate digitalization of the manufacturing sector"* from McKinsey & Company (McKinsey&Company, 2015), *"Industry 4.0: building your digital enterprise"* from PwC (Price Water House Cooper, 2016), "*Challenges and solutions for the digital transformation and use of exponential technologies"* from Deloitte Digital (Deloitte digital, 2015) , and "*the future of productivity and growth in manufacturing industries*" from Boston Consulting Group (Boston Consulting Group , 2016). After analyzing these reports, it was possible to come up with 14 technologies that represent the Industry 4.0. These different technologies that could be software, hardware or machinery, are divided into four major clusters: Automation, for these technologies that improve the automation of the process in the factory. Customer access, for technologies that make possible to gather information from the clients and suppliers in the supply chain of the plant. Data analysis, for technologies that enable a better understanding of data. Finally, Connectivity cluster, which is composed of technologies that allow humans to gather data or connect other components.

Figure 2 illustrates the Industry 4.0 technologies and the division of this concept in the four different clusters, mention previously. Automation group, compose by additive manufacturing (3D printing), drones, robots and autonomous vehicles. Customer access made up of social network, apps and websites and wearables. Data analysis, compose by big data analysis, routing and devices and artificial Intelligence (AI). Connectivity, made by cloud computing, digital products, sensors and data transmission. It is important to mention that there is a lack of consensus within the consulting companies defining which technologies belong to the industry 4.0. For that reason, it was decided to choose technologies that are present in all of the reports, and are independent technologies. For instance, Smart Energy consumption or Smart Building design are listed in the report of BCG (Boston Consulting Group , 2016). However, these "technologies" will not be considered in the overview because they are a combination of technologies such as sensors, cloud computing, data analytics and apps and websites, Therefore, they are defined as an application of a CPS rather than as an i4.0 technology.

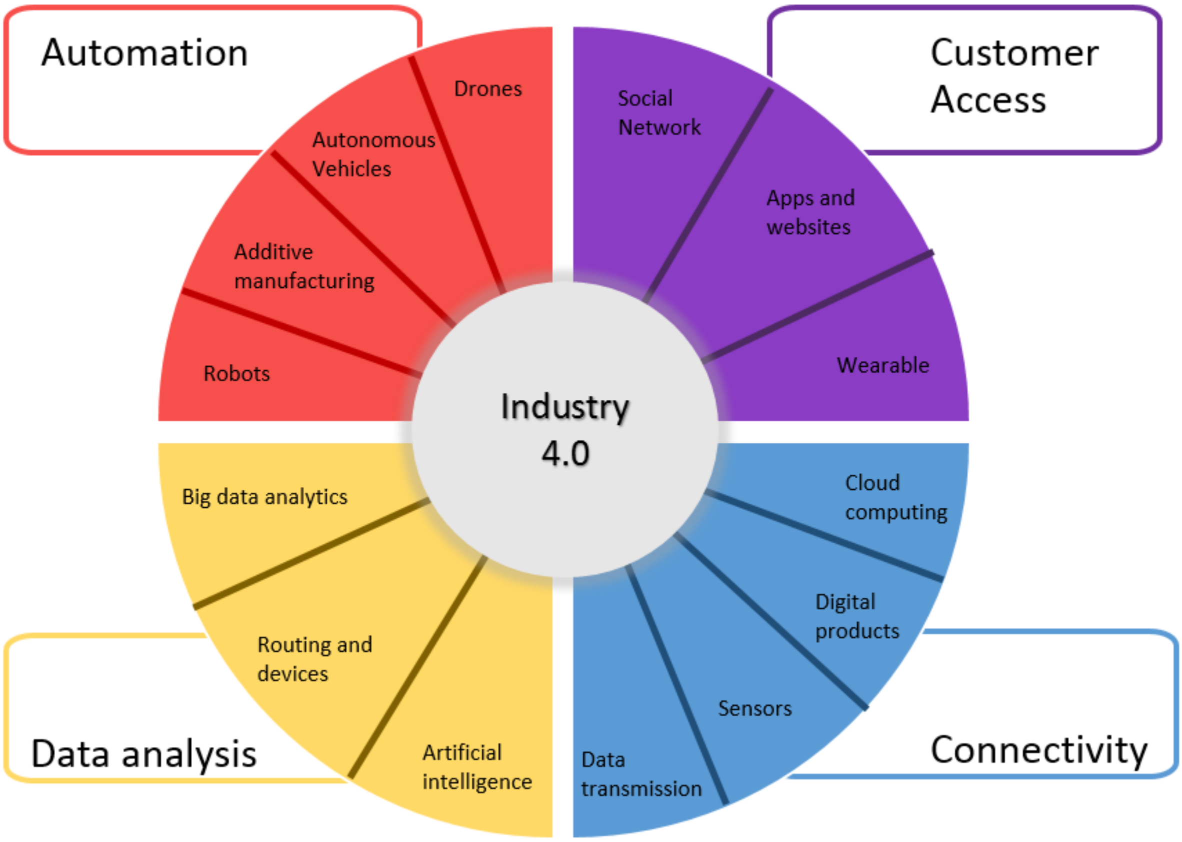


Figure 2 – I4.0 overview chart

After identifying the technologies that belong to the Industry 4.0, in figure 3 it is clear that a cyber-physical system is a network and combination of different technologies and stakeholders, which can have various applications in the industry. For example, one of the most famous CPS in the manufacturing industry are the smart assembly lines. These systems combine the I4.0 technologies such as robots, digital Products, sensors, big data analysis and artificial intelligence to make assembly lines, which are communicating constantly by machine to machine relations (Fiat Research Center, 2016). However, before assessing the impact of each technology and combining them in a CPS, it is important to describe and explore each technology in its own context. The following section will address this topic.

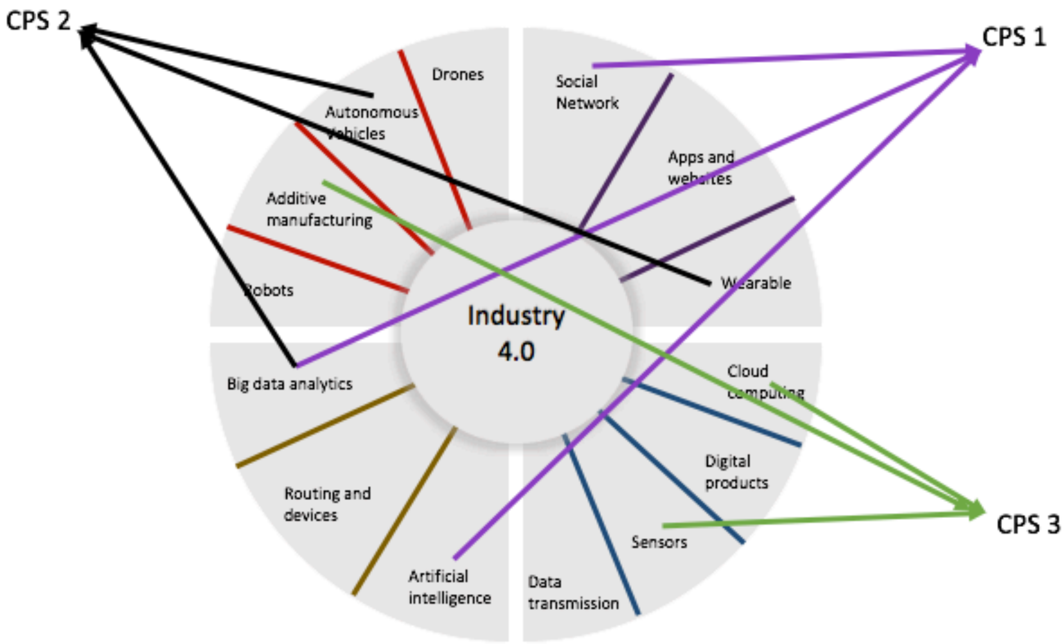


Figure 3 - Cyber physical systems relation with i4.0 technologies

2.5 AUTOMATION

Automation is a concept that comes from the third industrial revolution, in which computing systems and electronics created machines that can make several tasks with high quality while reducing the workers severely. The top of mind in this field of automation was cutting machines, mechanic arms and tooling devices that were mostly in USA, Germany, and Japan (GTAI, 2016). This domain is particularly important in the industry because it helps factories to produce the large scale of products at a low cost. Unfortunately, due to the fast pace in which consumers are changing their habits and markets are putting pressure on companies, to be more efficient and sustainable, factories can't use expensive machines that are only programmed to do one particular task. Herewith, one function machines don't give the opportunity to change product line and innovate without getting over cost or delays.

Furthermore, machines of the third industrial revolution lack of human-machine interaction (GTAI, 2016), this means that machines, robots, and other electronic devices can't work together with humans to develop or particular job together. In fact, in most cases when there is a task that has to be done by an arm robot, the company has to put a cage around the perimeter of the arm to prevent people from approaching the robot while it is working.

Finally, the last challenge that third revolution machines are facing is the lack of decision-making process (GTAI, 2016). E.g a traditional machine that produces a tool can't stop making the same device, unless a human turn it off or change its configuration. This lack of decision makes even more valuable that skill workers are at the factory, verifying the production line, making manual inspections and quality controls. However, these jobs can be reformulated if decision-making process becomes automated and intrinsic in the machine behavior.

I4.0 technologies in automation

Due to the lack of decision making, flexibility, and unsafe human-machine interaction, third revolution machines are being replaced by a new era of smart technologies. These innovations such as UAV's, autonomous vehicles, additive manufacturing (3D printing) or robots will make even more efficient, flexible and easier the production process in the factories all around the world.

Drones

The drone industry has been increasing at a tremendous pace the last couple of years. Just in 2014, the growth in funding for drone companies was of 104% on 2013, and it is forecast that the income generated by the UAV (unmanned aerial vehicle) in the U.S only will double from 1.2 to 2.3 billion dollars from 2015-2016 (Association for unmanned vehicle systems international, 2013). Tasks that companies are currently giving to drones are mainly in real estate, aerial surveillance, aerial imaging, agriculture and aerial inspection. Since this document is about industrial processing, there are three main fields in which drones are changing the industry: Asset management, surveillance, and mapping.

In the asset management field, the way of doing inspection and maintenance will improve dramatically with the use of UAVs. E.g. The British Company Sky Futures develops, drives and analyzed data from drones. They have been working with oil and gas companies providing thermal, video and imaging for offshore and onshore platforms mainly in the North Sea. The purpose of Sky Futures drones is to replace the current inspection system in which maintenance operators inspect with ropes, lights and special equipment vessels, burners, and connections on platforms. Their solution is to take aerial imagining, thermal inspection using UAVs and special cameras. Their idea is not only better regarding a quality of the review and safer for the operators but is also three to ten times faster than the manual inspection. Furthermore, with this technology control of all types of vessels, columns, and heat exchangers could be done without having to stop the process, meaning for the company more production and less downtime in their process.

In the field of security and safety, drones can make life easier and safer for guards and operators. UVA are vehicles that can approach a suspect, film and take information about the environment in a safe way. They can help the officials to have more eyes on the factory without having to expose themselves. They can measure weather conditions, leakage or any pollution on the environment without having to move from the control desk. In fact, since the price of drones is dropping tremendously due to Moore's law it is more cost efficient to buy UAVs instead of security cameras since they provide more information than fix cameras and they are cheaper than having a team of operators checking all night long the condition of the factory. E.g. companies like The Dutch drone company and 3DR are using this technology for clients that have big assets, and large territories to cover (ports and malls) to give a quality solution for their surveillance challenges.

Finally, mapping and aerial imaging are one of the most common uses that drones are performing. In the field of construction, mining, and energy these services are attractive because they provide vital information about topography, natural resources, and even environmental contamination. As an example, the French company Red Bird is currently working with Caterpillar to deliver high-performance data about topography, mining extraction profiles, and quantity surveillance. All made by drones that scan the terrain with their 3D camera and send information directly to software that analyses the data and give suggestion to the client regarding the excavation pit or the 3D modeling of the terrain.

The current stage of development of this companies allows customers to start already using this system at a fair price. Unfortunately, there are some countries in which the regulation of UVA's is not yet accepted and for instance in the U.S nearly half of the country has only approved one to four permits for drones services. In figure 4 a distribution of UAV permits by states in the US is shown.

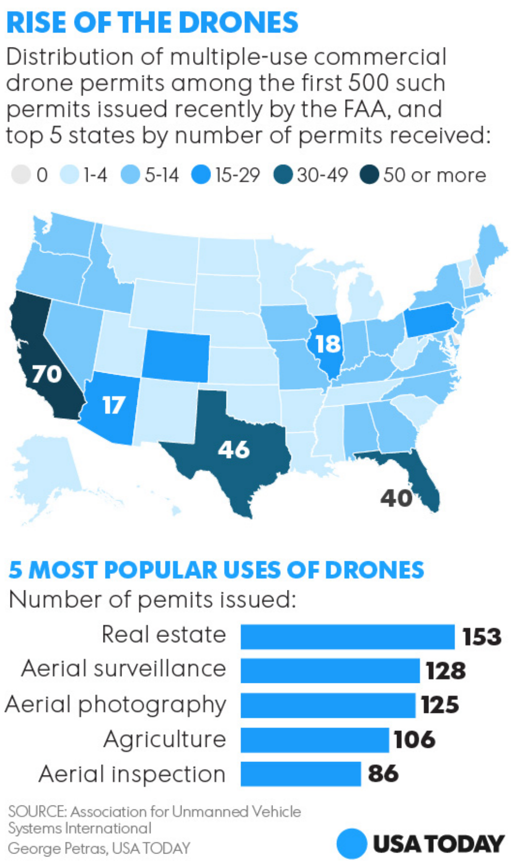


Figure 4 –UAV Permit distribution in U.S (Association for unmanned vehicle systems international, 2013)

Experts of the drone industry agree that the future of UAV's is prominent. Like it was mention before, this industry has been rapidly evolving from recreational to industrial and even transportation purposes. In fact, companies like Flirtey have already developed their first drone delivery system. It would take 3 to 5 years before start seeing drones delivering all types of goods in cities. Making supply chain cheaper, faster and better than ever before. In the control of significant assets in industries such as Oil and Gas, ports, airports, wind parks, solar parks, urban sewage, water and transportation systems drones will be a crucial part of inspecting and planning maintenance. As an example of this, the Pegasus project pretends to use drones for detecting fracture and problems inroads in such a way that drones directly identify and sent how much asphalt is needed and suggest what could be the problems on the road, this will facilitate the maintenance of roads and also it will create an entirely automated system of detection and repair with an excellent human-UAV interaction.

AUTONOMOUS VEHICLES

Autonomous vehicles have been working in ports and warehouses for a couple of years, developing mostly material carrying. These current systems use complicated algorithms and have a minimal capability due to the lack of perceiving the environment, not accurate GPS systems and poor connectivity. Thus, the challenge of this technology is to improve the human-machine interaction in such a way that is safe and flexible for the industry.

The future of autonomous vehicles will make more efficient, affordable, safer and easier the logistics in the warehouse, distribution centers, city and everywhere. In fact, almost all of the car manufacturer are investing millions of euros in self-driving cars. Volkswagen has said that the first self-driving pilot will be available in 2019, Ford in 2021 and other companies like Google and Nutonomy stated that their first commercial vehicle would be on the roads by 2018. Travis Kalanick, the founder, and CEO of Uber said, that with the self-driving cars the drop on transportation will be so sharp that it won't be worth it anymore to buy a car. Instead, people will pay rent for using self-driving vehicles because the majority of the charge on an Uber service goes to the driver.

In the industry, autonomous vehicles will also help workers to carry materials from A to B in the factory in an efficient and self-control way. The Toru for example is an autonomous vehicle that has been working in DHL warehouses in Germany carrying objects from one place to another based on what clients order on the website Amazon. There is also a new generation of robots (autonomous vehicles) that clean factories, alert if they detect any suspicious gas or even help workers with heavy lifting. These vehicles will be explained further on the section of robots.

Shortly, governments will have to approve regulations on the autonomous vehicles for public roads. But for the industry, it will be much easier to apply AVs for transportation and several non-operational services, and it could be that in two to five years self-driving cars will be the majority in factories, airports, and ports.

Additive manufacturing (3D printing)

The disruptive innovation for process and manufacturing industry is called additive manufacturing. This technology commonly known as for as 3D printing has been developing at a tremendous pace the last years. In fact, in figure 5, the tendency of growth of this technology is almost exponential, for both consumers and enterprises.

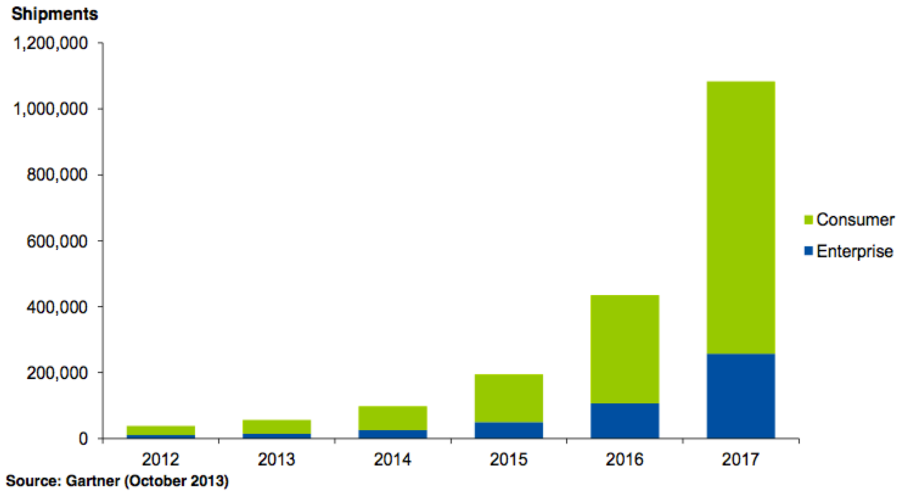


Figure 5 - Growth forecast in the 3D printing industry (Garnter, 2016)

This technology can translate within hours a computer design into a physical object with a micrometer accuracy. In fact, in the manufacturing sector there currently using 3D printing to make customized glasses, tools and all type of automotive parts, since 3D printing is an entirely different way of manufacturing products on the traditional process series process. In this document one express four key benefits that can improve the competitiveness and flexibility of the factory. First, Time to market using additive manufacturing will be some weeks rather than months, this because 3D printing allows within days (even hours) to have prototypes of end products, directly from the design file to the production process. In traditional processing to make a new product, machines should be reconfigured, and the entire production line should be modified, something more complicated and time-consuming than additive manufacturing. Secondly, customization with additive manufacturing is faster compared to the traditional processing. In the conventional method based on series systems, to customize a product the entire product line must change. Instead of 3D printing technology, all types, of prototypes and modifications can be made with the same production time. It means that with industrial 3D printers the term customized mass production can be achieved without having extra costs in the production line. Thirdly, with 3D printing the waste is nearly zero, products are made in the most efficient way, and optimization of end products is possible than using traditional methods. Finally, this technology also can create a plug and produce system because 3D printers can be connected directly to an app controlled by the customer. In this app, customers decide what they want, and the 3D printer starts producing. The era of pulling production process and customized mass production.

Even though 3D printing is currently used, this technology is still at an infant stage. In fact, the biggest challenge that faces is in product scalability. The time of making a prototype increase exponentially with the scale of the product. In order words, a small prototype of a couple of centimeters takes ten minutes to be raised by the machine, but the same prototype ten times bigger will require thousand times more time to be complete. Current research and institutes are trying to solve this problem, and it is expected that in a couple of years this scalability issue won't be a problem anymore. For industrial processes, there is also a pitfall in making 3D printing a continuous process. Experts in the industry say within a couple of years these problems won't exists anymore based on Moore's law and current developments such as the Italian company Exone that produce the first mass production 3D printer called the Serial, as it is shown in figure 6. Regarding regulation, governments already establish several requirements and specifications for 3D printing, since is a hot topics policy makers are trying to regulate it quickly.

Figure 6 – Exerial mass production 3D printer (Exone, 2015)

Robots

Robotics are probably a unique technology of the second machine age or fourth industrial revolution. An appropriate definition of a robot is a machine that is controlled by and internal or external computing system, made to develop certain tasks. In the introduction of this chapter it was discussed about the cyber-physical systems and why are they important in the I4.0. Based on the definition of the robot it can be related that Cyber-physical systems can be a group of robots that are interconnected to do several tasks as a group, with independent decision making and control relations. Due to the last phrase, it is vital to understand how robotics works in the world and what are the current trends in this industry.

In figure 8, it can be seen how the trends of the robot market for the near future are growing in different fields like services or manufacture. In figure 6 there is an example of how storage capacity has dropped in the last years, this allows us to believe that CPS systems are not anymore a dream or only for one industry, but it can be applied in every industry for almost every purpose.

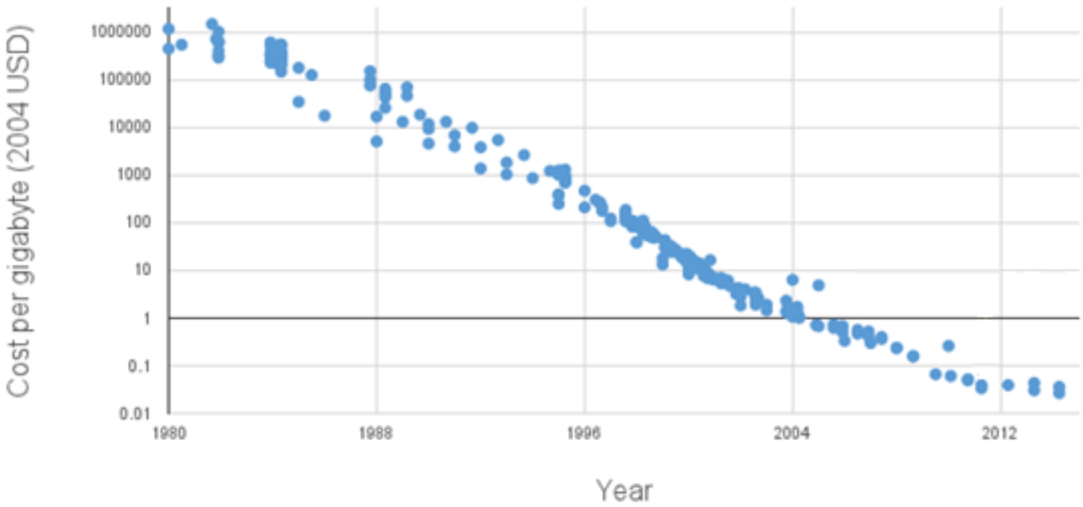
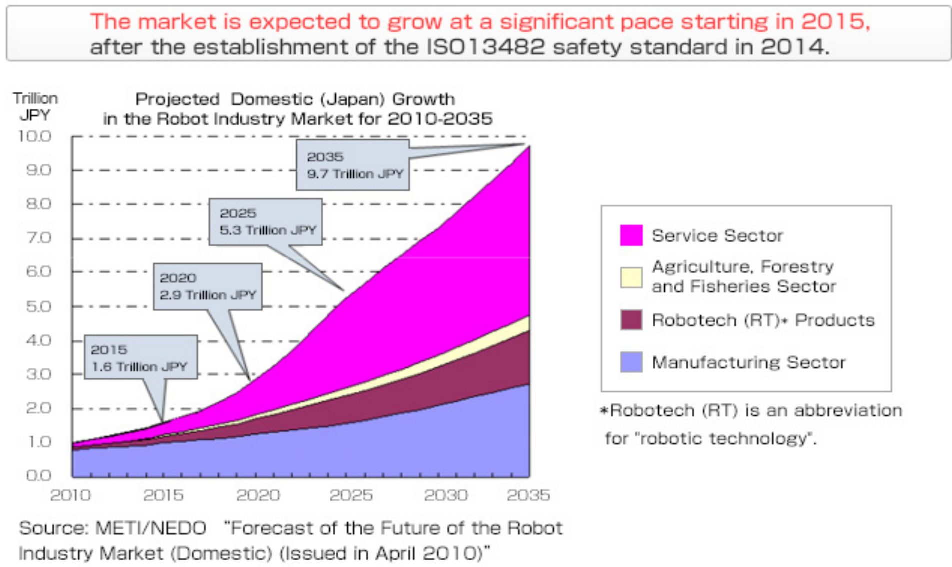


Figure 7 – Cost per Gigabyte in hardware (Machine intelligences Research Institute, 2014)



The Japan Patent Office Predicts that the Global Market Size will Total 4.1 Trillion JPY by 2020.

Growth of the Service Robot Market

Unit: Million JPY

Year		2011 (Results)	2012 (Results)	2013 (Estimate)	2014 (Prediction)	2015 (Prediction)	2020 (Prediction)
Service Robot Market	Japanese Market	20,975	40,695	54,485	61,780	373,300	1,314,400
		100.0%	194.0%	259.8%	294.5%	1779.7%	6266.5%
	Global Market	298,820	515,000	835,000	1,064,000	1,694,000	4,132,000
		100.0%	172.3%	279.4%	356.1%	566.9%	1382.8%

Source: Analysis of Technology Trends in Patent Applications (2013)
(Issued by the Japan Patent Office in February 2014)

Figure 8 – Growth prediction of the robotics market (Japan patent office, 2013)

Regarding robot's existing technologies, there can be divided into three different categories: Soft engineer, hard engineering, and services. These groups are made based on the way robots work and the requirements made by the environment. In the Soft engineering, field robots develop easy tasks inside a human environment (human around the robot). E.g. Baxter from the company Rethink Robotics is a robot that can do easy and repetitive task 24/7. This peculiar robot can learn tasks by memorizing its arm movement. In other words, Baxter needs than an operator move his arm to take a glass from A to B for the first time, after that "lesson" this robot develops the same task over and over again. Baxter is a type of robot that is useful in the factory, cheap, can operate every day and is easily reprogrammed to develop other tasks. This robot is in the field of a soft engineer because it is 100% safe. Baxter has sensors all over his body and also a camera that allow him to see humans, interact with them and helped them with their daily tasks. In hard engineering, robots develop high-quality tasks without human interaction but with a deep machine-machine communication. As an example the Cirris series produce by the company ULC Robotics, are a group of robots (Cirris XI, Cirris XR, and Cisbot) that grow together, inspection, repair, and iron joint sealing in pipelines. This group of robots communicates in such a way that the inspection robot XI tells to the repair and sealing robots what needs to be done, while operators control and verify fro, the control van up on the surface. This technology saves maintenance operations on gas pipelines from weeks to just eight hours; making the factories reduce their downtime and do works in vessels even when they still have gas running or hazard conditions inside the pipes. The last field in robotics is called service robots, and this machines develop all type of non-operational labors such as surveillance, transportation or helping operators with their duties. There are thousands of different commercial robots like Samsung VR20, RX1 from Miele or Philips FC8810 that are used for cleaning purposes or the KnightScope for surveillance robot to even the Canvas robot used for transportation of goods in the factory or warehouses completely independent.

Regarding regulation, Soft engineering, as well as service robots, are typically well regulated in developed and developing countries, but hard engineering robots are only restricted in develop countries specially (Japan, Germany, USA and South Korea). This means that for countries without any regulation on this subject it might take a couple of years to operate these hard engineering technologies.

2.6 CUSTOMER ACCESS

In the last years, digitalization cause radical changes in the way companies and factories sell their products (GTAI, 2016). It is clear that nowadays, there is a tremendous amount of data transfer by smartphones, wearable devices, and social media. Customers are more empower day by day to make their products, and companies use this information to know more about consumer desires and needs. This strong relation between corporations and customers make factories reframe their production process, make it more compact to the demands of the new consumers, and flexible to keep up the changes of the market. This customer-company relation will cause shortly a complete change from the traditional pushing production process to a pulling one (Schwab, 2016). Moreover, Customers via digital products, apps, websites and wearable devices can decide what type of product they want and how they want it. This customization makes pushing production less lucrative. Economies of scale might be in danger because when pulling systems are being applied; there is no need of inventory, standardization and the production will be leaner and more cost efficient (Deloitte digital, 2015). In this section technologies that link customers and companies will be described and explain.

I4.0 technologies in customer access

Direct communication between customer and factory are crucial for delivering better products that are suitable for the client needs. The techniques described below will demonstrate how to increase customer access, gather information about trends, needs, and new product development. It is important to understand that even though these technologies are not applied in industrial processes itself, their implication on the production line is enormous.

SOCIAL NETWORK

Nowadays, social networks are one of the most common digital technologies in the world. Online platforms such as Facebook, Instagram or WhatsApp are used every day by millions of people all around the globe. For instance, in 2016 Facebook announced that there are 1.71 billion active accounts of which 1.17 billion are daily users (Zephoria, 2017). This means for companies all around the world that there are billions of customers that can see their products and brands via social networks. Due to this platforms digital marketing was created and rapidly became popular as a straightforward way of increasing sales and brand recognition. In figure 8 it can be seen how revenues obtained by using digital advertising increase in the USA at a constant rate every year.

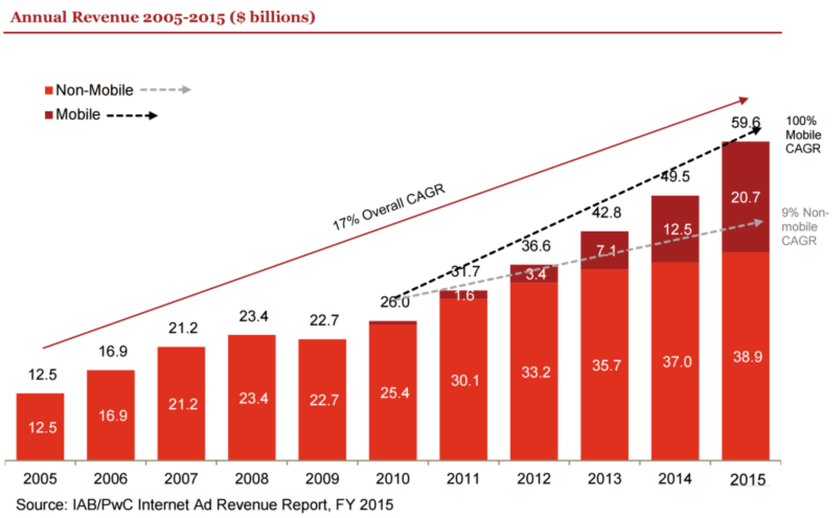


Figure 9 – US revenues due to digital advertising (PwC, 2015)

Even though social media seems not to be part of a factory or have any influence in the industrial processing, there are two primary reasons to which this innovation disrupt the industry: First, social media allows companies to have constant feedback about their products. They can see what customer like, don't like or believe in, allowing companies to change their production line based on customer real needs or desires, everything within hours, without a marketing study or survey. For example, if Nike wants to know about their new design for their shoes, they can easily show the design in social media and thousands of reactions of customers will argue and vote within days, given information about the shoes without even start to make a real pair of shoes. Secondly, smart factories should also build up their social network in which technician, engineers, employees, directors, suppliers and customers get together and collaborate on a daily basis. It is vital for the new industrial revolution, that collaboration takes places in the most transparent and efficient way. In this case, social media can be abstract into a factory environment in which information is transfer trough everybody and for everybody.

APPS AND WEBSITES

Apps and websites are technologies that developed due to the smartphones and internet connection. For instance, in the last years the growth of mobile commerce has constantly increased as it is shown in figure 10. These devices combine with an appropriate wireless connection allow customers, clients, and employees to download an application and connect with each other thousands of kilometers away.

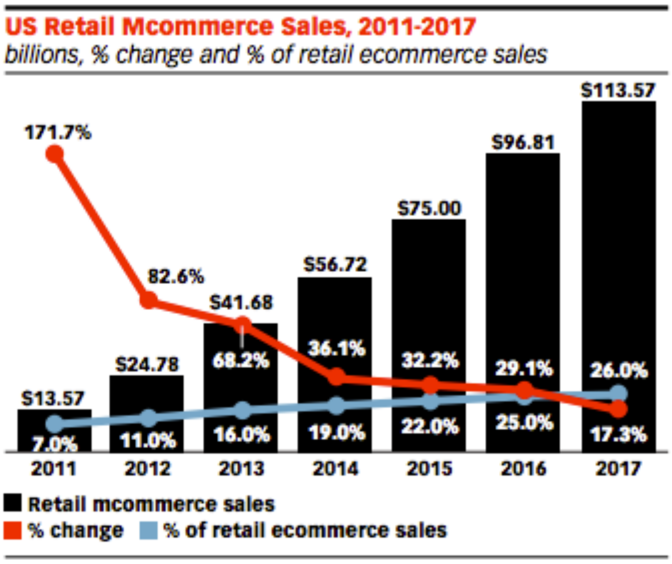


Figure 10 – M- commerce sales in the US (emarketer, 2011)

In the industry apps and website have various applications. E.g. technical support apps are replacing the old planned maintenance. In which a machine fails, the operator calls the support engineers, after a couple of hours they arrive, try to see what could be the problem and then fix it. Instead, via an app, the operator can communicate with a customer service platform in which technical support will be given with information about the state of the machine, the problem and how to solve it. Another application of Apps and websites are based on asset management control, machines communicate via internet and sensors if something unusual is happening while performing. In this case, asset managers can notify of the malfunctioning, and the maintenance team can plan a repair without the machine breaking up. As an example, the Siemens Industry online support app gives 24/7 technical support to the Siemens machines in such a way that the factory can reduce its downtime. They also have a control made app that controls devices from the smartphone without sophisticated software, algorithms or technicians on site. Finally, like it was mention before, consumers with an internet connection can easily customize their product through an app or website. This information about the customized product goes directly to the machines in the smart factory, and the production process starts. In this scenario, the customer via websites or mobile apps fits in his requirements and pulls the production process, without inventory and in a Just-in-time (JOT) production line.

WEARABLE

The wearable technology is a vital part of the internet of things (IoT). This concept is defined as devices or products that use sensor technology and wireless connection to send information continuously. In the wearable technology, there are a lot of companies that make all type of products combining and closing the gap between cyberspace and reality. Smart Watches augmented reality screens, Snapchat glasses or smart clothing are some of the wearable devices that are currently in the market. For this document, wearable technology are those tools that help make better and efficient the maintenance process. Making wearable devices is also part of the industry 4.0, but it will be discussed in the section of digital products.

For the industrial processes, wearables are particularly attractive for remote maintenance. These technologies help technician or operators find failure quickly even before it occurs and the production has stopped. Wearable devices, Apps, and sensors are combined in such a way that the sensors send information in real time about their current status; this means that if the machine detects any malfunctioning, it would immediately send that information to the data center. As soon as it arrives at the data center, it is immediately redirected to the apps. This apps or websites will notify the asset managers and technician about the status of the machine and some useful information to plan maintenance. This app also works to send a notification to the provider of this machine and the engineers that are outside the factory. Finally, with the help of the app and the rapid detection of the sensors the technician can go to the machine, wear special glasses and have a video conference with the engineers in the control center. He can also see in different views what is happening inside the machine and finally, he can officially fix the problem. In figure 11 an image of a maintenance operator using a tablet with augmented reality to solve a problem in the factory is another example of how the future of support maintenances will be in smart factories.

Figure 11 – Augmented reality used by BOSCH in engine maintenance

2.7 CONNECTIVITY

Connectivity is the domain that makes possible the link between physical objects, machines, robots and data centers. In this field telecommunication systems like routers, the wireless device has been improving at a tremendous pace in the last decades (GTAI, 2016). Technologies like WIFI connection or broadband are less than 25 years old and nowadays is almost impossible to live without them. Although current technologies are connecting millions of people, every day more devices are connecting to the internet and each one of them is transferring more data than ever before. Due to this situation of large data transfer and internet of and for things, a new brand of communication systems arrives, making more powerful, faster and reliable the access to the web (Schwab, 2016). In this section, it will be the analysis of the technologies that will improve the connection in the industry.

I4.0 technologies in connectivity

In this era in which 204 million emails are sent per minute, 500 million tweets are posted every day, and more than 5 million Terabytes of data are compiled on the internet (Daily Mail, 2013). Connectivity is everything. Fixing a machine when the engineers are all around the globe, making designers digital products into real goods and having a complete digital factory that simulates the real one, are some of the technologies that wouldn't be possible without the technologies that will be mention in the next paragraphs.

DATA TRANSMISSION: INFRASTRUCTURE FOR DATA TRANSFER

Data transmission is the title for all the technologies referring to the infrastructure in which data is transfer. For instance, WIFI or Ethernet are the most typical systems in which users connect to the internet. In one hand, WIFI users have been experiencing problems with the WIFI connection in places where many devices connect and transfer data. In this cases, the rate of data transfer is inversely proportionate to the number of devices (the more devices connect to the WIFI spot the slower the data transfer gets). On the other hand, Ethernet is only useful when there is a physical connection from the transmitter to the receptor. Therefore, for smart factories in which thousands of elements connected through the internet, WIFI and Ethernet will be left out by other more powerful technologies such as MU-MIMO, WiGig, Capacitance coupling, three bands and powerful routers.

Multi-user MIMO or MU-MIMO is a technology that keeps constant the data transfer rate regardless the number of devices that are connected to the network. WIGiG is another technology that is being developed by Cisco, in which the router creates a signal frequency that is ten times higher than the regular WIFI, in practical terms, this means ten times more speed in data transfer. One of the biggest challenges that are facing this technology is that due to the high frequency, the signal is not able to cross walls or obstacles. The three band model is a technology also develop by Cisco in which they combine the use of MU-MIMO and WiGiG to improve the data transfer rate regardless of the devices connected. This technology will allow smart factories to have many connected devices with a reliable and extremely fast data transfer.

Moving towards even more innovative technologies, the Swedish company Ericsson has been developing technology in which the human body can transfer data from one device to another. This disruptive innovation is called Capacitance coupling because as the name suggests, they use the body capacitance to send and receive data without any equipment. Ericsson says that this technology will be in the market in one or two years, depending on regulation and health care studies. Capacitance coupling could also be in the future the way in which workers just by touching machines or robots get information about their current status and maintenance plans.

SENSORS

The great drop in sensors cost as it is shown in figure 12, is what makes the fourth industrial revolution real. CPS as mention before, communicate and send information between each other, but without sensor technology, there is no chance that a robot or machine can produce data. Is due to sensors that devices can deliver information about weather, temperature, time, pressure, pollution and many other relevant variables for production processes all around the world.

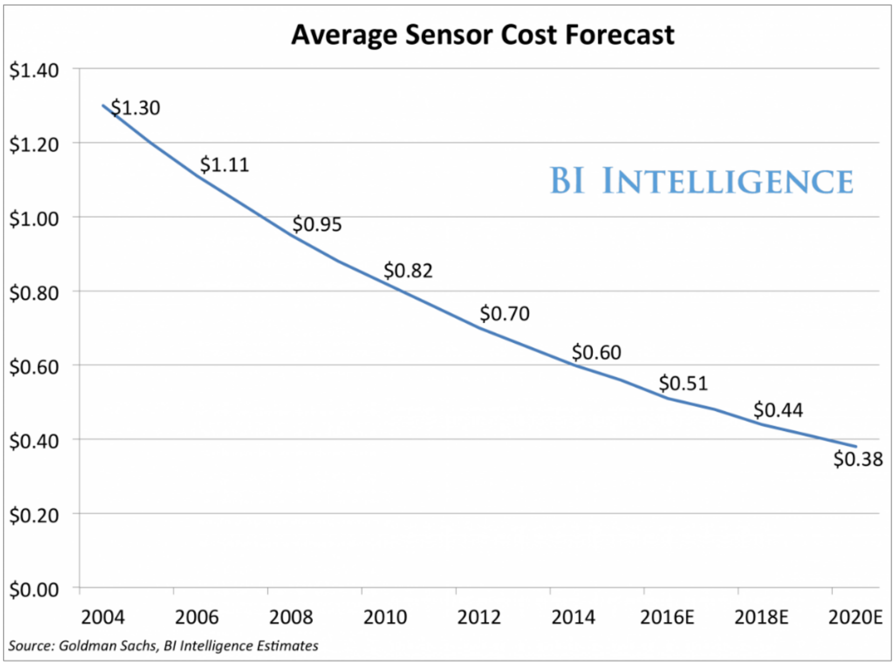


Figure 12 – Sensor cost forecast by Goldman Sachs (Goldmansachs, 2014)

Sensor technology is particularly important for maintenance and production process operations. On one hand, machines can perceive if there is an unexpected change of pressure if they have installed a thermometer. This information given by the sensor is what alerts the maintenance engineers that something is malfunctioning in the production. Without a connected thermostat, there is no way that the engineers realized there is a change in temperature inside the machine, and will probably understand when there is an explosion or leakage. In the other hand, via all type of sensors, the process can be controlled and optimize faster and in real time. For example, if a machine has a queue of products to be treated this information can be captured by weight or laser sensors. This information is sent to the control office and engineers will simulate the behavior of the production line and make arrangements, so the production process gets leaner, avoiding delays and waiting times.

DIGITAL PRODUCTS

Digital products, is an innovative and cost efficient way of making customized products, improve quality, customer service and optimizing the process line. E.g, the customer, buys via the company's website a pair of shoes completely customized by him. Digital production process starts with a wireless device and a bar code that machines can read and understand. The shoes start being made entirely independently looking for the machines that best suit for them, each pair of shoes having a different and unique path to follow in the factory. This pair of shoes will remain with the wireless device and bar code in such a way that company keeps track of where are they and their status. The customer will have the opportunity to scan the bar code and have real information about the way he walks, km he has been walking and health advice.

Digital products are currently being made by the car industry, and some companies like Acer or Huawei are experimenting with this IoT technology for their smartphones. There are several prototypes in the textile industry and construction, in which they build up elements that connect and send useful information to factories, customers, and suppliers. These digital products have been increasing and improving dramatically, in fact as it is shown in figure 13 the penetration rate and forecast of the digital products are growing in such a way that in 2020 the number of connected devices will be more than two times bigger that the world's population.

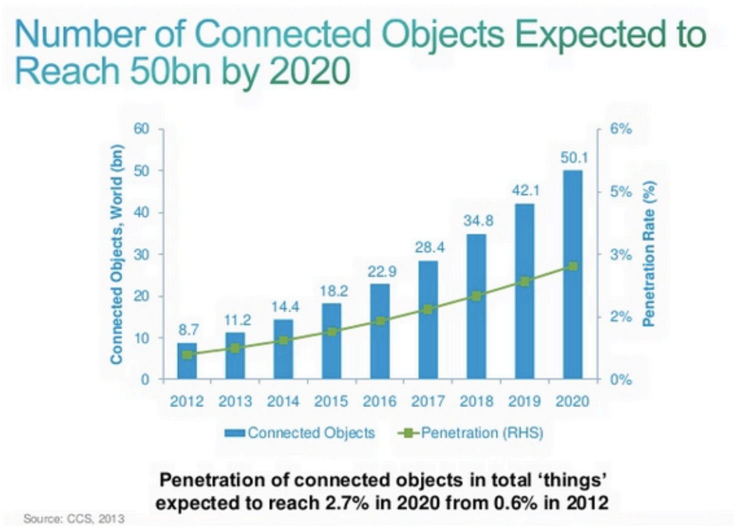


Figure 13 – Digital products forecast for 2020 (Cisco, 2013)

CLOUD COMPUTING

Cloud computing is an innovation that allows users to store, analyze and communicate information via internet in real time. Some of the most common cloud computing platforms are Dropbox, Google Docs or Yahoo finance. For the industry, cloud computing will be vital because of five main reasons: First, CPS will use cloud computing soft wares to communicate with engineers, customers, and suppliers in such a way that all the main stakeholders understand the data. Second, big data analytics and simulations can be done using the resources and algorithms of cloud computing platforms. For instance, Microsoft develops a cloud software called Azure that can analyze any information using virtual machines all around the world. Third, Integrated design processes can be produced efficiently having cloud computing platforms that allow to modify, change, visualize and share projects and deliverables. Companies like Oracle and Sap have some digital platforms that allow different parties from the same company to interact actively in projects like website development, construction, newspapers, and car manufacturing. Fourth, cloud computing improves collaboration between companies. For example, the website Apptus develop software that connects enterprises in the same sector with the purpose of share information. With Apptus, businesses can communicate with their competitors to exchange information about the market, future developments, and problems that the industry faces. This revolutionary concept describes perfectly how cloud computing uses data to share knowledge in an efficient manner. Finally, the use of cloud computing allows factories to allocate information in a smart and efficient way. This aspect is particularly important in the future of smart factories because when thousands of devices send data into the cloud every second. Is vital to have a proper system of filtering and understanding what information is relevant and which one isn't, to find more information about cloud computing filtering and seeking information look next title of digital data.

To make a smart factory, it is vital to have a cloud computing software. These platforms are the middle point between CPS and decision makers. In the Azure platform, for example, there is no need to make virtual machines and have data centers that process data continuously. Azure leverage on thousands of virtual machines that Microsoft has, providing an excellent analysis of data in real time. With this outsourcing of data analytics and storage centers, the smart factories will need less investment and workforce to pull their production process.

Regarding state of development and regulation, cloud computing is getting more popular in the industry, but it is still in the infant stage with only some few early adopters. Concerning regulation, governments approved the different type of cloud computing soft wares, but special considerations must be taken concerning cyber security when building a smart factory. If a smart factory outsources their data storage and analysis to other more specialized companies, they will have to sign contracts that secure companies that their information is going to be confidential.

2.8 DIGITAL DATA (THE DNA OF THE I4.0)

In the Fourth Industrial Revolution, data is the way in which a cyber-physical system composed of digital products, raw materials, suppliers, customers, decision makers, stakeholders, soft wares, engineers, and operators can communicate. In figure 14, it can be seen how data is getting bigger each year. In fact, this graph shows that last year data transfer arrived at 1 Zettabytes (10 to the power of 21) equivalent to more than 100 million iPhone 7 full of information (Bell labs Consulting, 2016).

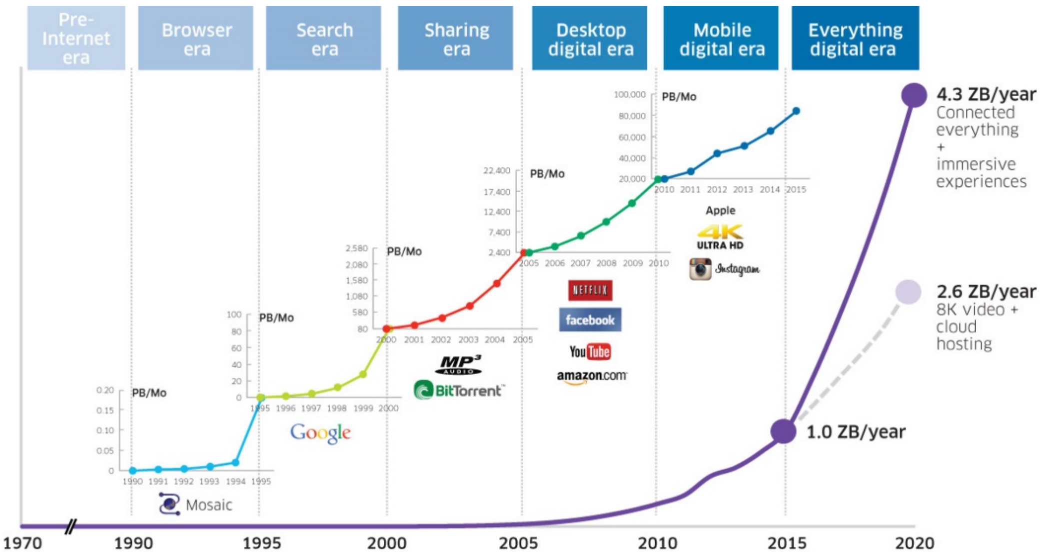


Figure 14 – Data forecast for 2020 (Bell labs Consulting, 2016)

This impressive amount of data creates new challenges in collecting, filtering, loading and analyzing data. Herewith, in the following the new I4.0 that deal with data, and get useful information to make decisions assertive, will be addressed.

I4.0 technologies in digital data

It is well known that data helps decision-making processes be more accurate and less risky. Shortly smart factories can take the decision based on real time information and can do scenario planning with the digital factory in such a way that they keep the flexibility and responsiveness for the changing environment (Schwab, 2016). The following technologies or innovations are ways in which smart factories can take advantage of a connected world, improve their sales, lower cost and comply with governmental regulations.

BIG DATA ANALYTICS

The big data analytics, as the name suggests is an activity of managing a large amount of information. This technology is used when the amount of data can't be analyzed by one computer alone, there is a continuous flow of information entering the system and when the rate in which information is received is fast and variable. In this scenarios, big data uses the computing power of multiple virtual machines (Hadoop) to split data and apply categorizing, clustering and predictive algorithms to find trends, errors or other information related to the company core business. For factories to implement big data analytics, there are different steps to follow.

The first step is to define the data source. There are five different sources where information can come from: people, transactions, the web, machine to machine (M2M), biometric, others. People data is commonly related to emails, post, texts, surveys, interviews, videos and all the digital expressions that are made by individuals. Transaction data is usually based on accounting and finance operations. For example, transfer money from one account to other, buying with a credit card, changing currency are data related to this field. Web data is the information coming from the websites directly. Clicks, websites visited, time on the site are some standard data information. This information is mainly used by digital marketers to understand the customer experience and improve sales. M2M is the information that is generated by a device, for example, sensors that measure temperature, air quality or pressure send their tests to other machines. GPS is one of the most common used M2M information systems. Biometric data is given by security services, frequently related to eye scanners, finger scanners or DNA readers.

The second step in this process is transforming data. This process is made by soft wares called ETL (extract, transform and load). This platforms extract data from the source, convert it into consistent data and finally load it again in a readable way. Part of the second step is to store data; this process can be done in four different clusters depending on what type of outcome is desired. The first group is a key value; which are ways of organizing data like in dictionaries (using keywords or characters). The second group is by files. In this type of arrangement, data base is semi-structured and divides the information into different files according to the subject or keywords. Third, are relational clusters; storing systems that make a network of nodes, parameters, attributes and arcs. This type of storage is especially useful for social networks analysis. Finally, the column-oriented storage is the most organized one and is similar to the file one, but it stores data in more dimensions. It is very efficient when each keyword has 100 or more attributes. This storage allows to save in chronological order and group columns in families, something that is hard with the use of other storage methods.

After extracting, transforming, loading and storing data the next step is to analyze it, this could be the hardest part of the entire big data analytics and requires different types of approach depending on the goal and the data. The most common tools are predicting, categorizing and clustering. Association, for instance, is an excellent categorizing analysis in which the user wants to find relations between variables. Data mining is a predictive approach used to predict and forecast behaviors. This procedure uses statistic methods to model and predicts possible scenarios. Clustering is a type of data mining, which purposes is to find a relation between clusters. It also uses statistic methods and some other probabilistic models. Finally, text analytics is a categorizing method that has the goal to extract information from documents. There is other text analytics that uses predictive tools to predict words for emailing strategies or posting analysis.

Finally, the visualization of data analysis can be done in thousands of different ways, from the text, graphics to forecasts. This last part is of particular importance to give convincing arguments to go for a decision or not.

Although the industry needs to transform towards the digital era, there are some problems that they need to face due to the new age of digital data. One of the biggest problems is Garbage in garbage out (GiGo). Present when the source is giving wrong information, and therefore the outcome of the analysis give nonsense. This type of problem is especially coming from sources like M2M and people. For example, inventing surveys results, manipulating data outcomes, changing values or a wrong configuration of devices, are one of the most common factors that make GiGo affect the decision-making process. Another problem is the mistaken or biased analysis. In this case, the engineers that are working with the database arrive to bad conclusions because they choose a wrong approach. The third problem related to big data is that if information is not well organized or is too big, the analysis will be slow, tedious or expensive. Factories that have these big data problems usually need a hundred computers and each run of analysis takes a few days. In that case, the benefits of having analytics are compensated with the cost and delays that the analysis will take. Finally, the last problem is basing decisions on real data analytics without giving any second thoughts. This last one is important because statistics and probabilistic approaches provide useful insights in relation to the input and data but, if there is information missing or there are plenty of assumptions in the model then is probable that the result won't be accurate nor assertive.

Nowadays, there are different soft wares, companies, and consultants that help out companies to solve their problems related to big data analytics. For example, Accenture Big data services are the business line of the US-based consultancy that works with the industry to deliver high-quality big data services in all the steps mention before. There are also cloud computing soft wares like Azure that have similar services, although one of the limitations of cloud computing is the ability to process data trough internet; This is still one of the pitfalls of the cloud computing big data services. Finally, the company could also invest in making their big data center, this at the beginning will be costly since it means increasing the workforce, buying equipment and introducing to the workers this concept. But experts say it will pay off when efficiency goes up, cost down and decision making assertive and faster (GTAI, 2016).

Another important part of big data analytics is demand forecast. In this sense, a great advantage of data analysis is that is allowed to reduce uncertainty in the prediction of threats or opportunities. In the case of smart factories, the demand outlook is one of the most important issues that can shape the factory in functional, structural and operative ways. Inventory, lead times, delays, machines, processes and logistics are aspects that can suffer from changes in demand. For instance, a company that can predict better the need for a product can reduce its inventory and shrink the process line.

Market forecast depends on historical sales and real-time conditions. For historical sales, keeping information update and use some statistical methods like time series or linear regression is enough. For real-time conditions, data analysis becomes more important. Extract information in real time, transform, analyze and combine it with historical data is the real added value of demand forecast tools. For instance, computer soft wares like Salesforce connects by cloud computing sales and production branches in such a way that production engineers know in real time how much inquiries are made by the sales staff, this, to decide whether to produce, buy or modify their current production line.

Database routing and devices

Since big data analytics is about storing, transforming and analyzing; the speed to which data is analyzed and the capacity to which data can be store are the two important aspects for big data to work. In this case, speed and storage are conditioned by physical objects such as hardware and RAM. In one hand, speed in data processing have increased drastically in figure 15 a graph of the evolution of the data processing is shown, and it can be seen that the rate of development is linear in the logarithmic scale, meaning that the relation between processing performance and times is exponential. In fact, a new iPhone has the same processing power that a super computer made by NASA 20 years ago. In the other hand, as it was showed in figure 6, the cost per Gigabyte of storage has been decreasing in the last decades at an exponential rate as well. These facts proof that big data can continue improving and every day it will become easier to analyze companies, markets, trends and factories with more and more input of data.

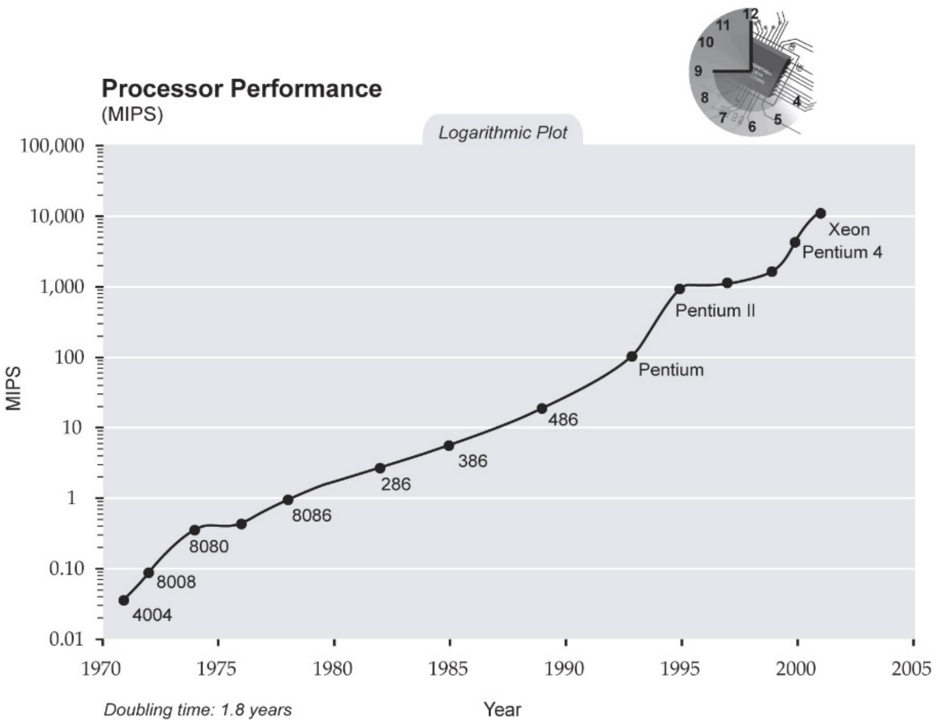


Figure 15 – Processor performance vs. year (logarithmic scale)

Another aspect in this database routing is that cloud computing allows factories or customers to run rigorous analysis supported by on-demand virtual machines. For example, in the software Azure, the company can decide how many virtual machines they need for the analysis. At that moment the software reserves individual virtual machines from their system to run the analysis and discount money from the company's Azure account.

ARTIFICIAL INTELLIGENCE

Artificial intelligence or AI is a computer program or machine that learns how to do tasks that require forms of knowledge and are usually done by humans (Russell Stuart J, 2003). In 1955 the Dartmouth project in artificial intelligence identified the seven areas in which a robot or computer program can be considered as AI (Russell Stuart J, 2003) Simulating higher function of the human brain, programming a computer to use general language, Arranging hypothetical neurons to form concepts, determine problem complexity, self-improvement, abstraction, and creativity. Based on this definition some companies have been developing technologies that fulfill those requisites. For instance, IBM's Watson robot won the price in the Jeopardy quiz show against the two best Jeopardy player in the history (The New York Times, 2011). Watson access to 200 million structure and unstructured files and without any internet connection it manages to find the correct answer for the jeopardy's game. Currently, the

Watson software is now being used for medical purposes (IBM , 2016). Another example of AI is Google Deep Mind project. This project has the aim to use artificial neurons networks to simulate the human brain. In fact, in 2015 the AlphaGo program manage to beat 5 to 0 to world champion of the game Go. This price was particularly important because this game is considered particularly difficult for computing systems due to the enormous amount of scenarios and possibilities. Current soft wares develop by this project have been under trial by hospital and research institutes.

The influence of AI in the industry is not yet perceived because this technology is still on the development face and there are some ethical questions, which need to be solved by scientist and politicians before first AI soft wares can be placed in smart factories (Erik Brynjolfsson, 2016). However, companies are already starting to look at the impact on the operators, decision makers, and customer, and take a position to see whether AI will create more benefits or damages to our industry and society.

2.9 CONCLUSION

During this entire chapter, all the theoretical concept and literature study was described. Starting from the definition of the process industry, and its characteristics. Following with the definition of a cyber-physical system and why this is the atom of the new era of digital developments. Explaining each of the four clusters, in which the I4.0 is divided, and finally, describing each technology with the several effects that it will cause in their context. It is important to mention that there is still debatable, which technologies represent the Industry 4.0 and which components are important to make cyber-physical systems. Furthermore, all of these 14 technologies mention above have a clear impact and functionality in the manufacturing industry. For instance, technologies such as robots, artificial intelligence and additive manufacturing (3D printing) have a disruptive impact on the manufacturing processes because they could change the way of making end products. However, after this literature study is it still not clear whether these technologies could also impact the process industry. Therefore, in the following chapter, there will be an assessment of the possible impact that each one of these technologies might have in the process industry.

3. The I4.0 for the process industry

This chapter, as the title suggests, will determine, based on qualitative research, which of the technologies mentioned in figure 2 might have a higher potential for the process industry. The method to make this qualitative analysis is the *phenomenological qualitative approach* (John W. Creswell, 2013) in which 32 interviews were conducted in 2016 with experts in The Netherlands, whose level of expertise is divided into two fields. On the one hand, 15 interviewees were senior consultants, university professors and managers of companies that are involved in the process industry. On the contrary, 17 experts such as academics, researchers, I4.0 consultants and managers of I4.0 manufacturer companies were interviewed to know about limitations, challenges, and potentials of each I4.0 technology, described in chapter 2. These interviews were done because there was not enough reliable information about the Industry 4.0 technologies in the process industry, as it was explained in Chapter 1. Before starting with the research and explaining the results of the interviews, it is important to define the criteria to categorized each technology based on a qualitative approach.

Categorizing criteria for the i4.0 technologies

The rules to see whether a technology might be interesting or not in the process industry in the short term is divided into two main aspects. First, the impact on the process industry, which is the direct consequence (positives or negatives) that a technological development has on an environment, and the magnitude of this effect (Tan, 2004). For instance, computers were a technology that generated enormous positive consequences in the third industrial revolution; therefore, it is considered to have a high impact in the industry. Second, the maturity of the technology, which is an important indicator for innovations because it is a measurement of the cost and level of propagation of particular technology (Ruttan, 2000). For example, a technology that has a low maturity usually means that is expensive and is not commercially available. In this research a technology that is mature and its impact is disruptive will be a KEY technology in which companies should prioritize the investment, in the next section of this chapter there will be a clear explanation of the assessment of the technologies for the process industry.

3.1 Assessing the I4.0 technologies

This section will determine the I4.0 technologies that should be prioritize by companies in the process industry. However, due to the lack of trustworthy information in the literature, it was opted to follow a qualitative methodology based on the book "*Qualitative Inquiry and Research Design: Choosing among five approaches*" by John W. Creswell (John W. Creswell, 2013). Given the fact that the primary research goal is to foresee the impact of the I4.0 technologies in the process industry, it was opted to choose a *phenomenology research approach* in which each technology in the process industry will be treated as an event or phenomena (John W. Creswell, 2013). Herewith, these 14 technologies will be explained profoundly by the 32 interviewees in different isolated opinions, after these interviews, the phenomenology methodology suggests compiling the information gather in the interviews, in a coherent and narrative manner, pointing out the characteristics of the phenomena and the views from the experts. Following this approach, the assessment will describe the opinion of the experts on each technology, insights about limitations and challenges of the techniques, and finally, it will give a qualitative score for both impact and maturity index. In the following section, there will be a better explanation on interview methodology.

Interview methodology

As mentioned before, 32 experts were interviewed in a period of one month between September and October of 2016. These interviews were semi structured with some fix questions and some other customized, based on the interviewee expertise. In figure 16, it can be seen the different types of experts that were chosen for the interviews.

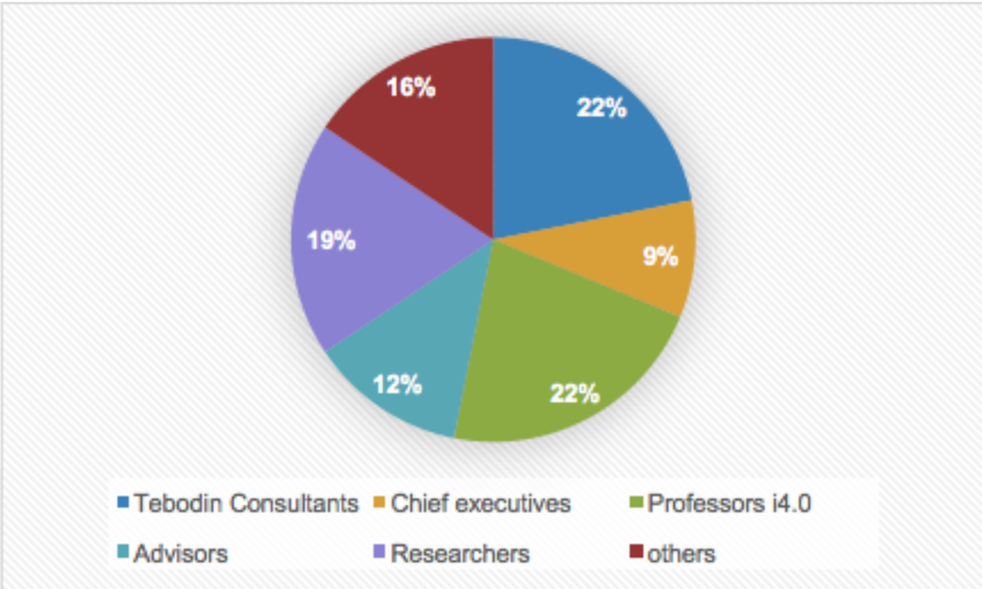


Figure 16 – Type of interviewees

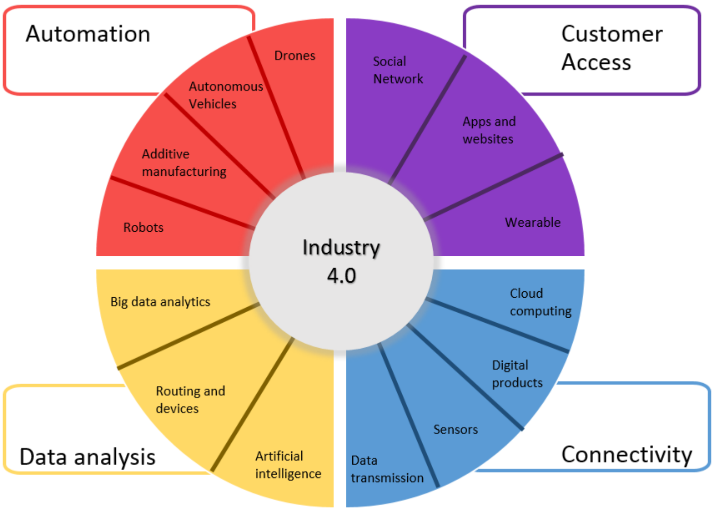
The goal of these interviews was to have a clear idea about the limitations of the technologies for process applications, and an opinion of the possible impact that the technology could have in a factory in the near future. Furthermore, in order to get an acceptable overview on all the technologies, at least 2 interviewees were found to describe each one of the i4.0 technology, in table 1 there is a list of experts that chose to talk about each i4.0 technology.

I4.0 Technology	# of interviewees
Drones	5
Autonomous vehicles	3
Additive manufacturing	10
Robots	7
Big Data analytics	8
Routing and devices	2
Artificial intelligence	10
Data transmission	3
Sensors	12
Digital products	4
Cloud computing	9
Social network	3

Apps and websites	4
Wearables	4

Table 1-Number of Interviewees per i4.0 technology

Finally, the semi structured interview had some fix questions that allowed each technology to have sufficient background to give a proper qualitative score. In this interviews the following questions were asked to all interviewees:



- On figure 2 there is an overview of the i4.0 technologies, which one of the technologies are you an expert on? What type of research are you involved on?
- Based on the technology the interviewee chose: which is the biggest limitation that this technology has and why?
- Based on the technology the interviewee chose: which is the current level of maturity of this technology (concept, prototypes, first commercial products, few competitors, mature product). Which applications have you seen of this technology in process installations?
- In your opinion when do you expected this technology to have an impact in the industry? What steps are need to reach that impact level?
- Categorize the technology in (disruptive, important, interesting, non- operational and useless) based on the impact that might cause in 5 years to the process industry?

Additional to the fix questions, there were also customized questions that were based on the description of the expert on each technology and the conversation that was held during that interview. Finally, all the personal information of the 32 experts will be kept confidential to protect the interviewees identity and field of work. This was essential because it allowed experts to speak about their limitations in the field of research and their opinion about the future of process installations.

Score criteria for categorizing the i4.0 technologies

The criteria for categorizing the i4.0 technologies in the process industry is based on what the experts believe might happen in the coming future in the process industry. In Table 2, the entire grading scale is described. E.g A technology "X" is being developed in universities and research institutes with no commercial devices or solutions, its impact on the process industry might be only in non-operational services, like cleaning or administration. Hence, the scale in Table 2 will grade technology "X" with a Low in maturity and Low in impact.

IMPACT		
Disruptive	Disruptive innovations are technologies that change the entire way of delivering processes. E.g Uber in urban transportation, Steam machines in manufacturing and cell phones in communication are examples of disruptive innovations.	Very high
Important	Important innovations are those that will improve several operational, supply chain or customer access processes. E.g Important innovations are office software for organizations, lean manufacturing in construction.	High
Interesting	Interesting applications are those that in combination with other technologies will help operational processes to get efficient.	Medium
Non-operational	No operational applications are those that won't change or improve the operation. However, they will enhance non-operational functions such as cleaning, surveillance, employees' communication, accountancy, etc.	Low
Useless	Useless technologies will not have an impact on the operational nor non-operational processes.	Very low
MATURITY		
Mature	Mature technologies are those that are commercially available. These technologies have well-known applications and risks.	Very high
Young	Young technologies are commercially available; however, their risks are not well known, and there is plenty of space for further developments. These technologies will be fully developed in less than five years.	High
Infant	Infant technologies are available only by some companies. Their applications and risks are not known accurately; however, companies are investing capital in it. These technologies will be mature in 5 to 10 years.	Medium
Research	Research technologies are not available in the market. There is only some research undergoing, but the limitations are still significant. These technologies will take more than ten years to mature (if they mature).	Low
Concept	Concept phase is the initial stage of innovation. There is only an idea (concept) of what the technology could do. There is almost no research on the topic, and it 's hard to predict if they will succeed. Ultrasonic planes or air energy collectors are some of the concept technologies.	Very low

Table 2 - Criteria for selecting the best fit in the process industry

In the following section the innovations, discuss in chapter 2, will be assess based on the same clusters of chapter 2: Automation, Customer Access, Connectivity, and Data analysis. In figure 17,18,19,20 there will be a recap of all the technologies and the cluster to which they belong.

3.2 AUTOMATION IN THE PROCESS INDUSTRY

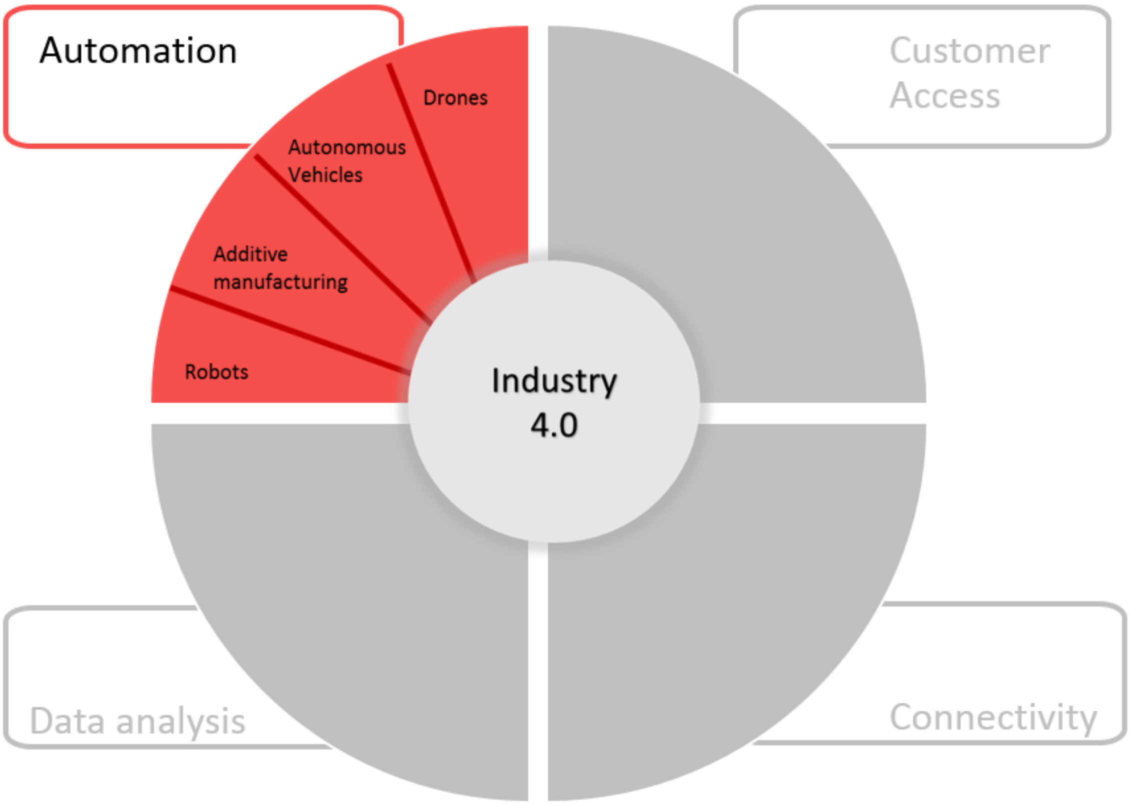


Figure 17 – Automation selection diagram

DRONES

Drones have been evolving at a fast pace, making available solutions with unmanned aerial vehicles (UAV's) more and more common and accessible than ever before. For instance, drones in logistics will have an enormous impact on almost all industries, but their technology is still in a research stage (UAV's for industrial purposes will only be commercially available in 20 to 25 years). In other tasks, a senior consultant in asset management and reliability for the process industry mentioned that drones could be useful in the inspection of significant assets that are difficult to reach or dangerous for humans due to harsh environments. An example of this type of controls could be in tall towers in refineries or chemical plants that are slim, tall and typically hot. An advisor for the ministry of infrastructure in The Netherlands mentions the importance of drones for surveillance of construction pits and large surfaces. E.g. - In significant production facilities or infrastructures, the idea of having drones that inspect and detect anomalies is an efficient and safe way of surveillance. Unfortunately, for the purpose of this research, the application of this UAV's is rather accurate, and this technology will not disrupt the way factories work and produce. In fact, the only impact visible will be in the asset management and surveillance. In conclusion, drones technology is at a young stage, but their applications are only in the non-operational activities, making their impact low.

AUTONOMOUS VEHICLES

As well as drone technology, autonomous vehicles (AV) will have a significant impact on logistics once they are regulated and commercially available. However, this technology is still at a research stage, and it will require a couple of decades until mature trucks and industrial AV, self-drive across Europe (see chapter 1). Moreover, none of the experts mentioned the consequences that this technology could have in the way factories operate and interact with customers and suppliers,

this means, that this technology impact score is very low for the process industry and their score on maturity is also low with no autonomous vehicle commercially available at the moment.

ADDITIVE MANUFACTURING (3D PRINTING)

As it was mentioned in the previous chapter, 3D printing is a disruptive innovation, and therefore it 's hard to predict the impact that this technology will have shortly. According to a post-doctoral researcher on additive manufacturing (3D printing), there are different pitfalls that this technology has to overpass, to become competitive in the industrial market. The first pitfall is Time: nowadays 3D printers can take days to make a 1-meter tall piece, this means, that the technology is not scalable enough to make steel beams and columns in a tight schedule. Secondly, it is Expensive: the fabrication of items made by 3D printers is usually costlier than the traditional methods. This margin becomes less necessary when the material or designs are harder to make regarding shape, but for ordinary cases, 3D objects will always be costlier than traditional ones. Thirdly, not all the materials can work for 3D printers: composite materials, for instance, are difficult to make on additive manufacturing. They require more time to make the end product and more labor to complete the process. Finally, additive manufacturing consumes plenty of Man Hours: the way in which 3D printing works requires human labor to check, move and perfection the end product. In practice, once the final product is 3D printed, workers need some hours to complete it and make it as good as a traditional molding method.

Due to the significant pitfalls of this technology, experts diverge in their views about the possible impact that this technology might have in the process industry. For practical purposes there is a group of experts that will be called pro-3D printing; they believe this innovation is disruptive and vital in the way factories will look like shortly. These experts support the idea that in less than five years 3D printing will be powerful enough to make operational assets more efficient. E.g. - A chemical factory can start making their vessels, pumps, heat exchangers and property using their knowledge on the production line. This idea suggests that, when a part fails in the factory, a spare part will be 3D printed rather than bought by the manufacturer. This group of experts also look at additive manufacturing as the future of the way of producing in 20 to 25 years. In their vision, microreactors and 3D printers together in a single machine will produce the material and the product 3D printed. These experts also think that additive manufacturing allows companies to make quick prototyping. Thus, helping the industry to get new products faster.

There are other groups of experts that are called No-3D printing. This group sees additive manufacturing necessary, but not for the process industry. They argue that the process industry is too conservative to apply this technology at a large scale. They also agree that there won't be significant changes in the way factories produce materials, arguing that 3D printing is a disruptive innovation for the manufacturing industry, but the impact on the process industry will be indirect and loose.

According to a Fabot manufacturer engineer, the future of 3D printing is divided into two major fields of research, both well sponsored by Universities and governments. The first field is continuous 3D printing, which was already explained in chapter 1. The second field is Fabots (fabrication robots): this technology unifies additive manufacturing and robots to build up bigger products that in 3D printers are impossible to make. Both of these technologies are still in a developing stage, but the potential that they might have in the process industry is already palpable. For instance, Fabots in construction that builds up concrete and steel structures are now in development at research institutes such as DAFB (Swiss National Centre of Competence in Research Digital Fabrication). In the other industries, the evolution of microreactors (like FlowId) combined with 3D printing will change the production line.

In conclusion, even though the additive manufacturing, Fabots, and continuous 3D printing are still in R&D in universities, research institutes and some companies, it is clear that the impact of this technology in the production process must be investigated and adapted to each business model. In this case, it is recommended for companies in the process industry to start developing prototypes and looking at what type of production process could additive manufacturing play a significant role.

For all the reasons mentioned before, the score on impact is very high because this technology could disrupt the way process industry makes end products. However, the score in maturity is low because there Fabots are only at a research stage.

ROBOTS

According to Klaus Schwab, in the manufacturing industry, it is paramount to connect the robots that assemble and weld with the entire process. Indeed, by doing that, managers can monitor, and robots can decide how to produce, when and where, this will increase the efficiency of the production line as well as the adaptability of the entire factory (Schwab, 2016). However, in the factories of the process industry there are no robots because continuous process lack of assembly lines and the production is not made in units, but in flow output instead. A senior consultant of the supply chain for the Oil and gas sector explains that in refineries there are no robots because the end product is not visible by operators and changes occur in reactors that are completely sealed and with tight for safety purposes. He explains that the use of robots will not be required in operation and won't add value to the process itself even in 30 years.

In non-operational functions robots are useful in several environments as shown in chapter 1, like heavy lifting in construction, subterranean and subaquatic vessel inspection in O&G, cleaning in hazard environments, surveillance and many others. For these cases, robots will reduce non-operational costs, but the impact will be minimal, and there won't be any change in shape, structure or functionality of the factory. Furthermore, the robot technology is still in an infant stage as well and, even though they have been improving enormously in the last ten years, there are still dangers for human-machine interaction. A professor and researcher in the field of artificial intelligence argue that maybe in 20 to 25 years, robots will have the sufficient maturity to develop natural human activities with a complete understanding of their environment and with a proper human-machine interaction.

In conclusion, robot technology has a medium impact, because in combination with other technologies like 3D printing or cloud computing they could replace some operational activities.

However, robots are still at a research stage for the process industry, and it will pass some years to see robots that replace basic maintenance tasks in factories.

3.3 CUSTOMER ACCESS IN THE PROCESS INDUSTRY

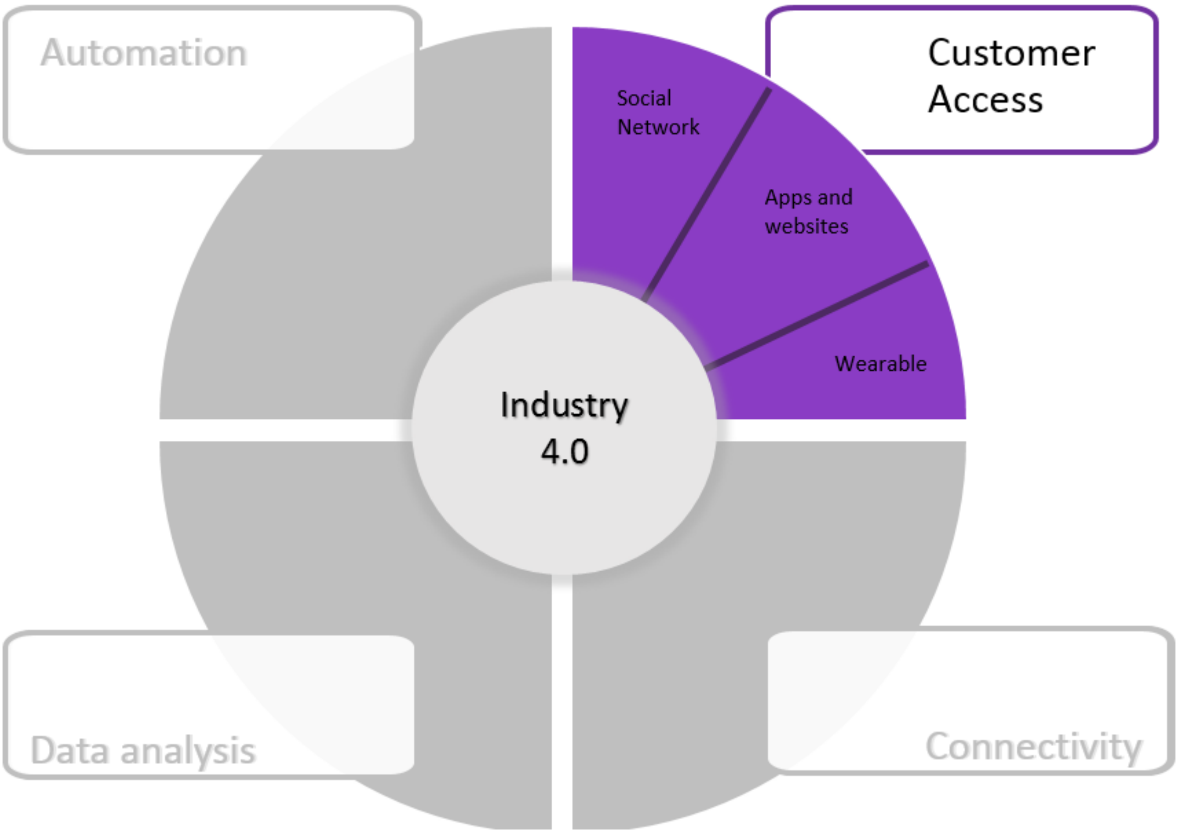


Figure 18 - Customer access selection diagram

SOCIAL NETWORK

A professor in project management for large engineering projects mentioned social media as a way of engaging stakeholders in new developments of projects. For instance, in the field of civil infrastructure, social media can help to integrate the community into the project. This type of strategies helps the final product to be more accepted by the community since they have seen it during the entire construction process and their thoughts and fears were taken into account during all the process. However, in the rest of industries, the impact of this tool is not significant because there is barely relation with the end customer. The process industry is characterized to be a B2B market. Therefore, customer trends, ideas, and visions are not directly affecting the production process and operation of factories.

After all, the score for the social network in the maturity is very high. Herewith, the technology is mature. However, the impact of this technology on the process industry is very low because there are really few applications for this technology in the operations and the supply chain.

Apps and websites

The field of apps and websites is already applied from almost all companies in the process industry. They use these tools to deal with internal clients and communicate efficiently. However, the potential of the customer and supplier connectivity is barely applied in the industry. For instance, according to a manager of an O&G company, the production process is ruled by mathematical models and predictive methods. These models are usually made by specialized experts and software that get information about sales, news and other important indicators, to forecast the amount of material to be produced in each of the refineries. With the forecast target, factory managers tune their machines and production to make the planned target possible. This process is also supported by websites and software, but it is not automated. There is still a lot of work to do to connect software together and start making a machine to machine (M2M) communications that are more efficient instead of sending 5 to 10 emails on a daily basis to arrange production and supply chain.

As mentioned in chapter 1, there is still the world to discover in the use of apps and websites to make fully M2M supply chain information flow. Apps and websites allow customer demands to influence the production as well as supply and workforce in real time. In conclusion, this technology is already mature, and the applications of apps and websites can be seen in almost all the industries and processes. However, there is still plenty of space for further development, especially in collaboration with platforms and M2M communications. Therefore, the impact score is medium, meaning that apps and websites in cooperation with other tools could revolutionize asset management and customer access and maturity score is very high.

Wearable

In Chemical, Oil and gas, and food and beverage, the impact of wearables is clear. For instance, for bulk materials that are delivered by tons, a wearable device on tanks or storage facilities (silos) could give real-time information about the consumption of the bulk material by the customer. With this wearable appliance, the factory can smartly produce more material when the tank is getting empty in a smart pulling system.

In the field of asset management, wearables are also a game changer. A chief executive of an ICT company believes that inspections and maintenance for all type of property can be done more efficiently with the use of wearable technology such as glasses, smart helmets or other tools. A senior consultant in asset management summarized that the utilization of this technology would replace two main costs in a factory: on the one hand, maintenance team usually takes 65% of their time understanding the cause of failure rather than fixing the problem. With a wearable technology, instead, operators are supported by asset sellers that have information about the status of the machine and the failure cause, reducing the downtime significantly, which means thousands of euros for the factory. On the other hand, there is no need of maintenance experts on site, because with the use of the wearables the operator will be guided step by step on how to solve the problem by engineers and technician from outside the factory. Moreover, without having to wait for the expert to come or pay an expert to be on site every time.

Furthermore, according to a professor of construction management and engineering, wearables with augmented reality have an ambitious role: helping workers with their daily tasks and give them information about safety issues; this will allow construction to be more efficient, smarter and safer. It can be seen in 10 years big infrastructure projects governed by wearable technology and BIM. Both technologies are connecting the design with the execution, keeping track of the entire process in real time, reducing the over cost and delays of the projects.

Even though the application of these technologies is broad, there are still some technology limitations. According to a professor of electrical engineering, wearable technology has significant challenges on batteries and weight, both of the problems caused by the battery paradigm: the more energy storage means more pressure in the device and vice versa. In conclusion, wearables' score in impact is high (more senior of all three technologies in customer access), because there is a lot of potential in collecting information from clients and suppliers to pull the entire operation in a pulling system rather than a pushing one. In the item of maturity, the score is medium, mainly because the technology is at an infant stage with some devices in the market, but yet at a lot of room for development and improvement, especially in the battery paradigm.

3.4 Connectivity in the process industry

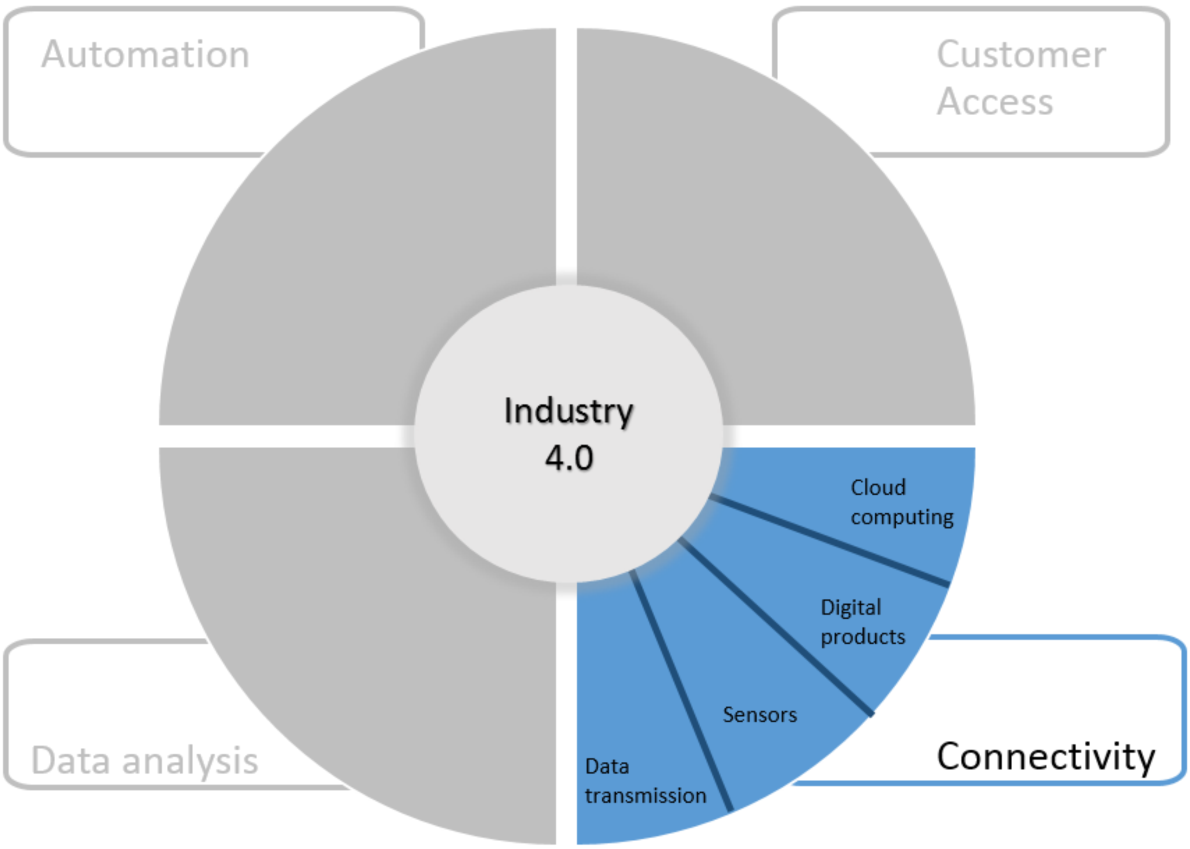


Figure 19 – Connectivity selection diagram

Data transmission

According to a professor of electrical engineering with specialized research in data transmission devices, there are revolutionary innovations such as WiGIG that are still under development, because even though the data transfer is high, the strength of the signal is so low that it cannot overpass a human body. The professor concludes that this type of technologies will be fully mature in 5 years, but they will have only applications in data centers and transmitters because there is no need for that amount of data transmission in houses or industries. Additionally, a researcher and professor on CPS consent that having extra power in data transmission do not add value to the process because the amount of information in a factory level won't exceed the data capacity of the common WIFI infrastructure. However, one of the aspects that a researcher in data transmission highlighted is the interference of signal: he mentions that, in a factory, there will be high interference of signal due to the hard assets and wireless sensors. For that reason, he recommends that for this type of infrastructure is better to use cable sensors rather than wireless or, if wireless is necessary, metallic assets should be painted with a signal-absorbent material. In conclusion, the impact of data transmission in the process industry is low, and the maturity score is medium because there is the massive investment in better data transmission devices in companies, universities and research institutes.

Sensors

Sensing technologies are the most significant innovation that could be applied in the process industry in the short term. The application of this technology impacts directly several fields like asset management, operations, wearable technologies and digital products, but indirectly nearly all of the I4.0 technologies and also the operation of the entire factory. For instance, a senior consultant in asset management and reliability mentioned that, in his field, the impact is gigantic and almost immediate. He argues that, with the use of sensors in the assets, the property management team can get information in real time about the status of the asset and it can determine if there are malfunctioning behaviors and correct them even before failure occurs. A sales engineer of sensing devices for O&G industry explains that the impact on the operational will also be high. Reactive sensors could make the production process better because, by having more information about the variables of the production process, engineers can understand more the process and validate their changes quickly and reliably. E.g In the chemical industry, a reactor can have a reactive sensor that activates heat exchangers when it perceives that temperatures and vapor are rising inside the reactor. This sensor will have the ability to recognize the abnormal condition and regulate it without the need of human labor.

However, according to a professor and researcher on CPS, some limitations make difficult for some applications the use of sensors:

- Cable sensors are reliable, safe and the best option, if the application is simple. Although, for harsh environments, long distances, and outside conditions, cables require plenty of maintenance and supervision.
- Wireless sensors with batteries are less reliable than cables because they need batteries. Since they are wireless, they also have cyber security issues. Finally, they require a high maintenance because the cells need to be regularly replaced.

- Wireless sensors with harvest energy devices are the less reliable hardware because they only send information when they can collect energy. They also suffer from cyber security issues, but they have a low maintenance cost because, once the sensor is placed in situ, it can last without any supervision for several years.

Even though sensing technologies have limitations nowadays, there are already existing technologies that can be applied in factories. According to the professor of CPS, the wireless sensors will be fully developed in 5 to 10 years because there are an enormous amount of research and investment on these technologies. In conclusion, the score of sensors is very high on impact and medium (energy limitations) for technological maturity index.

DIGITAL PRODUCTS

According to a senior consultant in Internet of things (IoT) solutions, digital product technologies have three significant consequences: firstly, digital products make possible to the customer to customize the product and the order. For instance, in the process industry, the client customize his order (quantity, quality, type, time, etc.) using apps and websites explained previously. This way of ordering means for the factory more reliability in the demand forecast and better understanding of customer needs.

The second aspect has to do with the digital product in the production process. With a digital product, the process will be autonomous, and the customer will pull the production. In the factory, a digital product will travel to the facility asking the machines for materials and processes in an independent way. On the one hand, according to a director of a consulting company, this innovation won't impact the operations in 5 to 10 years, because the process industry is conservative and this system goes against the economy of scale. On the other hand, a senior supply chain consultant believes that it is possible to apply this concept in some processes, improving the efficiency and making production line lean and without waste.

The third aspect is the digital product in the customer's hands. For this situation, the product via wearable technology can send useful information to the client, factory, and suppliers regarding the status of the material, new orders or interactive user manuals. In this phase, most of the interviewees agree that it is useful to have this digital product because it will increase customer-supplier relations as well as sales.

Regarding technological limitations, digital products in the customer side have limitations regarding wireless sensors (battery paradigm). In the field of digital products within the factories, a sales engineer for a sensor manufacturer says there are still some limitations because the technology is at an early stage and connecting machines and products will be expensive with the current technology. In conclusion, the use of digital products in the process industry will help to make the process industry more efficient and even change the way it produces materials. The score of digital product on impact is high. However, the limitations are still significant because they depend on innovation in energy harvesting and better sensing devices. Thus, the score in maturity is medium.

CLOUD COMPUTING

This technology will allow the factories to understand their data, distribute it to the personnel and make decisions on it. According to a chief commercial director in an IoT company, cloud software like Jasper help the companies to know where their assets are, what are they doing and gives the opportunity to change the condition of the given asset. For example, via Jasper, a controller in Den Haag can find useful information about a pump in Siberia. He can know where it is located, what is it doing and he can deactivate it directly from the cloud. It is possible that shortly (less than five years) a virtual factory will be in the cloud as well, giving the controller the power to manage the entire production line with the secure command; allowing him to make changes in the virtual factory and understanding the impact of these variations in the real plant.

Another significant impact that cloud computing has in a plant is allowing different stakeholders to get various information using the same data. Cloud software can capture the data from sensors, operators, decision-makers, customers, and suppliers while giving to each of these stakeholders different information according to their profile and interest. E.g. - Information about digital products, machines, documents, and orders are stored in the same software. However, this software gives information about the status of its products and the details of the order to the client. The operators get pieces of advice on maintenance plans, the decision makers get information about the energy cost and efficiency of the assets, the suppliers get info about new orders, and the machines get instructions on what to do and when to do it. This connectivity between different actors enhances collaboration, efficiency in the operations and improves customer service.

Cloud computing is a disruptive innovation for the process industries. This technology will reformulate the way the factory looks like, behaves, reacts and communicates. Therefore, the score is very high on impact and high on technological maturity.

3.5 DIGITAL DATA

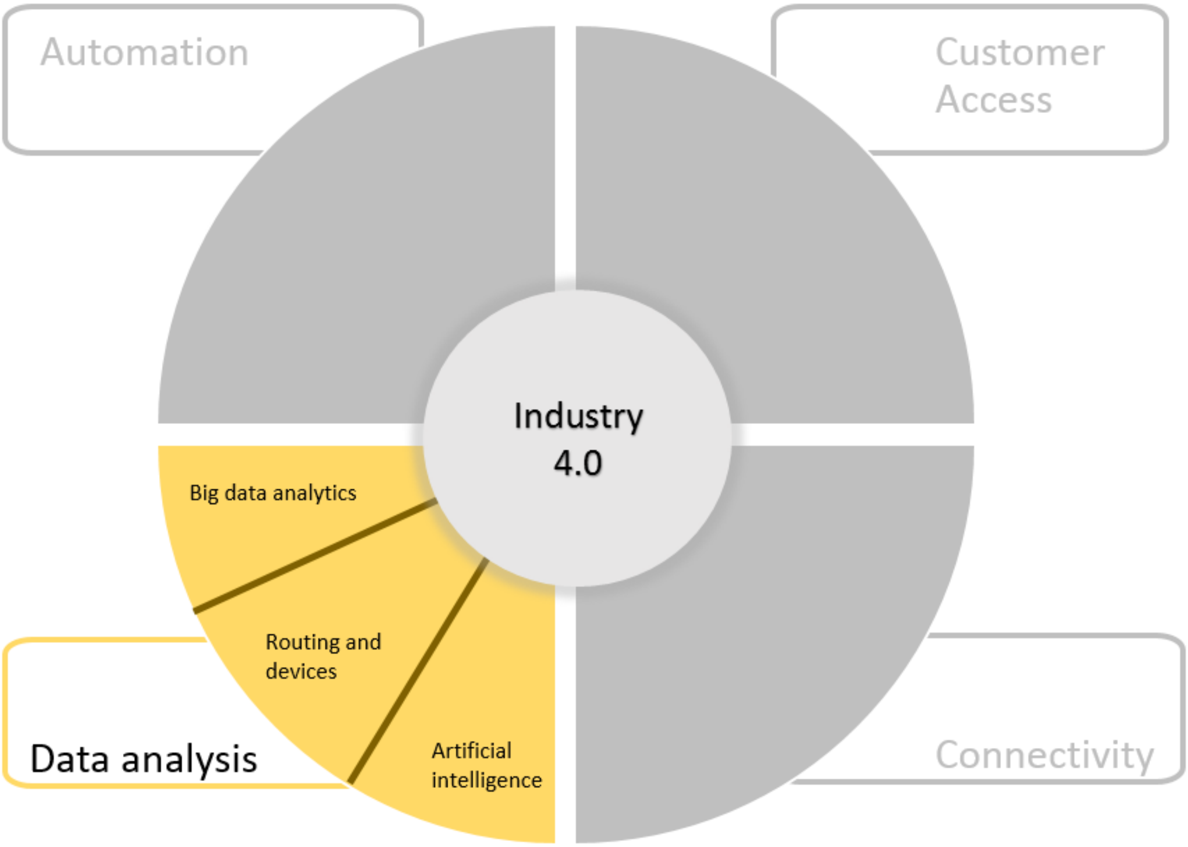


Figure 20 – Digital data selection diagram

BIG DATA ANALYTICS

The big data technologies are already in the market, and they are software or cloud solutions that develop deep analysis on data streams (see chapter 1). According to an IT professor specialized in big data, tools such as Azure are fully developed, and they give real-time information and statistics on what is going on with the data source. In fact, companies have been investing money in data capturing and data analysis tools, but they haven't seen any positive results because the data is wrongly gathered and it is not organized. Therefore, it is important that companies understand which data is relevant and start making pilots of CPS that can self-regulated according to data analytics tools.

The potential of big data analytics covers almost all aspects in a factory. Optimization of the operation, predictive maintenance, reactive plans and demand forecast are some of the fields in which big data will have a significant impact in the future. There is still room for further developments in this area since big data tools have not being applied in most of the fields in the industry yet. In conclusion, the score of big data analytics is for both items high. It is at a young stage with less than five years to fully develop, and it has a great potential to improve and optimize processes in the factory.

Database routing and devices

The use of virtual machines to improve data analytics but also to develop simple factory task will be more and more common each day. In fact, according to an ICT director at a consulting company, in 10 years hardware devices will have relatively low processing and storage capacity, because they will all be connected to the cloud and they will use storage and processing from virtual machines instead of using their processing capacity. In a factory, this way of processing and storing information could make faster, cheaper and better the analysis of the data. E.g Instead of having a plant with a data center and hundreds of computers working independently on their files, all the information would be gathered and shared in the same virtual machines, allowing faster analysis and decision making for all the internal processes, as well as collaboration with all the members of the company.

The technology of data routing and virtual machines is already being applied by large enterprises such as Microsoft, IBM or Google. However, according to the ICT director, almost all companies within the process industry are still working on hardware storage, and they use the processing capacity of their computers to run out their process. Moreover, the technologies for data routing are already in the market, but they need to improve to make the communication between devices and the user more user-friendly and faster. In conclusion, routing devices have a high score on technical maturity, because virtual machines are already used by several companies and even users. However, their potential is medium because only by combining their capability with other tools, like big data or sensing, this technology could have an impact on the process.

Artificial intelligence

AI is one of the technologies that will change the way of producing in the process industry. A professor and researcher on AI say that there are already several AI agents that allow companies to predict sales, weather, suggest decisions and search for information within their data. The expert suggests that AI, with the help of big data analytics, high processing, storage capacity and sensing devices will be common in 5 to 10 years. These AI agents will develop complex reasoning tasks in factories and even innovate the production process without humans to take care of it.

Nowadays, AI agents are still necessary and in an infant stage, because they can only do basic reasoning and their processing is expensive and slow. However, big IT companies, as well as computer manufacturers, are investing millions of euros in AI because their applications in all industries are limitless (see chapter 2).

The use of these agents can be only limited by imagination. There are hundreds of tasks that can be developed by AI actors shortly. In the next paragraph it will be shown some of the potential functions that these agents can do:

- Safety: in case there is an explosion in a production facility, the AI agent guides the personnel to a safe place. This, by using the information on the sensors and the processing capacity to perceive and react after the accident.
- Supply chain: the AI agent is connected to the global stock market. It predicts scarcity on material X for the next quarter, he warns the personnel and, with the approval of the

decision makers, the AI place the order in advance to avoid running out of material for the production process.

- Sales: demand forecast plus control on the production process.
- Asset management: with AI agents, failures can be predicted, and maintenance can be done before failures occur. In infrastructure projects, predicting the failure of roads based on climate, traffic and material condition could help to keep reducing downtime enormously.
- Engineer of the Future: AI agents will help engineers detect problems and solve complex engineering tasks by having access to historical data and the operation of current projects.

In conclusion, artificial intelligence algorithms can be used in almost all the levels of the factory, and their impact in the future will be very high. Nevertheless, AI agents are not commonly used nowadays; soon this type of technologies will get more frequent since this innovation depends wholly on the development of storage capacity and data processing; this is the reason why the score of AI is medium, herewith is still in an infant stage of development.

3.6 QUALITATIVE ANALYSIS

After the result of the assessment, in which the interviewees described each I4.0 technologies and gave them a qualitative score on impact and maturity, the final step is to make an analysis to select the technologies that might have implications for the process industry in the short term.
Based on the description of the experts and the score of each of the techniques in both maturity and impact, the technologies were divided into four categories following the order of importance for the process industry. "KEY" technologies are the ones that have various effects on the operation of the company or factory, their risks are known, and they can be applied in the several process applications. Based on this definition, it is suggested that managers of process companies implement these "KEY" technologies as soon as possible in their respective business models. “IMPORTANT" technologies are, as the title suggests, important to take into account while investing in new business models, or making improvement plans. These technologies are not likely to impact all the process industries because they have particular purposes. However, they can be combined in a CPS to provided added value to the whole process. "UNKNOWN” technologies are those that have an unclear or debatable impact in the process industry. These technologies should be in the mind of the managers but should not be an investment priority. “NOT IMPORTANT**”** technologies are the ones that will not create any major effect in the process industry, and therefore it is suggested not to invest on them, even if they are mature.

RESULTS OF THE QUALITATIVE ANALYSIS

The results of the qualitative analysis are shown in Table 3. Out of this chart, it can be perceived that experts agree that five out of fourteen technologies (drones, autonomous vehicles, robots and data transmission) might not impact the process industry in the short term. It is also concluded that additive manufacturing (3D printing) has an enormous potential, but it is blurry whether the implications for the process industry will be direct or indirect. In the analysis, the top scoring technologies are sensors, artificial intelligence, and cloud computing, which means that according to the experts, companies in the process industries should invest efforts including them in the production process. Finally, there are other five technologies like big data analytics, routing devices, digital products, wearables, and

Apps and Websites, in which experts agree that there might be an application in the process installations. However, their applicability depends on the factory and the company's business cases.

Technologies	Maturity	Impact	Actions
Drones	High	Low	Not important
Autonomous vehicles	Low	Very low	Not important
Additive manufacturing	Low	Very high	Unknown
Robots	Low	Medium	Not Important
Big Data	High	High	Important
Database Routing & devices	High	Medium	Important
Artificial Intelligence	**Medium**	**Very high**	**KEY**
Data transmission	Medium	Low	Not Important
Sensors	**Medium**	**Very high**	**KEY**
Digital products	Medium	High	Important
Cloud computing	**High**	**Very high**	**KEY**
Wearables	Medium	High	Important
Apps and websites	Very high	Medium	Important
Social network	Very high	Very low	Not important

Table 3 - Qualitative analysis results

3.7 CONCLUSION

After literature research, assessment of technologies and qualitative analysis. It is concluded that not all of the Industry 4.0 technologies, proven to be crucial in the manufacturing industry, are important in the process industry. In fact, according to the experts, the "KEY" technologies that should be under consideration in the process industry are sensors, cloud computing, and artificial intelligence. These innovations should be at the top of mind of the managers of the process companies because they can optimize the production process, improve stakeholder engagement and make better analysis, using more and better data. According to the qualitative analysis, these three technologies are already available in the market, and it is likely that their importance will rise in the up coming years. "IMPORTANT" technologies like digital products, big data analysis, database routing and devices, wearables, and apps and websites, should be in the mind of managers in the process industry. However, their impact relies heavily on the business model of each production installation. Another outcome of the qualitative analysis is that additive manufacturing (3D printing), which is one of the most disruptive technologies in the manufacturing industry, turns out to be categorized in the process industry as an "UNKNOWN" technology. The reason is that there are contrary perspectives in the interviewees regarding the impact that this technology might have in the process industry. Moreover, the maturity of this technology is not high enough, making it difficult to foresee a development of this technology and make conclusions. Based on the results on additive manufacturing (3D printing) it is recommended to keep an eye on this technology and try, if possible, to find out possible business cases that will come up with the development of this technology. Finally, drones, autonomous vehicles, robots, data transmission and social network were qualified as "NOT IMPORTANT" technologies. According to the experts, their impact won't be relevant in the process industry, and even though they are important in the manufacturer industry, it is dubitable that they will have major effects in the process industry.

The goal of analyzing the impact of the I4.0 technologies in the process industry was achieve using the phenomenological qualitative approach. However, as explain in chapter 1, the real potential of the Industry 4.0 is the ability to create the network of components that combine the physical and cyber space, also called as cyber-physical systems. Hence, in the next chapter, there will be a case study of a real process industry facility, in which all the theory gather from the previous two chapters will be put into practice. Next chapter, will focus on the methodology to design of a cyber-physical system based on the "KEY" and "IMPORTANT" I4.0 technologies, and there will be an assessment of the possible impact of this CPS in a process installation, as well as, an assessment on the methodology to design cyber physical system in the process industry.

4. Designing a cyber-physical system for a process facility

In this chapter, the following questions will be answered: How can a company design a cyber-physical system in the process industry? And how to validate the outcome of a cyber-physical system design, for a process installation? To answer the first question the methodology chosen to design a cyber-physical system was the *5C level architecture* by Jay Lee et al (Jay Lee, 2014). The second question, will be answered using the *validation square*, this method helps to validate and determine whether a methodology is proper for a particular purpose. At the end of this chapter there will be a validation square for the 5C level architecture methodology in which the representativeness, structure, performance and scalability of this methodology will be analyzed.

The methodology to make a design from problem definition to evaluation is based on the paper by Verschuren and Hartog (Hartog, 2005). First, general description of the case study, explaining the characteristics of the factory and the company was chosen for this research. Second, based on the information given by Tebodin's senior consultant, there will be a description of the problems of the particular facility. Third, there will be a goal definition, solving the question what is the design for? Fourth, definition of the boundary conditions and the requirements that the design must comply for the process installation. Fifth, conceptualization of the design as a cyber-physical system. Six, detailing the design based on the paper by Lee et al. (Jay Lee, 2014). Seven, describe the components and techniques that this CPS has, the relations between them, how they look like in both cyber- physical space and the relationships that the system has with the stakeholders. Eight, analyze the impact of the designed CPS in a bi-dimensional approach. One dimension focusing on the implications of the requirements described in step two, whereas, the second dimension will concentrate on the consequences for the stakeholders. Nine, asses the 5C level architecture methodology with a validation square based on the paper of Seepersad et al (Karolyn C. Seepersad, 2005).

Privacy constraints

Before explaining the case study, it is important to clarify that Tebodin has tight privacy regulations with their clients; therefore, there won't be any details regarding the location, production process or company name. Additionally, there won't be any sketch or images that could relate the client to the real factory, and the design of the CPS will not interfere with the current projects undergoing with the customer and production facility. Finally, the mockup design of the CPS in figure 32 and 33 has absolutely nothing to do with the real factory machinery or installation. This sketch is just an illustration to proof the physical environment of the CPS. All the information gathered in this section is provided by a senior project engineer at Tebodin in charge of this client and has nothing to do with client's perspectives, goals or views. The information given by the engineer is no confidential information and will not compromise the customer's private production process.

4.1 DESCRIPTION OF THE INSTALLATION: BULK PRODUCTION FACTORY IN THE NETHERLANDS

The owner of the plant is a Dutch company that produces bulk material from a mineral, which comes from overseas locations. The mineral arrives at the port by boat and is transported from the port to the factory on a truck, manage by a transportation company. In the plant, the company converts the mineral mechanically into powder or grains of different types and qualities. The installation contains three separate facilities: the storage for raw materials, which is a facility with a big empty room where all the raw material is stored. Secondly, the production facility, which is a building of three stories with different machines inside, and at last, a vertical storage tank (silo) where all the powder and granular materials are placed. Furthermore, the operation of the factory is fully automated, meaning that there are no standard works on the site except for maintenance services and quality checks. Finally, the facility aims to works 24/7 all year, and the company's primary goal is delivering high-quality products to their clients. In fact, due to that goal, this company offers customized solutions to their customers. Hence, there are hundreds of different end products according to what the customer demands.

The supply chain of the factory consists of various stakeholders that interact with the plant in direct or indirect manners. In Table 4 is a description of the type of relation that the stakeholders have with the plant and company, during the whole supply chain. It is important to notice that there are only two direct links between the factory and the stakeholders. One with the process engineers and the other one with the maintenance team.

Stakeholder	Relation
Supplier of supplier	No relation
Supplier	There is a fix amount of material that is deliver on monthly basis to the factory
Maintenance team	Usually a consulting company is in charge of making the asset management plans and the personnel of the company execute the plans.
Process engineers	Reside in the factory and are controlling the system that is highly automated. They do the quality checks manually
Noise control specialist	There is no control specialist
Management board	They are indirectly involved in the production. However, every month the process engineers send a report to the management team with basic information about the production process.
Transportation company	They outsource the transportation. No enough information about this stakeholder.
Manufacturer company	No relation
Customer	Customer purchase via the sales engineers. They are the ones that make the orders and upload them to a internal system.
Customer of customer	No relation

Table 4 - Stakeholder information in the production facility

In the following section, there will be more detail information about the different types of requirements and goals that the company will like to achieve with the process installation.

4.2 PROBLEM DEFINITION

As Verschuren and Hartog suggest, there has to be few main elements drive the design of a system or structure (Hartog, 2005). Hence, in this step, there will be a definition and explanation of the main problems that will drive the design process. This definition was also made based on the expertise of Tebodin's senior project engineer. For this case study, it was decided to select three main problems based on the focus level. One operational (machine level), one control problem (factory level), One strategic problem (company level).

According to the senior project engineer, the high noise level is the major operational challenge that the company has been facing for the last couple of years. The vibration of the machinery produces a low-frequency sound that resonates through the entire building. This high level of noise makes the company unable to invest in more machinery, only because it will add more noise and the environmental authorities will probably sue them or even stop their production. To prevent this high noise problem, the company is using painting and dampening devices that managed to reduce the noise. However, they still have problems because these passive reducers are not capable to reduce dramatically the levels of noise that they have been reaching.

The second major problem is the lack of reliable information for maintenance and quality checks. Currently, support and quality are done in periodical checks, and the company has no data management systems. Therefore, the maintenance and quality team cannot learn from their previous failures. For that reason, the senior project engineer believes that a tool that helps them store and analyze quickly failure modes will improve factory's availability.

Finally, from a strategic perspective, there is a significant disconnection between the suppliers, the production process, and the customers. The senior engineer stated that currently, the customer places an order, via email, and then the sales employee put the order in their internal system. Ones the request is in the system, the operation engineers read the order and verify if it is possible to make it. Finally, after they check that the order is possible, they placed it on the production line. On the supplier's side, the company requests the raw material from overseas suppliers by email. However, in case the content doesn't fit the quality standards, the company has to send back the raw material to the provider and use the inventory of end-products to cope with the demand. In conclusion, even though the production process is highly automated, the connection with customer and suppliers is made entirely by Human to Human communications.

4.3 GOAL OF THE DESIGN

Since the objective of the research is to proof that combination of Industry 4.0 technologies can be applied in the process industry, the primary goals of the design will be. ***Reduce the vibrations of the machinery (Operational), improve the information in maintenance, quality and operation (Control), and finally, connect all the stakeholders in the supply chain process (Strategic).***

4.4 Boundary conditions

In this section, the boundary conditions that the company set for the process installation are going to be described. This information was provided by a senior project engineer at Tebodin, who worked in the design of the structure and process facility. These requirements will be defined and organized based on the methodology expressed by Verschuren and Hartog, in the paper *Evaluation in design-oriented research* (Hartog, 2005). This method was chosen because it gives a proper definition of requirements, based on stakeholder and focus level. On one hand, conditions or requirements that address the purpose of the installation will be considered as *"Functional Requirements"*, those that list the ways of using the facility will be categorized as "*User Requirements"*; the ones that set boundaries based on the political, social, economic, environmental, technological and legal circumstances will be *"Contextual requirements"*; whereas, *"Structural requirements*" will be the ones that need to be achieved in order to reach the other requirements (Hartog, 2005). On the other hand, requirements can be categorized based on three focus levels. *"Operational requirements"*, for those who define tasks to be done in the operation, "Control requirements", that allow engineers and administrative to gather, monitor or react towards the system, and final, "Strategic requirements" that make possible to understand the behavior of the entire system in the past, present and future (Hartog, 2005). For instance, in this case, study, operational requirements describe the machines and operator's daily work, control requirements define the factory dynamics and the control of the system, and finally, strategic requirements establish the rules and objectives of the entire supply chain.

This step is crucial because these boundary conditions will verify (Step 6) if the system can improve or not the current situation of the process installation. For instance, if the design of the system doesn't affect these requirements, it means that it is unlikely that the design will add value to the company, thus, it will be concluded that design might not be useful in the process industry.

Operational

4.4.1 Functional

These requirements indicate the functions that the system should enable once it is realized. This type of condition is usually described as the goal of the scheme.

In the case study:

- Noise need to be reduced in the production facility

4.4.2 User

This type of requirements is made by the user of the system at an operational level.

In the case study:

- Reduce the number of humans in the production facility
- Reduce the noise protection gear for the operators
- Increase safety condition for the operators

4.4.3 Contextual

Contextual requirements are those that explain the relation of the noise reduction system with the physical and virtual environment.

In the case study:

- Air quality can be improved by dealing with fine dust
- Increase the energy efficiency of the machinery

4.4.4 Structural

Finally, the structural requirements are those that explain the characteristics of the structure that fulfills the other conditions.

In the case study:

- Noise control system should be reactive
- Noise control system should be connected with the structural slab of the building.

CONTROL

4.4.5 Functional

Functional requirements indicate the functions that the installation should enable once it is realized. This type of element is usually described as goals of the factory.

In the case study:

- Produce end products at a lower cost
- Deliver better quality products
- Increase the number of machines in the factory

4.4.6 User

This type of requirements is made by the controller of the installation.

In the case study:

- Improve the automation of the production process
- Increase the amount of information to help the maintenance team
- Improve the quality of the information for the operation engineers

4.4.7 Contextual

Contextual requirements are those which explain the relation of the factory with the physical and virtual environment.

In the case study:

- Connect this plant with the manufacturer's data and the other facilities for peer to peer analysis
- There can’t be any soil contamination due to the proximity of the installation with a water body

4.4.8 Structural

Finally, the structural requirements are those that explain the characteristics of the structure that fulfills the other conditions. However, in the case study, the senior engineer didn't mention any structural requirement.

STRATEGIC

4.4.9 Functional

Functional requirements indicate the functions that the installation should enable once it is realized. This type of elements is usually described as goals of the supply chain.

In the case study:

- Make a leaner supply chain faster and with less cost and efficiencies

4.4.10 User

This type of requirements is done by the user of the installation.

In the case study:

- Increase the transparency of the information between internal and external stakeholders
- Engage the customer and the suppliers in the production process as much as possible.

4.4.11 Contextual

Contextual requirements are those which explain the relation of the factory with the physical and virtual environment.

In the case study:

- Connect the factory, with other similar facilities of related companies

4.4.12 Structural

Finally, the structural requirements are those that explain the characteristics of the structure that fulfills the other conditions. However, in the case study, the senior engineer didn't mention any structural requirement.

In figure 21, there is an illustration of how requirements are categorized according to their level of focus.

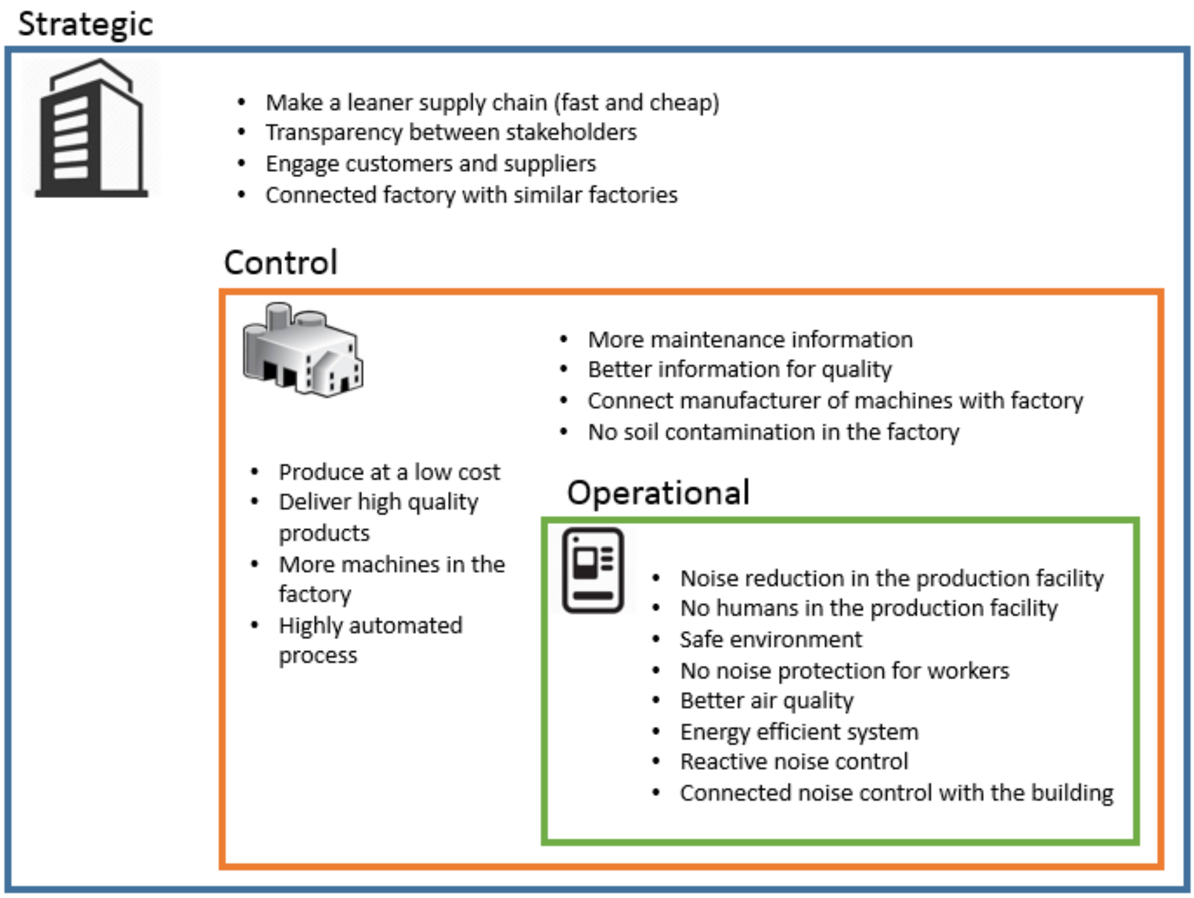


Figure 21 – Requirement categorization (strategic, control and operational)

4.5 CONCEPTUALIZATION OF THE DESIGN

It was established previously that the design should reduce noise in the production facility while also connecting stakeholders in the supply chain, and getting better and more information about maintenance and the operation. To solve these problems, the concept design will be a cyber-physical system with the following characteristics:

First, it should be a 5 Level CPS that can make independent decision making, highly connected with the employees, as well as the production facility. The reason why it was decided to create the highest level cyber-physical system is to describe properly all the steps of the 5C architecture methodology. However, in a real situation the designers should try to asses the pros and cons of each 5C level and identify which type of level is more beneficial for the situation.

Second, the design should have the KEY I4.0 technologies explain in chapter 3 (artificial intelligence, sensors, cloud computing) and if it is necessary also the other IMPORTANT technologies. With this context in mind, the following section will describe and explain the design of the cyber-physical system.

4.6 GUIDE TO MAKE THE CPS

In this step, the CPS will be created based on the paper by Lee et al. called *the 5C level architecture* (Jay Lee, 2014). This article explains a methodology to make cyber-physical systems in 5 levels: connection, conversion, cyber, cognition, and configuration. Each of this steps uses different i4.0 technologies according to the company's needs and challenges.

LEVEL 1: CONNECTION

As explained in the first chapter, connectivity is important in the construction of any CPS. In the 5C level methodology, the first level, or connectivity, has two considerations: First, the description of how the system is going to gather data in the physical world, and second, the protocol to collect and read the collected data. Hence, this section will be divided in the same two considerations, as explain in the 5C level methodology.

4.6.1 Sensors: Gathering data from the source

Since the case study is about a process installation and the high levels of noise caused by the vibration of the machines in the production facility, the way of gathering noise/vibration data is by adding a floor that has a grid of sensors that detects in real time the vibrations of the machinery. Each wired piezoelectric sensor as shown in figure 22 will translate deformation from the vibration of the machines into an electric signal.

Figure 22 - Piezoelectric sensor

This floor full of sensors will be placed on all the machines so that it can measure the vibrations correctly.

4.6.2 Protocol: Sensor to computer

An analog device will translate the deformation of the piezoelectric sensor into information (decibels) prior the analysis. In this particular case, it will be used the NI myRIO that is a kit made by National Instruments that convert piezoelectric signal into information for the software to read. In figure 23 there is an image of the myRIO tool kit that includes the cables, analog device, and connection to the sensor.

Figure 23 – NI myRIO analog device

Level 2: Conversion

Level two, or conversion, means that the CPS can organize, convert and store in a smart way all the information coming from the sensors. This level is crucial because the physical devices connected in the CPS send data that 's hard to understand by the analysis soft wares and stakeholders; therefore, there has to be a converter from data (coming from the source) to information (going to decision makers). It is important to highlight that the conversion level is not in the physical space, as the connection one, and therefore its component is all inside the computer.

4.6.3 Cloud Computing 1: The platform

The platform is probably the most critical cyber component in the entire system because it will contain all the soft wares and services that convert, analyze and create a cyber-copy of the physical system. In this case study, the platform used will be Amazon web services(AWS) because it was easier to work with it. However, there are other similar platforms like Azure from Microsoft or Google platform that could provide similar services and solutions to the system. The cost of this platform is calculated on demand, which means, that the total cost of the services is based on the hours that the employees use them or the amount of the information operator's store or analyze.

4.6.4 Cloud Computing 2: The conversion software's

In the case study, the conversion level usually has to do with functional soft wares like LabView from National Instruments. Recently, Amazon web services allowed National Instruments soft wares to run on their platform, meaning that, LabView will run in public servers in the Amazon platform, as well as the analysis and even communication explain further on in this chapter.
Within LabView, there has to be some coding to translate the input from the analog into decibels (vibration/noise) information. After finishing this coding, the system will be capable of making graphics, similar to the one shown in figure 24. In which the X and Y axes are the length and width of the floor, and the Z axes belong to the decibels measure by each sensor

(in figure 24 expressed by the colour scale). LabView was chosen because it was the most compatible software to read the signal from myRio analog.

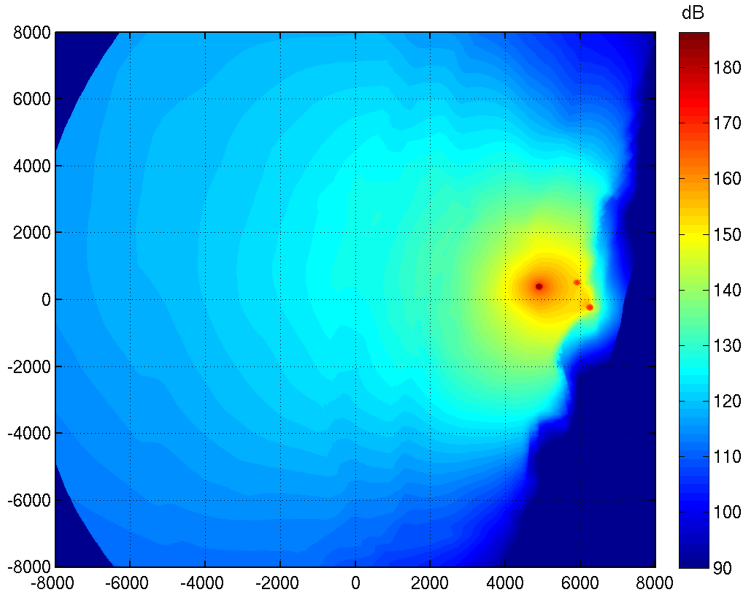


Figure 24 – Sound graph for the floor of the installation

4.6.5 Cloud Computing 3: Storage on the public servers

Storage is a challenge for the design of a fully connected system. Stakeholders, as well as, internal machine to machine (M2M) relations need to find the information they are trying to address. Additionally, the amount of information that needs to be store due to the network of relationships is significant, complex and fast. Hence, in this CPS there has to be a particular component that stores data on public servers and organize it for analysis. For this reason, the cloud service used is RedShift. This service, within the AWS, will store the information of LabView every couple of seconds in a database with SQL compatibility during extended periods of time. Having the opportunity to upload all the information of the physical world (people and machines) in this cloud service means that all the company files and work done can be stored in one central hub, the RedShift database.

In the case study, storage has to be done for three different purposes: First, data should be stored in decibels to find out peaks of noise and verify if they comply with the Dutch environmental law. Second, data has to be store for maintenance, saving the daily vibrations of the machines at all-time. Third, noise information has to be stored in the same database as the information from the machines especially on quantity flow per machine, orders in process and materials use.

Level 3: Cyber

The cyber level is according to Lee et al (Jay Lee, 2014) the virtual space that has the goal of analyzing, storing and monitoring the information provided by the previous levels. In the case study, this cyber hub has already been created in the last level (Cloud computing 3). However, is at this level where all the different analysis will be done, and the data analytics services of the cloud platform will be used. This part of the system is essential because it allows the different stakeholder to understand how the system behaves and communicates between components and stakeholders. To understand the cyber level four different (cyber) components will be described in the following section.

4.6.6 Cloud Computing 4: Noise analysis software

The noise analysis will require basic data analytics tools provided in the cloud platform (AWS). For this case study, the best service is Kinesis. This AWS service allows the user to get secure information from databases such as RedShift at a tremendous speed. Kinesis service should analyze the information every couple of seconds and verify if the noise is exceeding the maximum limit in the Dutch environmental law. In case there is over limit noise condition, this component should be connected to other components that alert the user about the current state of sound, this will be addressed further on the last level.

4.6.7 Cloud Computing 5: Maintenance analysis software

The maintenance analysis is more complicated than the noise one. First of all, the machine manufacturer should give insights about failure modes based on the sound frequency, meaning that, the CPS should engage this stakeholder and make him feed the files in the RedShift database. Then, Amazon Quicksight service will compare existing flows of vibrations coming from the sensor grid, with the normal and abnormal waves that the manufacturer of the machines upload previously. QuickSight is used in this case because it is compatible with RedShift database and because it provides better analytics and visuals than other services. Finally, in case this analysis tool finds a match between the failure modes and the machine behavior, it will alert the maintenance team and machine manufacturer that there might be a machine failure so that they can fix it.

4.6.8 Cloud Computing 6: Operations analysis component

The operational analysis is the most challenging aspect in the cyber level because it needs information for various stakeholders. First, prior the analysis it should be, in the RedShift database, information about the production process, the customer, the raw materials, and finally, information about sales. In RedShift, the information will be the store, concerning all the data from the factory. However, it is important to clarify that this will require some extra work because IT experts should connect the software that is currently being used in the factory to the Redshift database in the AWS. The company should use other two I4.0 technologies to gather the information about customer needs and behavior. One, wearable technology to trace the containers of the bulk material and connect these wearables to the cloud platform using the service AWS IoT platform, this IoT platform, combines the wearables immediately to the cloud and store their data in RedShift. Two, app and website to automate the orders made by the clients, this website or app can also be done in the cloud platform using the service AWS mobile hub, which will allow the company to build up a basic mobile app in a short period. Finally, to get the information about the materials and orders from the supplier, it will be needed that this stakeholder uploads their files of orders, materials and quality in RedShift, meaning that both customer and suppliers will require an individual account on the AWS platform. Only after doing all these previous steps the service Quicksight will be able to compare, correlated and understand the relation between the different data, and make simple but interesting analysis like Relation between material "A" and sales in the last years or even between material "B" and failure mode "X".

4.6.9 Cloud Computing 7: Storage and Communication

Finally, after all the analysis done it is important to store and communicate the findings. For storing, it will be used the same database service in the AWS called RedShift. This tool is used because it is compatible with all the other services that will be explained in the next levels. On the other hand, communication will also be done in the cloud, by a service called WorkSpaces. This service will be in charge of communicating and interacting directly with all the stakeholders. WorkSpace is nothing else than a desktop in the cloud that helps different users to find or analyze the information in a variety of ways, according to their interest and knowledge. With WorkSpaces, we make sure that each of the stakeholders knows where to place the information, the engineers were to do the business intelligence, and the decision makers were to see the factory's overview. For example, thanks to WorkSpaces, a supplier will have a different interface than a manager while interacting with the same database or services. The provider will find information about the orders and when the money will be transfer to the account, whereas, the manager will have the ability to make financial analysis or see graphics of the production in the factory.

It is important to understand that each of the services explains in this section require personnel that can read them and makes them work. However, with the cloud platform, there are, for each service, several tutorials that help the engineers to get expertise on this tools. Examples of this are the tutorials in tuning the IoT devices, make the desktop, build the app, organize the data, and analyze available for free.

With the components of the cyber level connected and described, the CPS is now capable of deeply understanding the system. Moreover, this level 3 also links several stakeholders and provide them with excellent tools for the noise, productivity and company development. In the case study, for example, plant engineers will get information about sound, similar to the graph shown in figure 24, maintenance team will get alerts about the abnormal behavior of the vibrations of machines (in case there is), machine manufacturer will get constant information of each machine for peer to peer analysis, the operations team will get information about the production process, the plant engineers of other factories, within the same company, can see how the tool works and compare it with their factory ,and finally, managers can see the big picture about the production line or the current peaks of noise level. Figure 25, express how the cyber level and in particular the RedShift database (5.3.4 Cloud computing 7) has various types of information according to each stakeholder.

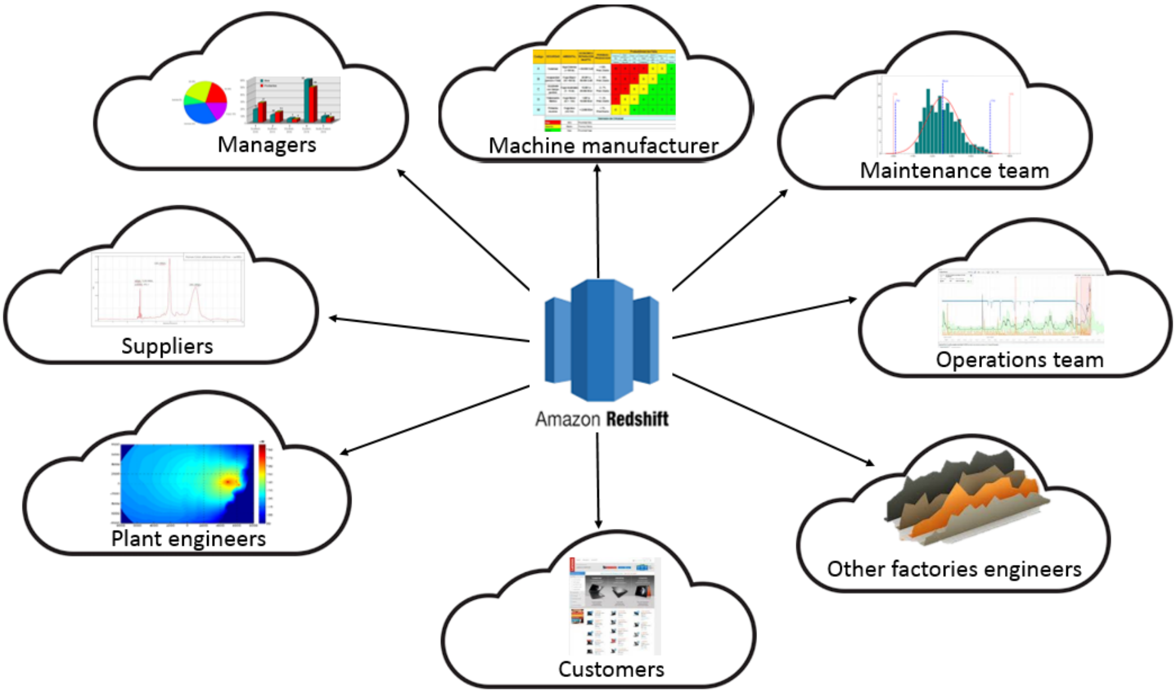


Figure 25 – Information of each stakeholder in the Redshift database

LEVEL 4: COGNITION

Nowadays, it is common to see CPS with the three previous levels: new cars, manufacture factories and highly automated refineries area some examples of 3 level CPS that can gather, organize and analyse data at an enormous speed. However, the cognition level is something that most of the companies haven't reach yet and mainly in the process industry almost none of the factories have developed a CPS with cognitive capacity. Cognition, according to Lee et al (Jay Lee, 2014), is a system that can learn and generate knowledge from experience (the past or other system experience). A CPS with a cognition level can optimize the process, and it can prioritize solutions based on goals defined by the humans. This self-understanding capacity can only be reached using some AI algorithms also called AI agent, in which there is a bi-directional interaction machine-to–machine (M2M) and machine-to-human (M2H) that feeds the system.

The cognition level requires information of the physical system, as well as, the stakeholders that influence this system. Hence, the complexity of the AI agent depends largely on the amount of interested parties and systems in which this agent is exposed. For that reason, this level of cognition will be divided into three phases of development based on the degree of exposure and complexity of the system (figure 26), C1 cognition from the system, C2 cognition from the systems and C3 cognition from the systems and their actors. In the following sections, this phase will be explained.

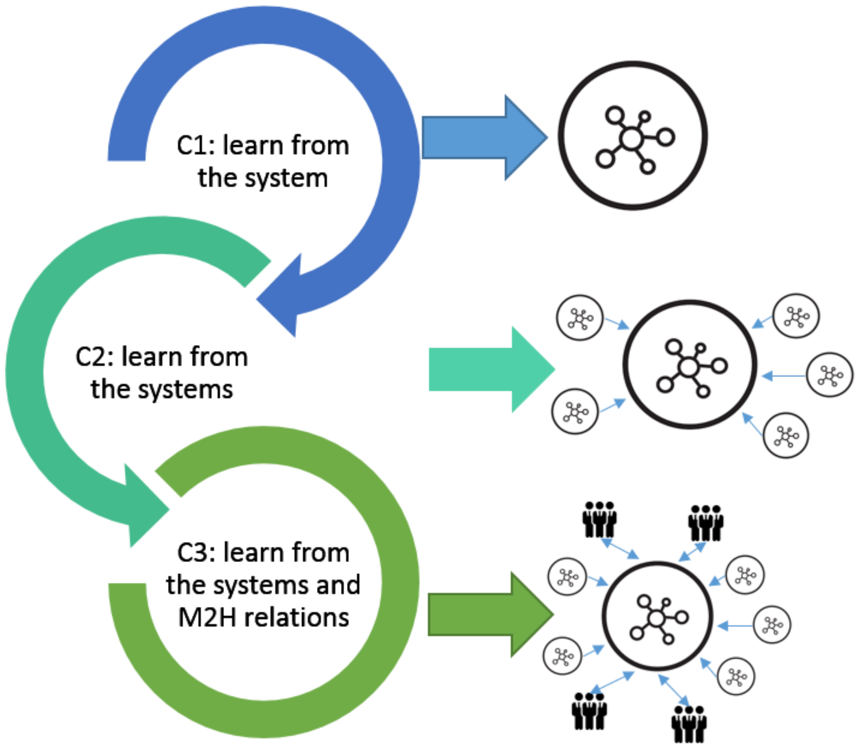


Figure 26 - Summary of the cognition steps in the case study

4.6.10 Artificial intelligence C1: Cognition from the system

A C1 cyber-physical is an AI agent that can identify trends in the data hub and can improve the current decision making process, everything based on the information of one system. For instance, in the case study the machine learning (ML) from AWS will be used. With this service, users can develop simple AI agents that identify which is the location that reduces resonance and vibration or identify types of failure, based on the historical data collected by the CPS in the cyber and converting levels. It is crucial that this AI is connected with the RedShift database, which was made previously because is from there that the AI will dig into all the information shown in figure 25. This C1 agent will help the company solve problems such as what type of materials shall the company make in the next months? What sort of dimensions of raw materials makes fast the production process? And many others.

4.6.11 Artificial intelligence C2: Cognition from the systems

C2 agents differ from the C1 because their machine learning algorithms have the ability to enter other sources of data in other cyber systems. For example a C2 agent will browse information in the web or it will have enter to the stakeholder's personal data. It is not required that the information of the other stakeholders has to be necessarily in the platform. This, because the C2 agent can have liberty to access to other systems data, differently from the C1 that can only focus on one system data. However, In case the other systems doesn't allow this agent to access to the information it will remain a C1 agent.

The reason why the C2 is better than C1 is simply because it can have more data to play with, making it smarter, because it can see the entire supply chain including clients of the clients, suppliers of the vendors, competitors or even governmental agencies. By doing this, the AI will enter, for instance, to the manufacturer data hub and detect types of failure more accurately, based on information of other twin machines working with other companies. This agent could also dig into the operation software of the factory and compare in real time the efficiency of multiple alternatives with cyber components such as QuickSight. In conclusion, this level makes the AI more accurate by getting him in touch with the more related data source of other systems.

4.6.12 Artificial intelligence C3: Cognition from systems and M2H relation

Finally, the last level of cognition is the total stakeholder engagement, in this step, the human-machine interaction will be bi-directional and symbiotic. Herewith, the AI will give valuable insights of the production, noise, maintenance, sales, quality of materials, better supply chain decision to each stakeholder according to their interest. Moreover, each stakeholder will also feed the AI with information that he needs to get "smarter," like opinions about certain topics, tacit knowledge, experience and many others relational information. The C3 agent will need a rise in the machine behavior of all the human stakeholders. E.g Every time that the maintenance team receives an alarm from the AI saying that the machine "X" might break with a 90% probability, they will have to check the machine, understand the failure, repair and then analyze the causes of the failure. After doing that, they will upload the procedure to solve the problem to the data hub (where the AI based its analysis). With this, the next time that the AI encounters a failure, like the one mentioned before, it warns the maintenance team which failure is and what could be the possible cause of failure, making shorter the analysis and decision making. In summary, the human-AI team gets faster, more accurate and smarter every time they work together with bi-directional interactions. Finally, this AI can get into the sales information of the company, getting the customer queries and efficiently managing the production process with minimal downtime and high quality.

It is important to clarify that for this last step, AWS services like Amazon Lex (chat and text analysis), Rekognition for gathering and understanding visual data and Polly that translates text into speech, will be needed. With this services, it is very likely that the CPS will be able to communicate verbally with the stakeholders, follow them in the maintenance procedures and even talk with the customers. C3 cognition phase is the smarter and more human-friendly AI. However, it is also the most dependent on human interaction and stakeholder engagement.

In conclusion the cognition level, makes the CPS capable of helping employees make the work better in the factory and also in the company. However, to make possible this CPS there need to be a profound understanding of how the data will be handled, who will be in charge of it, which stakeholders will interact with it, and also highly qualified engineers that work properly on the cloud platform. Therefore, it is recommended to a client interested in these models to start step by step upgrading the AI capacities without rushing to a huge agent that nobody understands or use. According to an expert in artificial intelligence algorithms, the secret of all AI agents is that they need constant feedback and proper interaction with the users. If it doesn't receive feedback, it will be a complicated, expensive and useless agent.

LEVEL 5: CONFIGURATION

Configuration is the last level of a CPS architecture and will focus on translating the decisions and analysis from the previous cyber components into physical actions. This level is the final echelon of the constant feedback that the cyberspace gives to the physical system without supervision or any human control. In fact, the components of this level act as a resilience system that tunes, replaces and prevents undesirable conditions in the entire network. In the case study, there are three major problems that the CPS should immediately react on: Noise, maintenance and quality alert, and active engagement of the stakeholders in the supply chain. For this reason, this section will be divided into the components that solve each one of the problems.

4.6.13 Noise control: Pneumatic vibrators grid

In order to address the problem of noise in the physical installation, there will be a layer of pneumatic vibrators below the sensor network. These devices as shown in figure 27, will be connected and entirely managed by the AI agent. The objective of these vibrators is to generate an opposite vibration that cancels the machine vibration, thus, reducing resonance drastically. This concept of actively canceling noise was first developed by the company Bose in 2013 (Bose, 2016). However, this CPS is actively canceling vibrations not on a headphone, but on the entire floor of a building, allowing the company to buy new equipment from the factory without having to worry about the noise issues. It is important to mention that the calculation of some decibels that this system will reduce is out of the scope of the research.

Figure 27 – Pneumatic Vibrator

4.6.14 Maintenance, Quality and Operations alerts

Concerning maintenance, quality, and operation, the CPS should be in charge of managing the machines independently in the production facility. It needs to control the amount of material to produce (based on sales), turn off and on machines according to the maintenance checks and primarily interact with humans in such a way that they can be alert when something is happening or might happen in the process installation. The CPS has to prioritize the maintenance plans according to the production process and the condition of each machine, to do this, the system will use the WorkSpaces service to connect machines and stakeholders. For instance, machine learning service (ML) to send decisions to each machine and device, the RedShift database, and finally the machines should be connected to the cloud servers in a similar way that sensors are attached to the cloud in level one (5.1 Connection).

The added value of this reactive CPS is that the factory will manage based on real-time information gather and analyzed in the other levels. For example, the AI agent can make changes on the physical production line in a whole independent machine to machine (M2M) communication, making it faster and more reliable than human to human (H2H) communication.

4.6.15 Engagement with the stakeholders of the supply chain

The last reactive component has to do with the active communication and interaction that there has to be between the CPS and the stakeholders. However, this step is already reach ones the CPS reach the cognition level and specially the last condition (C3) in which the AI is actively responding and interacting with voice, messages, videos and alerts with all the stakeholders. Finally, it is important to mention that there are thousands of physical components in which this engagement can be reach: Smartphones, wearables, computers, headphones, speakers, cameras or even clothes are some of the things that make the interaction between the cyber system and the stakeholder in the physical world possible. For example, googles with augmented reality allow the operator to see which component in the machine is broken, based on the analysis done by the AI agent, or a pop-up message that alerts the management team that there should be a decision to make regarding the procurement of new machinery, based on the data analysis carry on by the engineers and the AI.

In conclusion, this last level (configuration) of the 5C architecture means that the CPS can gather, organize, analyze, monitor, communicate and react over the entire physical system. The new relation between the real and cyberspace will create something called by Klaus Schwab as *"Plug & Produce"* factories (Schwab, 2016), in which decisions are made independently by machines and there is a high level of interactivity between humans and the factory.

4.7 DESCRIPTION OF CPS

This section will describe how this CPS will look like in the real factory, how will the components be placed and how this CPS will operate. Before starting, it is important to clarify that the objective of this research is not making a detailed design but to investigate the potential of the CPS (combination of i4.0 technologies) in the process industry. Therefore, the description of the noise control system will end in a mock-up design with explanations on how it might be and work in a real context.

The components that this noise monitoring system will need are divided into six different fields according to the configuration level explained above: gathering, organizing, analyzing, communicating, monitoring and reacting. In figure 28 there is a list of components for each of the fields mentioned above. It is important to notice that out of the six tracks only two of them (gathering and reacting), in orange, are placed in the physical world, which suggests the importance of having a cyber-copy that links gathering and responding together. Another important remark is that the entire process of gathering till reacting will take just a couple of seconds, which means that the CPS has almost an immediate reaction to solve any possible problem that has to do with the operation. E.g if the machine "X" is in one corner of the floor and it is exceeding the noise limit, then, the vibrators will activate only in the corner where the machine vibration is exceeding the limit. This capacity makes CPS valuable for companies that need to react quickly to market changes or want to achieve customized mass production because the CPS will change and adapt quickly to changes in customer behavior, supplier demands or even management decision.

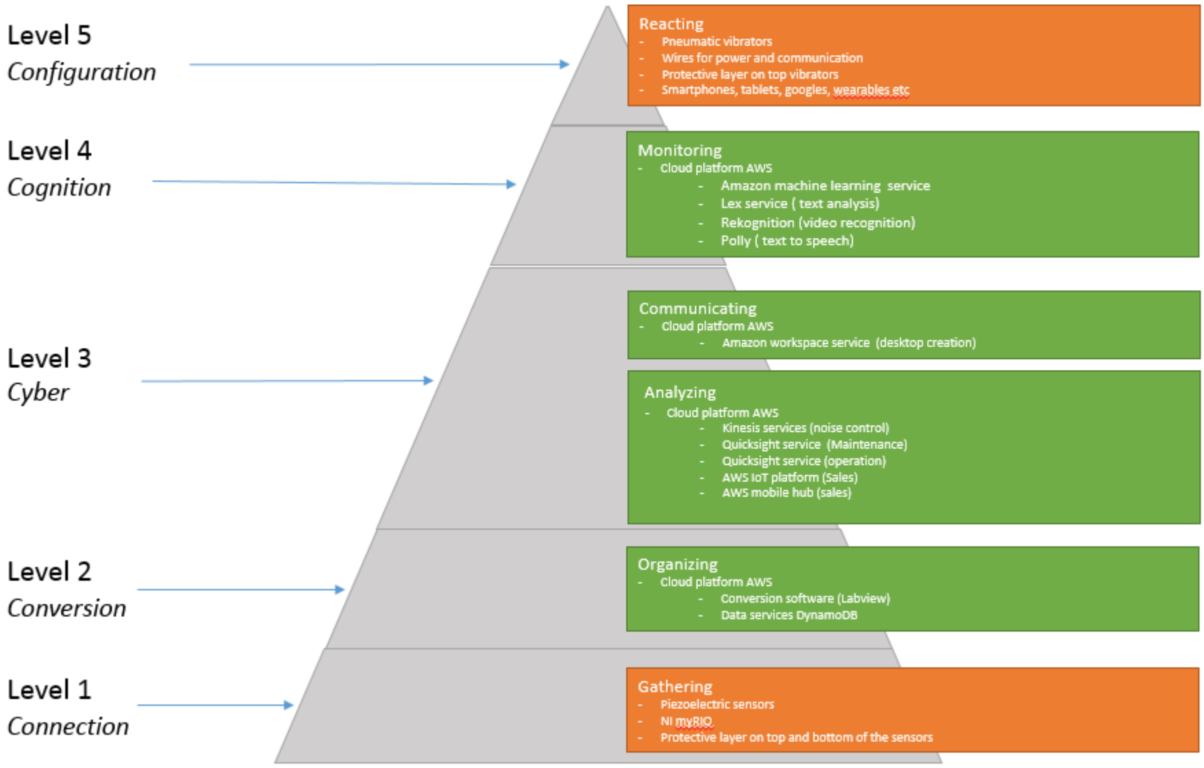


Figure 28 – Description of the components of the CPS by levels

After showing which components (cyber and physical) are part of this system. In figure 29 there is a map of how the information flows between components and how the system involves different stakeholders. It is important to state that the bi-directional arrow that is located between the AWS WorkSpaces service (desktop) and the stakeholders is the access point that all the human actors have with the cyber-system. This access point will allow each one of the parties involved (see figure 24) to get different information according to their interest and capability. The AWS WorkSpaces will link all the cyber components to the stakeholders, and for them, it will be as simple as looking at a desktop on a computer with different accounts, in which every report will link to different customize dashboards and services. For example, maintenance engineers will enter to the workspace to make maintenance analysis or see machine status. Simultaneously, an employee from the company is also entering WorkSpaces, but he is running different financial analysis in the Quicksight service related to the procurement of a new machine, all possible via the WorkSpaces access point on the AWS platform. Another aspect to point out in the CPS description is that there are three different types of communications: the green arrows express the machine to machine (M2M) communication inside the cloud platform, the red arrows describe the machine to machine communication (M2M) outside the cloud platform, and finally, the grey arrows explain the bi-directional communication between machine and human (M2H). In this network, there are 13 red, nine green and 9 gray communications between the different components.

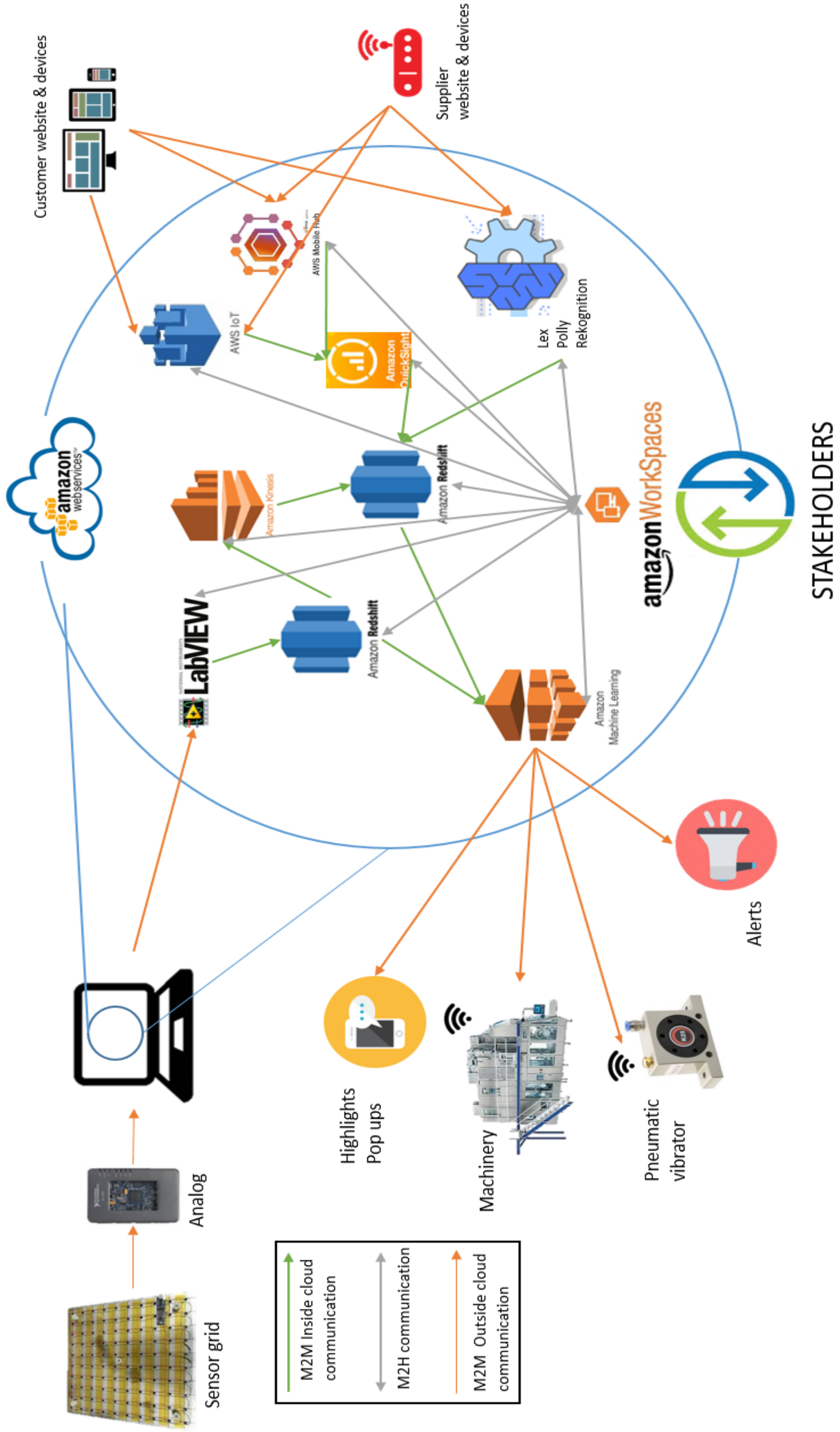


Figure 29 – CPS components in the case study

Finally, in figure 30 and 31 there is a mock-up design of how the physical components would look like in the production facility. In this design, the floor consists of three layers: The first one (in contact with the machinery) is the sensor grid, the second tier, is the grid of vibrators, and finally, the third layer is the concrete slab (structure).

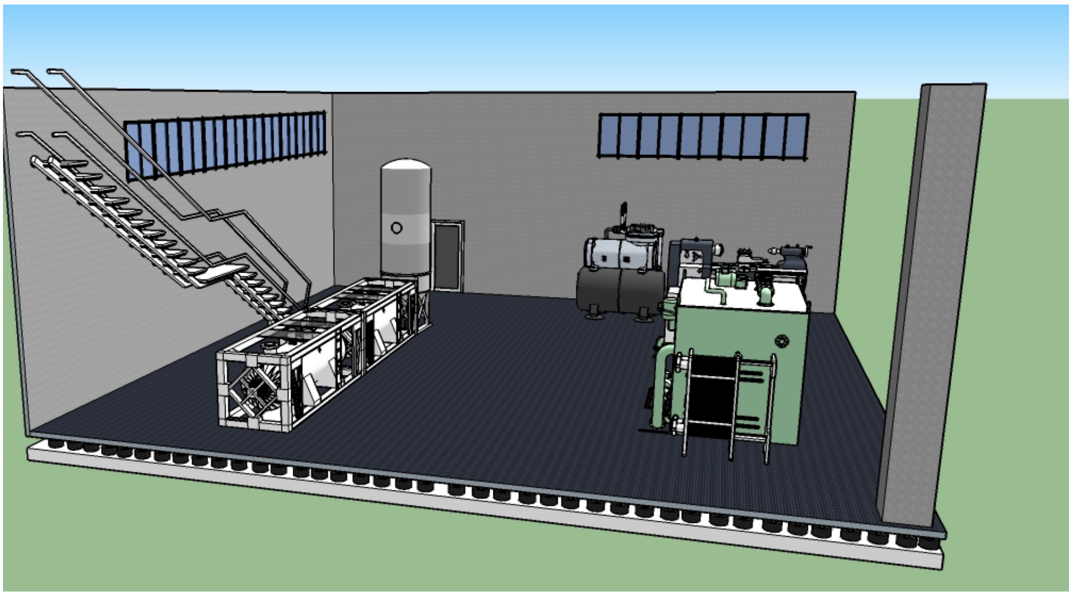


Figure 30 – Active noise cancelling CPS sketch

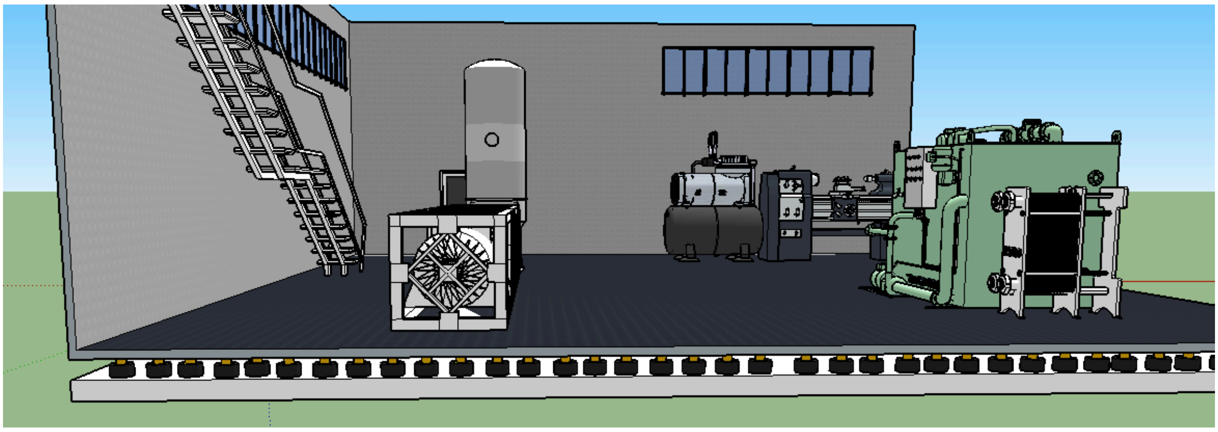


Figure 31 – Layers of the floor (structural, vibrating and noise grid)

4.8 IMPACT OF THE CPS IN THE CASE STUDY

The last step of this chapter will discuss the expected impact that the CPS might have with the requirements set before (step 2) and on each of the stakeholders. Hence, this result will be divided into two broad categories. On one hand, the impact that the CPS has on the requirements stated in step 2 and, on the other hand, the possible effects that each stakeholder will perceive based on their relation to the system.

Impact on the requirements

This section will verify if the CPS might create a positive, negative or no effect on each of the requirements stated in step 2, starting with primary goals and following with the operational, control and strategic requirements.

4.8.1 Main Goals: Noise control, information and engagement

- *Noise control (Production facility):*

The noise canceling CPS should reduce noise caused by vibrations of the machinery. This system allows the operators to identify and diminish the resonance of the building, posed by the vibrations of the machines.

- *Information maintenance, operation, and quality (Factory):*

Maintenance, operation and quality should improve because of two reasons: first, the amount of data gathered will increase due to the sensor grid, wearables, and website. Second, the quality of the information will be higher because of analytics services, such as Kinetics or Quicksight and AI services, like Machine learning. Additionally, this system should make the operation, quality and maintenance highly independent, with more machine to machine interactions, rather than machine to human.

As an example, maintenance could use the sensor grid to gather information about normal and abnormal vibrations and, consequently, the CPS will react upon the system to shut down the machine, alert and advice the maintenance team on what should be done with the asset.

- *Engagement of the stakeholders in the supply chain (Supply chain):*

This CPS should help to engage all the stakeholders in the supply chain of the bulk materials for several reasons that will be explained in the section 8.2 about the impact on the stakeholders.

4.8.2 Operational

1. *No humans in the production facility:*

The CPS should reduce the amount of work hours. In the production facility, they will be reduced since must of the activities are done by the components (physical and cyber) of the system. In fact, the only activities that will be done on site will be repairing, cleaning, installing and moving machines; the rest of them will be fully developed off site by engineers and operators.

2. *Safe environment:*

The CPS will probably decrease the probability of having a dangerous situation for two reasons: first, the fact that there are fewer employees in the production facility also means fewer accidents and adverse conditions for them. Second, one of the biggest problems of this factory was the high level of noise, which means that, by solving the noise problem, the factory should also be a safer environment for the operators. However, this CPS will also require some special considerations in cyber security because, if the system is hacked, the environment won't be safe anymore.

3. *No noise protection for workers:*

It is probable that the noise would be reduced to such extent that wearing personal noise protection headphones won't be required.

4. *Better air quality:*

The CPS won't have any impact on air quality in the production facility.

5. *Energy efficient system:*

The CPS should be made to be energy efficient because it controls in real time the machines, optimizing the production process and the power consumption of each device. For instance, in case there are low orders, the system works with fewer machines, or changes the production flow to fit the demand only. However, this system will also increment electricity consumption, because the active noise control needs pneumatic vibrators and the entire cyberspace needs the power to work and provide services.

6. *Reactive noise control:*

The CPS has the pneumatic vibrators that should react on the part where machines are exceeding the limits of the Dutch law. Everything is completely automated from the beginning of the noise until the reaction of the vibrators, which means that this requirement should be fulfilled.

7. *Connect noise control with the building*

This condition could be achieved with the CPS because the physical components of the system (sensor, grid, analog, and vibrators) are all connected to the structure of the building.

4.8.3 Control

1. *Connect manufacturer of machines with factory*

The CPS should be in charge of connecting the machine manufacturer with the system. First, by giving an account in the AWS workspace, where information about the machines are accessible and therefor analysis can be run. Second, data on other machines should be provided to make peer to peer review and get better insights on the machine vibrations and modes of failure.

2. *No soil contamination*

The CPS won't have any impact on soil pollution in the production facility.

3. Produce at low cost

Reducing the production cost has to do with cutting operational expenditures. According to Applied Corporate Finance book (Damodaran, 2015), the operational expenditures (OPEX) costs are accounting, license, maintenance, advertising, office, supplies, legal fees, utilities, insurance, property management, property taxes, and travel expenses. In Table 6, they will be shown the possible effects of the CPS on each of the operational expenditures.

Operational expenditure	Effect	Description
Accounting	–	No changes
License	↑	More licenses for cloud computing soft wares
Maintenance	↓	Better control of maintenance operations
Advertising	–	No changes
Office fees	–	No changes
Supplies	↓	Less waste, due to a more lean production
Legal fees	–	No changes
Utilities	–	Balanced change
Insurance	↑	Extra insurance for cyber security issues
Property management fees	–	No changes
Property taxes	–	No changes
Travel expenses	↓	Less travel expenses for maintenance team

Table 5 - Effect on the Operational costs with the CPS

It is important to notice that the operational cost "Utilities" are difficult to foresee because some utilities might get higher while others might get lower. For instance, services such as electricity might get higher because of the energy consumption of the sensor grid, vibrators, and computers. However, by making leaner the production process, the power consumption from the machinery will get lower by a certain percentage. In conclusion, to determine whether the cost of utilities will get higher or lower there will have to be a more profound research on the economic implication on the CPS in the factory. Thus, for this research, this item remains untouched supposing the energy consumption will balance the energy savings.

4. Deliver high-quality products

Thanks to the connectivity between customers, suppliers and the production facility it is possible to achieve better quality products for the clients. For instance, if suppliers are well connected to the factory they can see what type of materials fit the most for a specific end product and, in collaboration with the engineers of the factory, continuously improve the final product by making simulation and improvements in the several analytic tools on the cloud platform.

5. *More machines in the factory*

It is expected that thanks to the active noise control system the noise should be reduced and therefore it will be possible to place more machines in the production facility.

6. Highly automated process

As mention before, the process should be more automated with the CPS because there will be more M2M communication, by also changing the role of operators from part of the production process to controllers of the system. Plug and produce factories have a high level of automation and efficiency.

4.8.4 Strategic

1. Make a leaner supply chain (fast and cheap)

The CPS should connect all the stakeholders of the supply chain with symbiotic relations and mutual benefits (see an impact on stakeholder), meaning that the incidence of the entire chain will be higher than ever before. However, these benefits will only be palpable if there is a proper understanding of the complexity of the network and if the stakeholders can disclose their information. It is important to remember that a CPS without human interaction worth nothing.

2. Transparency between stakeholders

Transparency should be improved with all the stakeholders because all the information should be stored and shared, making common ground for development between stakeholders. However, as mentioned in the previous requirement, stakeholders should first agree on which information will be disclosed and which will not, because if there is no disclosure of valuable information, the symbiotic relations won't occur. Only after agreeing on what information will be part of the CPS, the system will have sufficient information to give insights of the supply chain and the factory. Therefore, this requirement won't improve if the stakeholders don't negotiate and talk about transparency of information and data management.

3. Connect factories with similar factories

This subject, as well as transparency, needs negotiation from the different stakeholders. The company can make sure that all the facilities within the enterprise are connected via the CPS. However, it is also well known that if the system gets in touch with competitors' information or other facilities in other parts of the world, the results of their analysis will be better and more accurate. Therefore, this requirement will only be fulfilled if there is a discussion of what information to disclose to parties.

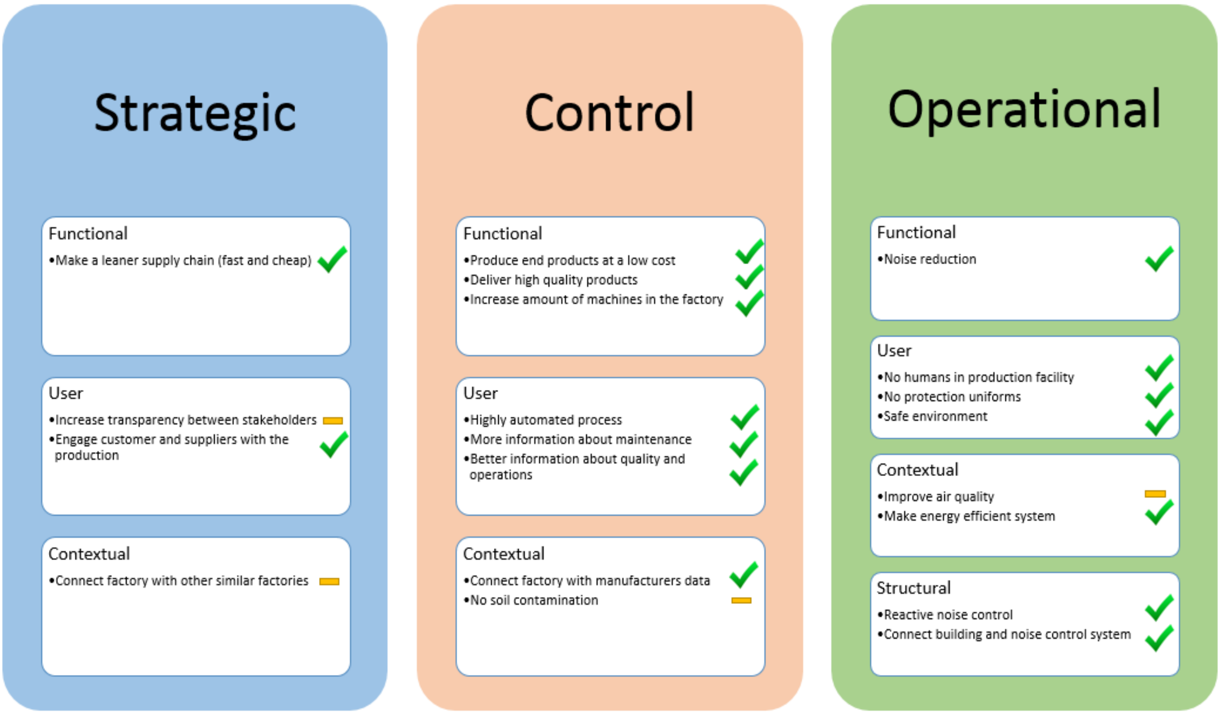


Figure 32 – Overview of the effect of the CPS in the factory/company

In conclusion, this CPS improves most of the goals stated by the senior engineer in Tebodin and, for that reason, it is considered that this CPS might create added value to the company and it can be connected to the current IT systems to provide better and more efficient information about the entire factory. In figure 32 there is an overview of the goals stated in this step and the effect that the CPS might have on the company.

IMPACT OF THE CPS ON STAKEHOLDERS

In this section, there will be a description of how stakeholders are connected to the system, which type of relation they have with the system, and what should be the added value that both the network and stakeholders receive from this relationship. It is important to clarify that part of the key issues of a CPS is the ability to connect different stakeholders and make them interact with the physical or cyber environment. This interaction, as explained before, is bi-directional or symbiotic, because both parties are related with each other for mutual benefits.

4.8.5 Connection between stakeholders and the CPS

This CPS is made up of cyber and physical components, each of them interacting with other components and stakeholders. In figure 29 there is a description of how the elements of the system are interrelated between each other. However, in that description it is not clear the relation between components and stakeholders. For this reason, in figure 33 there is a table of the different relations between the CPS and the stakeholders. For instance, the relationship between the maintenance team and the sensor grid (the point with a blue dot) implies that the support receives information for the sensor network plus the analog. In this table, the empty cells represent that there is no relation between the stakeholder and the component. For example, the customer has no connection with the sensor grid or analog. In figure 33 (down corner) there is a definition of the type of relationship that the stakeholders held with the components of the system.

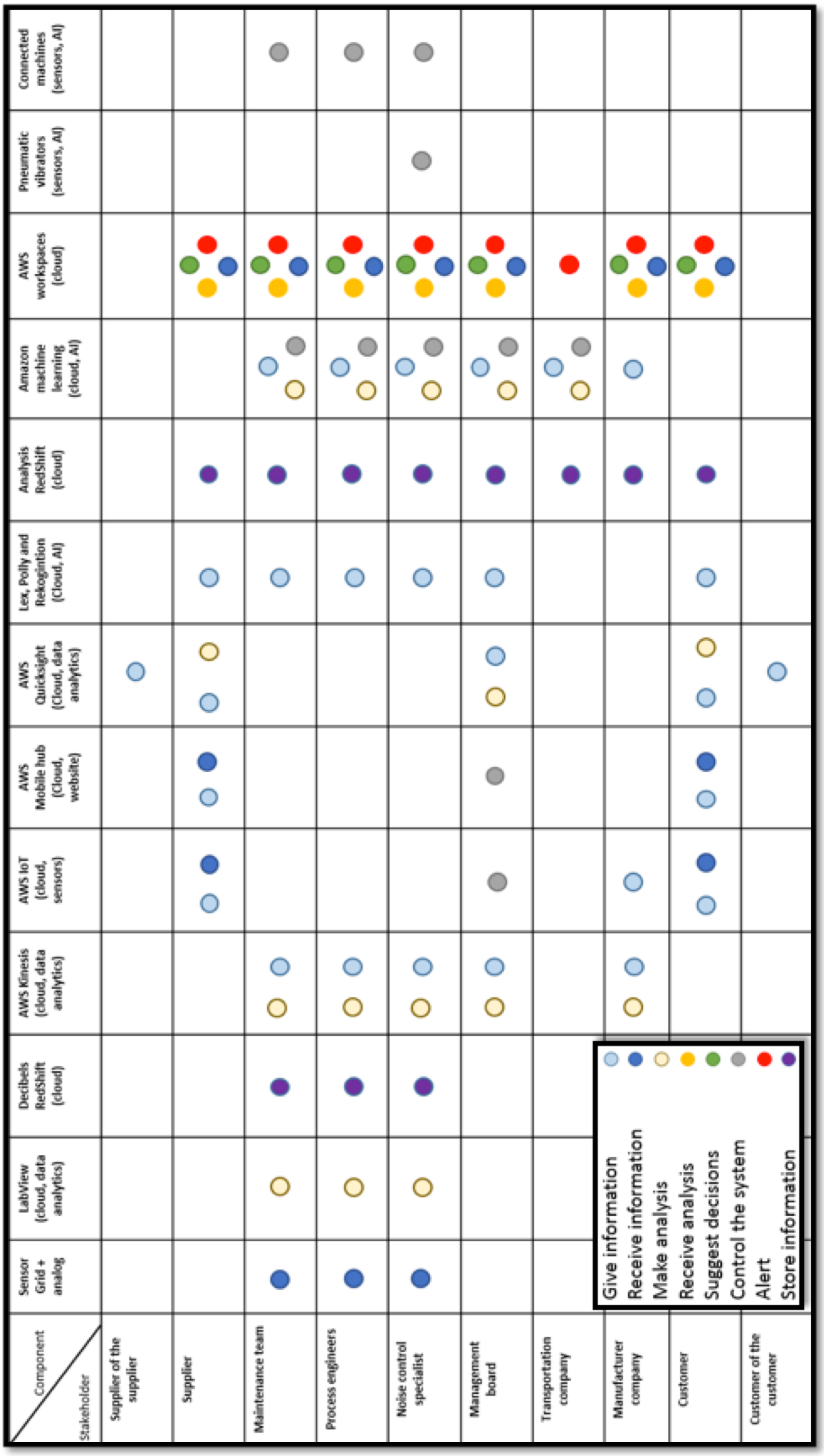


Figure 33 - Relation between interested parties and CPS components

Another important aspect about this stakeholder relationship is that, as it can be seen in figure 33, it involves a mutually beneficial relation or symbiotic relation. For instance, the machine manufacturer company has nine different relations with the CPS: with the Kinesis service of data analytics it gives information for peer to peer analysis, with the same tool it can also make and run analysis with data gather in this service, with the use of IoT devices and services in the cloud it gives information to the CPS about other machines in other factories, with RedShift it can get in touch with all the information granted by the previous services, with the machine learning (artificial intelligence) the machine manufacturing company gives information of the machine development and historical data and finally, in the WorkSpace, the company receives information about all the analysis, suggestions on how to make the machines suit better the process, alerts in case of failure. All these relations are only possible by following in detail the 5C level methodology and having knowledge on what each of the components does in the entire network.

4.8.6 Impact of the CPS on each stakeholder

After looking at the types of relations that the CPS has with the stakeholders, this network of interdependencies will create an impact on the system and on each stakeholder. In this section, there will be an analysis of the effects that the CPS might cause for each stakeholder and the entire system. First, it is important to understand that the more relationships the system has, the higher its impact will be. In figure 34 there is a list of each stakeholder, the number of relations that it has with the system and the impact that the CPS will cause on the stakeholder. In the operational level, the noise control system might cause significant advantages because the entire process, from gathering to reacting, should be completely automated. In the control level, the maintenance and operational team might change the way of working, by having real-time information, monitoring the system outside of the factory and allowing operators to make maintenance easier and faster each day. In production, there should be a change from a pushing to a pulling system. Production should be connected with customer demands and supplier constraints, as well as, creating common ground for investigation with machine manufacturers and suppliers. Finally, from a strategic level, the impact could be significant for the management team. The board of directors will probably have better and real time information about the entire supply chain, allowing them to react to market changes and improve their decision-making process. Finally, with an automated production facility, the company should be able to cut costs and increase the speed of the fabrication, improving customer satisfaction.

Stakeholder	# of relations	Impact
Supplier of supplier	1	Better processing due to a better supplier information.
Supplier	12	Real time info, insight of the production process, insight on material behavior on site, one unique data source, automatic placing of orders, quality simulations and improvements, common ground for innovation, transparency, pulling production process.
Maintenance team	15	Real time info, insight of the assets in the factory, reliable information about the process, one unique data source, alerts in case of failure and suggestions in decision making, maintenance simulations and improvements, completely automated process, shorter repairing time, preventive and predictive maintenance instead of reactive.
Process engineers	15	Real time info, insight on the production process, energy control, one unique data source, alerts in case of failure and suggestions in decision making processes, production simulations and improvements, completely automated process, optimization of the production with real time data of suppliers and customers.
Noise control specialist	16	Real time info, insight on the production process, energy control, one unique data source, alerts in case of failure and suggestions in decision making processes, production simulations and improvements, completely automated process, reduction of resonance, improvement of environmental conditions, safe environment for the operators.
Management board	15	Real time info, insight on the production process, energy control, one unique data source, alerts in case of problem at a factory level, production simulations and improvements, customer and supplier engagement in order to improve customer service and quality control, been able to procure more machines in the production facility, make a cyber copy of the factory, take decision with real time consequences, mass customization, automated pulling system, less cost in the production, less time from raw material to customer, less inventory, higher customer services, closer relation and common ground with the stakeholders.
Transportation company	5	Automatic placement of orders, more insights on transportation aspects.
Manufacturer company	9	Real time info, insight on the machine behavior, energy control, one unique data source, alerts in case of failure and suggestions in decision making processes, machine simulations and improvements, better quality checks, improve customer service, get more data of the behavior and use of the machines, common ground for innovation, better relation with the customer.
Customer	12	Easier purchasing process, insight of the production process, fast production, one unique data source, automatic placing of orders, mass customization.
Customer of customer	1	Better processing due to a better customer information

Figure 34 – Impact on each stakeholder

It is now clear that the CPS could bring various positive effects in the factory and stakeholders. Finally, the next section will focus on the analysis of the 5C methodology based on the validation square proposed by Seepersad et al (Karolyn C. Seepersad, 2005).

4.9 VALIDATION SQUARE – ASSESSING THE 5C METHODOLOGY

In this section, there will be a validation of the 5C level architecture methodology applied to the process industry, based on a validation square developed by Seepersad et al (Karolyn C. Seepersad, 2005). This square will focus on identifying four aspects that methodologies in engineering disciplines must have: Theoretical structural validity, Theoretical performance validity, Empirical structural validity and Empirical performance validity. Figure 35 will show the different categories of the validation square.

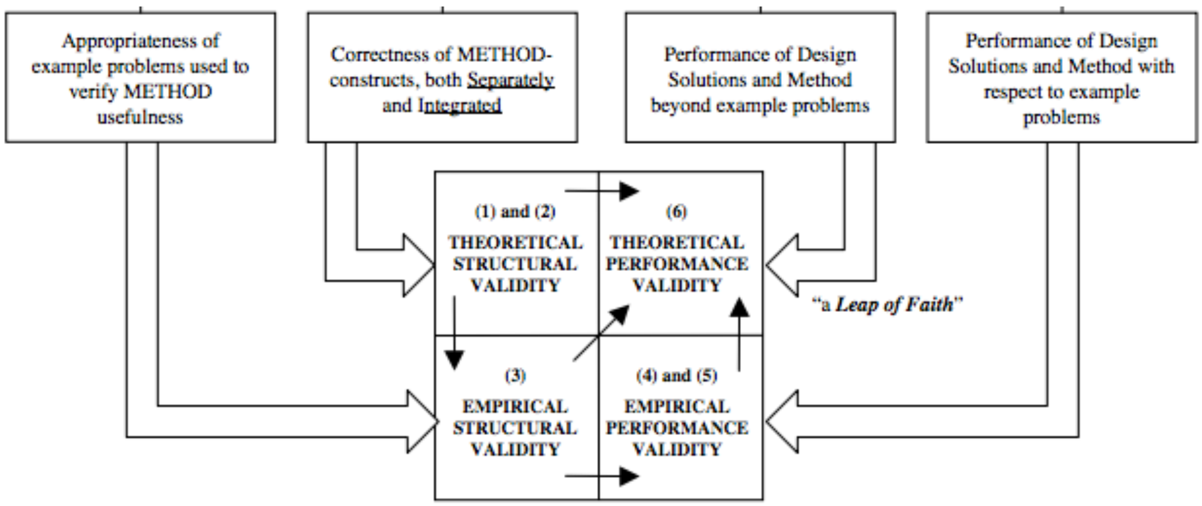


Figure 35- validation square (Karolyn C. Seepersad, 2005)

THEORETICAL STRUCTURE VALIDITY

According to Seepersad et al (Karolyn C. Seepersad, 2005), a methodology has a valid theoretical structure if the model is consistent, which means that theoretically the design process and design outcome are align and coherent. In this case the methodology was clear, consistent and fluent, with step by step procedures. The outcome of this methodology is a design of a cyber physical, using the KEY and important technologies of the industry 4.0.

EMPIRICAL STRUCTURAL VALIDITY

Based on the paper by Seepersad et al (Karolyn C. Seepersad, 2005) the empirical structural validity relies on the representativeness of the case study chosen. In other words, how well does the examples used in the methodology represent the context. For this validity, the case study chosen was a bulk production process factory, for this case study the requirement was set up clear and the needs for a design that solves noise, stakeholder connectivity and better information were set up. However, this example will only be representative for the mineral production process and in particular for factories that have machines connected to the slab of the structure.

Empirical performance validity

The empirical performance validity based on Seepersade et al (Karolyn C. Seepersad, 2005) focus on two main aspects. The first one is the usefulness of the output in each example, which means that the design output solves a problem or need accurately. In this research, the output of the design of the CPS using the 5C level methodology is well aligned with the boundary conditions, goals and requirements of the company, which means it is useful.

The second aspect is the usefulness of the method: this aspect defines whether the case was good enough to deliver certain outputs. For this topic, the case study had enough information to deliver a valid output. However, the integrated validity can't be stablished because there was only one example, and therefore, there was not possibility to compare outputs between examples. Finally, to analyze the usefulness, a group of examples must be analyzed and compared. Unfortunately, in this research there was only one example and therefore it is impossible to analyze properly the integrated usefulness of the method.

Theoretical performance validity – leap of faith

The last category on the validation square is the theoretical performance validity: this category explains the usefulness of the methodology beyond the examples. In other words, how useful a methodology could be in other cases regardless of the case study chosen. In this research, it is possible to see that the 5C level architecture modified in this report could be applied in the entire process industry. This leap of faith is based on the argument that cyber-physical systems have so many different applications and components that is not difficult to think that other process installations will require the design of CPS. Moreover, in chapter 2, section 2 it is stated that the process industries have converging trends and challenges, specially regarding innovation, digitalization and automation. Therefore, it is probable that the 5C level architecture could be applied in different industries and applications, within the process industry. Finally, based on the categorization of the technologies and the application of them in the CPS, it is possible to foresee that the outcome of the methodology could solve several problems in a process factory.

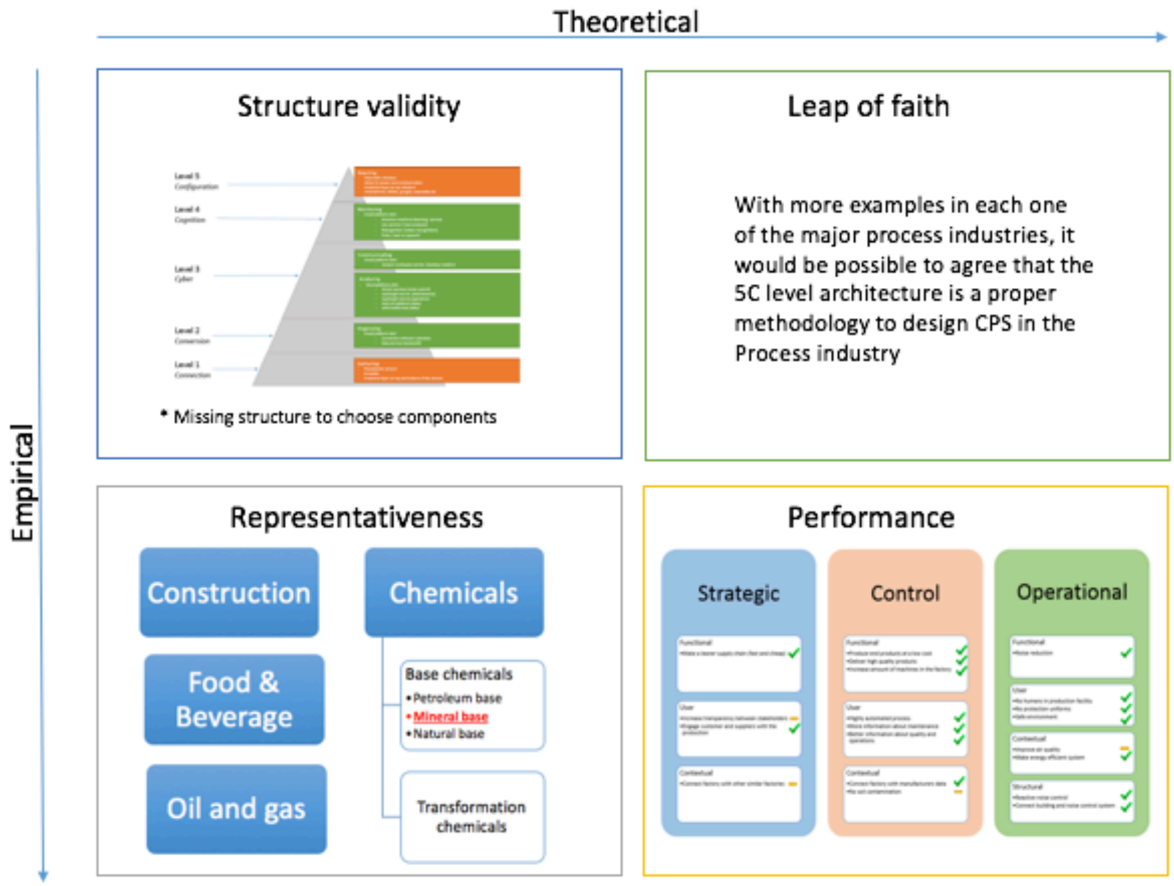


Figure 36 – Validation square of the 5C level methodology

4.10 Conclusions

The main outcome of this chapter was proving that it is possible to build up a cyber-physical system with the KEY and IMPORTANT technologies by using the 5C level architecture methodology. In fact, this system could generate several benefits like connecting ten stakeholders and 13 components in nearly 112 relations, expecting to generate at least 35 positive effects in the entire supply chain. Furthermore, it was also concluded that there are plenty of new ways of combining the real and cyber space with the challenges and problems of a real factory. Herewith, the active noise cancelling CPS is just one of the various systems that can be built for this case study. Another important conclusion is that all CPS designs must be tailor-made to the needs of the client; Even though the sensors, cloud solutions, and other I4.0 technologies are standard products (Hardware, Software) the way of using and connecting them must be unique for each company and factory.

In terms of the outcome of the design, the conclusion is that there is a direct relation between the numbers of nodes of the network and the benefits that the system could provide. Moreover, it could be concluded that by using the 5C level architecture methodology for the process industry, the design assessment could also work as expected output for a real CPS. In other words, with the result of this design methodology, the company could know a priori what to expect on the network.

In this chapter, it was proven that the methodology 5C architecture by Lee et al (Jay Lee, 2014) might also work for the construction of CPS in the process industry and not only on the manufacturer industry as it was planned. However, based on the validation square, to proof that this methodology could work for other process industries it is suggested to do more case studies. Furthermore, in this validation square it was also found that the 5C methodology needs experts that know the components of each i4.0 technology and how to connect them properly. Therefore, the 5C level architecture is limited to a certain group of engineers and experts that know about i4.0 technologies and are able to develop CPS.

CONSIDERATIONS

To have a useful CPS, the stakeholders should discuss and negotiate how much information will be disclosed to the system. For instance, if the company decides to make a CPS but this system is not inviting other stakeholders to feed the system and play with it; the investment of this complex network will be lost, and the system will not make the significant impact in the production facility. In fact, in the case study out of the 112 relations, 43 of them are feedback that the humans are giving to the machine. Another consideration is that the CPS must be developed by stages; it is not recommended to start with a level five system because this will consume a lot of money, energy and time. Instead, the company should upgrade level by level the CPS. Learning in each step what is right and bad for the company and getting expertise in how to deal with these complex networks. In this case study, a 5 level CPS was made, making hundreds of relations and making various benefits. However, starting with a level 2 or 3 CPS will also give some advantages and will reduce the risk of investing money and human resource on a lost cause.

Finally, in this chapter was also demonstrated that it is possible to connect the structure of the installation (building) with the purpose of the facility. For instance, in the case study, the link between the building and the machines that produce the bulk material was the noise cancelling system. This apparently simple concept of making structures that fit an operational purpose might cause disruptive new ways of designing structures and factories. In fact, based on the previous chapters, the next chapter will foresee the possible new features and changes that a plant in the process industry will have in the next five years.

5. The Process Factories in 5 years.

This section will respond to the question: How factories in the process industry will look like in five years? For that purpose, this chapter will foresee the changes that the process installations might have based on literature research, the information gather by the experts in chapter 3 and the case study in chapter 4. However, it is important to clarify, that this chapter will focus on the consequences that these changes might cause in the form and shape of covered process installation, such as the one of the case study and the factory on figure 37.

Figure 37 - Covered process installation

In this chapter, there will be a list of changes that the process facilities might experience in 5 years as a consequence of the implementation of cyber-physical systems in their production process. Highlighting the impact that this changes might have on the form and shape of the factory.

5.1 CUSTOMIZATION - PULLING THE PRODUCTION PROCESS

According to Klaus Schwab, with cyber-physical systems that communicate via machine to machine communications (M2M), it is probable that the production process will tend to move from a pushing to a (lean) pulling system. This shift will be a consequence of the change from standard to customized end products (Schwab, 2016). In a world in which the trends are individualizing and the customer has a higher decision power, pulling production is the only way of coping customization without having waste material or huge over costs. According to the paper "The benefits of lean manufacturing" by professor Molten (T.Molten, 2005), pulling systems have several consequences in factories such as: Decrease in lead time for customers, reduce inventory, reduce process waste and rework. However, since the focus of this chapter is to analyze the impact on shape and form of process factories, a reduction in inventory is the only one of the consequences, listed by Molten, which will cause a change in facility's shape and form. It is stated in Molten's paper that a reduction of inventory, without compromising the production capacity, will shrink the factory area and volume enormously. For instance, in the factory of the case study, the area reduction could have been at least one-third of the total area if the CPS was fully operational. In conclusion, pulling systems will make new factories smaller by lowering the inventory, and therefore, shrinking the storage facilities.

5.2 ACCURATE INFORMATION (THE CYBER TWIN)

One of the major benefits of having a cyber-physical system is the ability to get more data, better information, and especially, in real time (Schwab, 2016). CPS in a process factory will allow every machine or structure to have a digital twin that measures, feels and behaves exactly like the real machinery. In fact, due to this digital twin, it is possible to have a better understanding of the machinery and production process, in such a way, that it might cause a substantial reduction in the number of redundancies in the production line (Siemens, 2017).

As explain in chapter 3, the process factories are characterized by having a continuous flow of material and, as a consequence, several redundancies to cope the high availability of the installations. According to an asset management consultant, process engineers have to make sure that there is always a backup system for the critical components in a process facility. However with the digital twin, the system could self-heal and react immediately to undesirable condition, therefore, the factory wont need redundant components in case of failure (Siemens, 2017). For this reason, it is logical to think that without the need of backup systems or redundancies, process factories will be more lean and smaller, having less components but a higher monitoring on the critical ones.

5.3 OPERATION – STRUCTURE LINK

The active noise cancelling system designed in the case study (chapter 4), is an example of a how cyber-physical systems connect the structure and the production process to get integrated solutions. As explain in the conclusions of chapter 4, there are several options in which the structure of the factory can actively be part of the production process. For instance, energy saving, smart lighting, active diffusers or waste management are some examples in which the operation of the building is linked with the structure of the building (Carlo Ratti, 2016). These linked systems, allow companies to cut operational and non-operational expenditures in ways that haven't been done before. According to Carlo Ratti, the director of the Senseable City Lab at the Massachusetts Institute of Technology (MIT), the Songdo Central Park in South Korea is a perfect example of how structures and operations together can provide excellent integrated solutions. In Songdo, smart buildings have a transportation system that monitors traffic in real time and pneumatic trash systems that pull waste from individual households to a central hub, without human operation (Carlo Ratti, 2016). In conclusion, the structure of the factories in 5 years will probably be like the Songdo Neighbourhood, with embedded systems that track, monitor and react to the environment and the production process, in a whole decentralized way. In terms of shape and form, it is difficult to predict whether factories will change the structure. However, in smart buildings, facades, roofs, ceiling and floors are probably the most common elements that will link operation with structure. Herewith, it is probable that these elements will change in form and shape depending on the business model of the company and factory.

Another possible change that factories will suffer in form and shape is the level of interaction between the user and the building. According to Carlo Ratti, the levels of interaction between buildings and users will continue to rise in the next years (Carlo Ratti, 2016). Herewith, the walls, doors, machines, pipes and other elements in the factory will give relevant information about their condition to the user, making him aware of abnormal behaviors or activities.

5.4 PREDICTIVE PRODUCTION- AI AGENTS IN A FACTORY

Artificial Intelligence is probably the i4.0 technology that will have the biggest impact in the production process and shape of the facilities. According to Kevin Kelly, in his book "*The Inevitable*," artificial intelligence is so unpredictable that it could change almost everything, from the way of doing things to the way of approaching a problem. He states that in the near future AI's will make Ai's, or AI's will make research on complex optimization, or even AI's will write books and articles on specific topics (Kelly, 2016). In fact, according to a professor expert on artificial intelligence, in a couple of years, AI's will probably be capable of controlling and making an improvement at a machine level or even system level, replacing some human operations and being the hub in which different actors communicate. However, based on the assessment in chapter 3, it was perceived that the big changes of AI technology might not arrive within the next five years. It is not likely that the AI's will be so smart that they can alter the production process and change the factory shape dramatically. Moreover, according to the world economic forum (WEF), AI's disruptive changes will probably occur in 10 to 15 years, when computing power and deep learning algorithms reach a human reasoning capability (World Economic Forum, 2016).

In this near future (less than five years) the AI will contact the maintenance team when there is a failure, it will tell managers when procurement of new machinery might be needed to cope the demand, will communicate with customers and help the operators develop tasks. These changes will redefine the role of human work in factories. According to a professor and researcher in the field of cyber-physical systems, it is possible that CPS with artificial intelligence power will decentralize the production process and reformulate the fact of having humans in factories. In conclusion, concerning shape and form, is probable that areas aimed for humans will be reduced or relocated outside the factory, shrinking the factory surface and also making it more machine oriented rather than human oriented.

5.5 SUPPLY CHAIN CONNECTIVITY – OPEN SOURCE, NEW DEVELOPMENTS

According to a senior business developer at a consultancy firm, the role in the supply chain of almost all process companies is to transform raw materials into several ranges of products, which are then sold to other businesses. These business to business (B2B) transactions are usually based on contracts, making the relation between process companies and final consumers loose. However, according to Byrnjolffson in his book *"The Second Machine Age"*, with embedded hardware and software components in the physical world, the machine to machine (M2M) communications will transfer within seconds information about the supply chain, to all the stakeholders. Logistics, inventory, materials used, customer satisfaction and many more. With this M2M relations the supply chain will be connected in such a way that the limits of companies will be blurry and the information will be share during the whole process. This will require that the information between companies and stakeholders is open source in a way that every employee working in the process can see and manipulate the process. This connectivity between different companies and factories will change the shape and form of process installations. For example, the company MyMuesli that produces customized muesli in Europe, is an example of how connectivity of the supply chain change the business model and the muesli production. They have several local production stores that fulfill the needs of the vicinity, reducing logistics costs and the production cost (no humans in the production process) and some bigger production factories that produce muesli for location with a less market share (My Muesli , 2017)

6. Conclusions and recommendations

6.1 CONCLUSIONS

This document has the purpose of showing the possible impact that cyber-physical systems (combination of i4.0 technologies) might have in the process industry and how can they be applied in a process installation. During the entire document, there were five major conclusions that were derived from the literature study, interviews and design process:

The first conclusion is that in the process industry, in the next 5 years, out of the fourteen technologies listed in industry 4.0, only three of them (sensors, artificial intelligence and cloud computing) have the potential and the technological maturity to be placed in process installations. Additional to these KEY technologies, other five technologies were considered as IMPORTANT, which means that they have a technological maturity but their application in the process industry is limited to certain tasks.

The second conclusion is that cyber-physical systems can disrupt the process industry. However, the design and execution of these systems should be fully customized to the case and managed by engineers and IT professionals able to choose the technologies, connect the components and maintain the system. This conclusion is important because it means that, in order to design CPS, there will always have to be an assessment and design process that can't be avoid with standard methodologies.

The third conclusion is that the methodology used to design a cyber-physical system (5C level architecture) could be valid for the process industry, however, more case studies and designs should be developed, in order to assure that the methodology is adequate in other process industries.

The fourth conclusion is that design and engineering companies, like Tebodin, should use the methodology shown in this report as a design philosophy rather than a methodology. In fact, every time that a client asks for a design of a factory, building, machine, pump, vessel, etc., the approach of the design/engineering team should always be to create an object that acts as a CPS (gathering, organizing, analyzing, monitoring, communicating and reacting towards the environment). By using the 5C level architecture as a design philosophy the added value to the client should be higher than the single inert object. As for the design/engineering firm, the added value of making a CPS should also rise because the new system will require additional services like asset management control, sustainable consulting and CPS management, in order to work efficiently and adequately.

Finally, the fifth conclusion is that, even though forecasting how factories will look like in the next five years, it highly depends on the company, product and management desires. There are some aspects that will tend to be common in the smart factories. For instance, factories will tend to shift from pushing to pulling production systems. Companies will tend to develop cyber twins for their crucial machinery and then for the whole factory. The inert objects in factories such as structure, vessels, roofs and other, will tend to be more interactive and connected to the production process. Artificial intelligence agents will be more and more common in the factory production process, and finally the connectivity between systems will tend to increase making companies able to link the entire supply chain process and allowing them to share information and knowledge in the way.

6.2 RECOMMENDATIONS

Having concluded the analysis and design process of this research, there are seven recommendations that are going to be mentioned for future academic projects in this field of work.

The first recommendation is to use more than one case study in order to validate whether the methodology to design cyber-physical systems is adequate enough to represent the entire process industry. It is suggested to use at least one case study per industry (oil and gas, chemicals, construction, food and beverage).

The second recommendation is to continue with the development of the design, making an actual prototype of a cyber-physical system in a process installation and assess the expected impact (found out in this research) with the real impact. This will give a much better approach to validate whether CPS are feasible in the process industry.

The third recommendation is to focus on an application rather than an industry. In other words, it is more convenient to proof whether cyber-physical systems work for a specific application, that several process industries have in common, rather than work on a CPS that will fulfil the needs of an industry. This way of thinking might lead to a better identification of the problem and, consequently, to a better solution.

The fourth recommendation is to assess the financial impact of a cyber-physical system. As it was mentioned in this document, the more levels the CPS has, the higher the impact will be in the factory and company. However, it was not mentioned how much it will cost to upgrade a CPS from one level to another. Herewith, by doing this financial research it will be possible to identify under which circumstances it is more convenient to upgrade or downgrade a CPS according to a cost/benefit analysis.

The fifth recommendation is to tackle the problem of noise, connectivity and information with different concepts of CPS, after doing that a morphological chart (figure XX) can be used in order to asses the concept and arrive to a design that fulfills more all the requirements. By doing this process the result of the design will be much better than only assessing one concept.

For the Tebodin it is recommend to take this methodology explained in the report and make a workshop in which different engineers come up with various concept fro a particular factory. With this methodology they can improve their knowledge in cyber physical systems and they can start providing industry 4.0 solutions to their clients, by design and making CPS for specific applications.

Finally, it is recommended, for future developments, to create a methodology wider than the 5C level architecture, which includes a method to choose and sort technologies, as well as a methodology to link components in the system. This wider methodology will be more structured, more representative and will not require experts to design cyber –physical systems.

Sub function \ Solution	1	2	3	4	5
Means of controlling throttle valve	Torsion spring	Hydraulic system	Pneumatic system	Compression spring	Spring in carburetor
Pedal connection to cylinder	Hydraulic cylinder	Pneumatic cylinder	Cable		
Pedal attachment to cable or cylinder	Shaft	Single slot	Double slot	Clevis pin	
Return force on pedal	Torsion spring	Hydraulic force	Pneumatic force	Extension spring	
Pedal pad design	Integral with pedal	Design separately then attached			
Pivot shaft location	End of pedal	Along pedal arm			
Pedal Arm profile	I	C	U	O	T
Ribbing pattern	V	X	No ribbing	2 rows of V	2 Rows of X

Figure 38- Morphological design chart

7. Works Cited

ABB Norway. (2013). *Oil and Gas production outlook.* ABB, Norway. Oslo : ABB group.

American Chemical Society. (2013). *The Chemical industries in the UK*. Retrieved from The Environment : http://the-environment.org.uk/bristish_isles/history_chemical_industry_UK.html

Association for unmanned vehicle systems international. (2013). *The economic Impact of unmanned aircraft systems integration in the United States.* Global: AUVSI.

Azhar, S. (2011). *Leadership Management.* Atlanta.

Bell labs Consulting. (2016). *Advising the industry on the path to network 2020.* New Jersey: Nokia .

Bhargav. D , S. Kubler . (2016). Opportunities for enhanced lean construction managament using internet of things standards. In S. K. Bhargav Dave, *Automation in Constuction* (pp. 86-97). Elsevier.

Bose. (2016, 12 1). *bose* . Retrieved from www.bose.com: https://www.bose.com/en_us/products/headphones/noise_cancelling_headphones.html

Boston Consulting Group . (2016). *The Future of productivity and growth in manufacturing industries.* Global: BCG .

Bureau of Economic Analysis. (2016). *Gross Domestic Product by Industry: Third Quarter 2016.* Bea.

Bureau of Labor Statistics. (2017). *The Employment situation - Janurary 2017.* BLS.

C. Ratti, M. Claudel. (2016). *The City of Tomorrow: Sensors, Networks, Hackers and the Future of Urbna Life .* Boston: Yale Unviersity Press.

Cisco. (2013, 7 29). *The internet of everything in motion.* Retrieved from cisco.com: https://newsroom.cisco.com/feature-content?articleId=1208342

Cooke, K. (2015, January 6). *The Guardian.* Retrieved from www.theguardian.com: https://www.theguardian.com/environment/2015/jan/06/oil-price-casts-shadow-over-frackings-future

Daily Mail. (2013, July 30). What happens in just one minute in the internet? London, London, UK.

Damodaran, A. (2015). *Applied Corporate Fianance.* New York: Wiley.

Deloitte digital. (2015). *Challenges and solutions for the digital transformation and use of exponential technologies.* Zurich : Deloitte digital .

Dyke, T. V. (2016, February 12). Food and beverage trends in a transformative time. *Institute of Food Technologist's* , p. 2.

Emarketer. (2011, Nov). *emarketer.com*. Retrieved from emarketer.com.

Empire State College . *What is the Construction industry? .* UK .

Erik Brynjolfsson, A. McFee. (2016). *The Second Machin Age.* Boston.

Exone. (2015, 11 18). *www.exone.com*. Retrieved from Exone: http://www.exone.com/Portals/0/Systems/exerial/X1_Exerial_US.pdf

Fiat Research Center. (2016). The Future of manufacturing for the automotive industry. *Factory Innovation - Ecofactory*, (p. 29).

Garnter. (2016, October 13). *Worldwide shipments of 3D printers to grow 108%*. Retrieved from www.gertner.com: http://www.gartner.com/newsroom/id/3476317

Goldmansachs. (2014). *BI intelligence estimates.*

GTAI. (2016). *Industrie 4.0: Smart manufacturing for the future .* Berlin: GTAI.

Hartog, Veschuren (2005). *Evaluation in Design- Oriented Research .* Nijmegen: Springer.

IBM . (2016, 10 17). *IBM* . Retrieved from ibm.com: https://www.ibm.com/watson/health/

Institute of Industrial & Systems Engineers. (2008). Making Cereal Not Cars. *Indusrial magazine* , 8.

Japan patent office. (2013). *Analysis of technology trends in patent applications.* Tokyo : JPO.

Jay Lee, B. Bagheri, H.Ang. (2014). *A Cyber-Physical System architecture for Industry 4.0 - based manufacturing Systems.* Cincinnati: Elsevier.

John W. Creswell, C. N.Porth (2013). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches .* SAGE publications .

Karolyn C. Seepersad, K. Pederesen. (2005). *The Validation Square.* Atlanta , Georgia , USA: GIT.

Kelly, K. (2016). *The Inevitable .* New York: Viking Press .

Kleijn, L. B. (2015). *Management of Projects.* Den Haag: nap.

KPMG. (2010). *The Fuure of European Chemical Industry.* Global: KPMG Global.

Kulatilake, P. (2016). *Innovation in the construction industry .* Built Environment - Sri Lanka .

Longwell, J.Harry. (2002). *The future of the oil and gas industry: Past approaches, New Challenges.* World Energy.

Machine intelligences Research Institute. (2014, 5 12). *intelligence.org*. Retrieved from intelligence.org: https://intelligence.org/2014/05/12/exponential-and-non-exponential/

Malte Brettel, N. Friederichsen. (2014). How virtualization, decentralization and Network building change the Manufacturing Landscape: An industry 4.0 perspective. *international Journal of Mechanical, Aerospace, Industrial, Mechatronic and manufacturing engineering* , 8.

McKinsey&Company. (2015). *Industry 4.0: How to navigate digitalization of the manufacturing sector.* Global: Mckinsey digital.

My Muesli . (2017, 3 15). *My Muesli* . Retrieved from mymuesli.com: https://uk.mymuesli.com/story

National Science Foundation. (2015). *CPS Vision Statement* . Baltimore.

Oosterhuis, K. (2011). A New Kind of Building. *Constantin Spiridonidis*, (p. 25). Thessaloniki.

Petr Kadlec, B. Gabrys. (2009). *Data-driven soft sensors in the process industry.* United Kingdom: Elsevier.

Price Water House Cooper. (2016). *Industry 4.0: building your digital enterprise .* Global: PwC.

Price Water House Cooper. (2015). *Internet ad revenue report.* New York: PwC.

Price Water House Cooper. (2016). *2016 Global Industry 4.0 Survey .* Global : PwC.

Price Water House Cooper. (2016). *Are you pepared for a future that limits fossil fuels?* Global: PwC Strategy.

Ridder, H. (2016). *Proejcts Dynamics in the Cosntruction Industry.* Delft.

Russell Stuart J, P. Norvig. (2003). *Artificial Intelligence: A modern Approach.* New Jersey: Prentice Hall.

Ruttan, W. Vernon. (2000). Technology, Growth, and Development: An Induced Innovation Perspective. *Oxford Press* , p. 10.

Schwab, K. (2016). *The Fourth Industrial Revolution .* Davod, CH: World Economic Forum.

Sheffrin, M. Steven . (2003). *Economics: Principles in Action.* New jerse: Pearson Prenice Hall .

Siemens. (2017, 1 18). *Digital Enterprise suite*. Retrieved from siemens.com: http://www.siemens.com/global/en/home/company/topic-areas/future-of-manufacturing/digital-enterprise.html

Suh, Tanik, Carbone, Eorglu. (2014). *Applied Cyber-Physical Systems.* New York: Springer Science and Business.

T.Molten. (2005). The benefits of Lean Manufacturing. *ICheme* , 662-673.

Tan, B. Seng. (2004). The Consequences of Innovation. *The Innovation Journal: The Public Sector Innovation Journal* , 49.

The Economy watch. (2010, march 10). *economywatch.com* . Retrieved from Economy watch : http://www.economywatch.com/world-industries/manufacturing/?page=full

The New York Times. (2011, 02 17). *The NY times*. Retrieved from nytimes.com: http://www.nytimes.com/2011/02/17/science/17jeopardy-watson.html?pagewanted=all&_r=0

Umpleby, S. (2008). *Definitions of Cybernetics.* New York: George Washigton University.

US Commercial Service. *Global Edge .* United States .

VDI Nachrichten. (2013). Industrie 4.0. *Hannover Industrial Technology* (p. 13). Hannover: VDI .

Weng, Y. Agarwal. (2012). From Buildings to Smart Buildings - Sensign and Actuation to Improve Energy Efficency. *IEEE* , 6.

Weyer. (2016). Predictive maintenance in industry 4.0. *Smart Data Innovation Conference.* Karlsruhe : Institut fur Technologie Karlsruhe.

World Economic Forum. (2016, Decemeber 13). *World Economic Forum*. Retrieved from weforum.org: https://www.weforum.org/agenda/2016/12/the-future-of-ai-heres-what-microsoft-researchers-think

Zephoria. (2017, Feb 2). *Zephoria* . Retrieved from zephoria.com: https://zephoria.com/top-15-valuable-facebook-statistics/

Zuhlk, Weyer, Ohmer, Gorecky. (2016). Future modellign and simulation of CPS based factories. *Intellgient Manufacturing Systems* .