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The concept of "Industry 4.0" applied to a SME

Relatore
Ing. Maurizio Faccio
Università degli Studi di Padova
Correlatore
Ing. Michele Vacchi

Candidato
Alberto Trevisan

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Abstract

In the last years manufacturing enterprises are facing the fourth industrial revolution and all the associated concepts like Internet of Things, Cloud Manufacturing and Cyber-Physical Systems. While the biggest companies can easily implement this new technologies, the smallest ones don't have an outlined way to follow, so the risk, due to the financial commitment, is too high. This work wants to give the readers a knowledge about the "Industry 4.0" world with an exhaustive explanation of the whole potentiality of its tools and as well as provide a possible way to follow for owners of Small Medium Enterprises (SME). The main objective of the thesis is to report the improvements given by the digitalization of an industrial system in terms of analysis and management of the whole industrial process.

This thesis is structured as follows: the first chapter starts with a bibliographic research which analyzes through some graphs and tables where the innovation in this fields is heading, followed by a brief historical view and ends with a presentation of cyber-physical system; the second chapter examines the several tools and software (like MES, ERP, PLM), sorting them into chronological order of use by a company during the product life cycle, their interconnection with the shop-floor and the improvements given by their use; the third chapter treats a case study of the implementation of fourth industrial revolution for a SME and the results reached; the conclusion reports a summary of the whole study and some future improvements.

Contents

Introduction

In the last years the industrial world is facing a new revolution, called *Industry 4.0*, following the development of new digital technologies, that allow the companies to create a digital twin not only for the shop-floor, but also for all the industrial processes from manufacturing to administrative ones. The advent of even more complex machines, that create their virtual copy through sophisticated sensors, and more useful software allow to control real-time and everywhere what is happening inside the whole company and so to easily manage some issues. Furthermore those data collected could be analyzed in the future to understand how to decrease, for example, the production time and, especially in some particular items like aerospace products, to answer to the customers about quality requirements through an history of the manufacturing operations. Althought the existence of those new technologies, their implementation and integration require an accurate analysis of the working method used by the examined company to obtain useful results. While the biggest companies use standard procedures and they have enough financial resources to more easily manage the revolution, each small medium enterprise requires a detailed customization of the new tools and software.

Since the literature does not so clarify what the fourth industrial revolution is, the first aim of the present thesis is to define the concept of *Industry 4.0* through the ordering of some ideas exposed by different authors. This is treated in the first chapter starting from a bibliographic research that wants to outline the main themes linked to this new revolution; subsequently a section analyzes the first three industrial revolutions from the point of view of what technologies allowed them to take place and how they changed the industrial world; also thanks to the first two paragraphs, the last section of the introductory chapter defines *Industry 4.0* together with the targets reachable by its implementation and explains the main new technologies, that are allowing the fourth industrial revolutions, like cyber-physical systems. The second objective of the present work is to define in a detailed way the most useful tools necessary for the implementation of the concept of *Industry 4.0*, from the software like PLM, ERP and MES to the technologies that allow their linkage and the storage of their collected data like innovative communication protocols and cloud-computing; this topics are treated in the second chapter with a dedicated section for each of the following themes: Product Lifecycle management, Enterprise Resource Planning, Manufacturing Execution System, Industrial Communication Networks and Big Data storing. After describing and analyzing the *Industry 4.0* world in all its shades, in the last chapter a true case study of implementation of this concept is treated regarding a small medium enterprise. Starting from a preliminary analysis of the company examined with the description of the state of the art in terms of machinery and software already implemented; then the integration of MES within the information system and its interconnection with the machinery and the others software are explained. In particular this last part treats the main objective of the entire thesis, that is to show the improvements given by the implementation of the concept of *Industry 4.0* through real results derived from data collected in the company examined. The conclusion summarizes the whole project and exposes its possible future developments.

Chapter 1

Analysis of the concept of *Industry 4.0*

In this first chapter it is chosen to analyze in detail the concept of *Industry 4.0* as reported by different authors and to order the collected idea to give it a clear definition. To reach this aim, the following introduction is divided into three main sections: "Bibliographic research about Industry 4.0", "Technological drivers of the first three industrial revolutions" and "What is the fourth industrial revolution". The first section tries to predict through a statistic analysis of the results from a bibliographic research, how the factory of the future will be in terms of technologies used. The next section analyzes the first three industrial revolutions from the point of view of what technologies allowed them to take place and how they changed the industrial world, in such a way that it is possible to understand what similarities can be seen with the fourth industrial revolution and consequently to learn from them. The last section defines the concept of "Industry 4.0" and describes how and why the industrial world has taken this direction. Furthermore it analyzes the CPS, that is the main brand-new technology associated with the fourth industrial revolution.

1.1 Bibliographic research about *Industry 4.0*

As first step of the thesis, a bibliographic research is done through the greatest databases like Scopus [35], Science Direct [36] and Web of Science [37], firstly to understand what are the main concepts and where focus the attention for this work and in a second moment to understand what is the future of I4.0.

1.1.1 General research

Starting from a general research with keyword *"Industry 4.0"* to be found within title, abstract or keywords of the articles and the reviews and taking into account the period from 2010 to present[1], all the abstracts were read to select the documents to download. The results of the previous database query are reported through the following histograms (Fig. 1.1, Fig. 1.2 and Fig. 1.3) representing the amount of articles and reviews group by publication year.

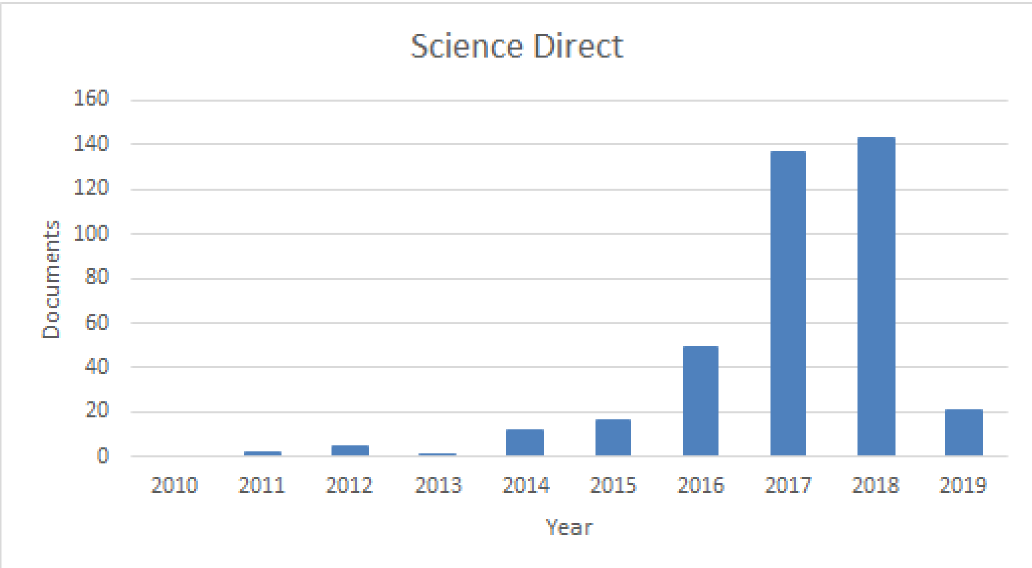


Figure 1.1: Documents per year in Science Direct.

[1]Research query:
TITLE-ABS-KEY(industry 4.0) AND DOCTYPE(ar OR re) AND PUBYEAR > 2009 AND (LIMIT-TO(LANGUAGE , "English")) AND (LIMIT-TO(SUBJAREA ,"ENGI") OR LIMIT-TO(SUBJAREA ,"COMP") OR LIMIT-TO(SUBJAREA ,"BUSI") OR LIMIT-TO(SUBJAREA, "ECON"))

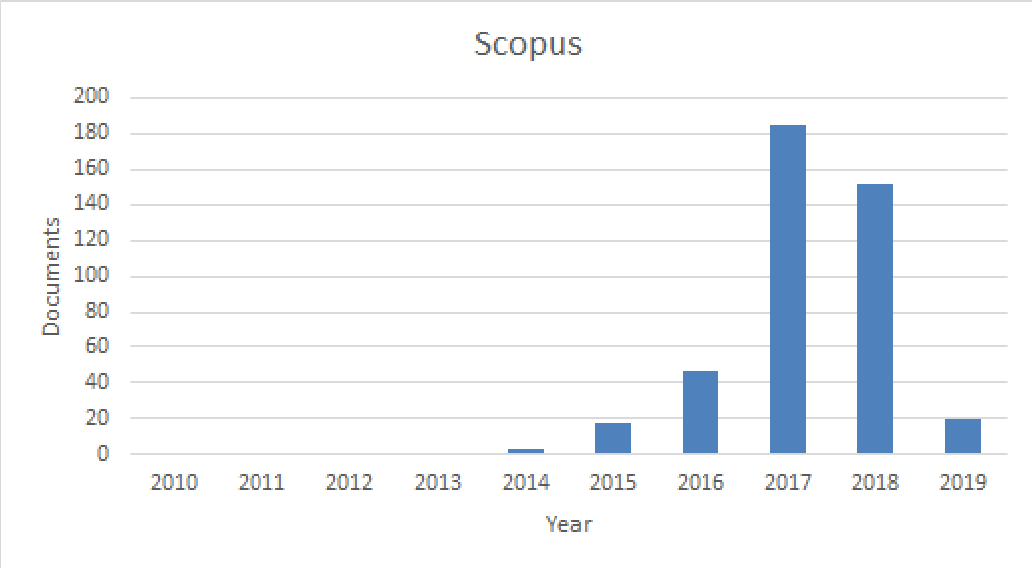


Figure 1.2: Documents per year in Scopus.

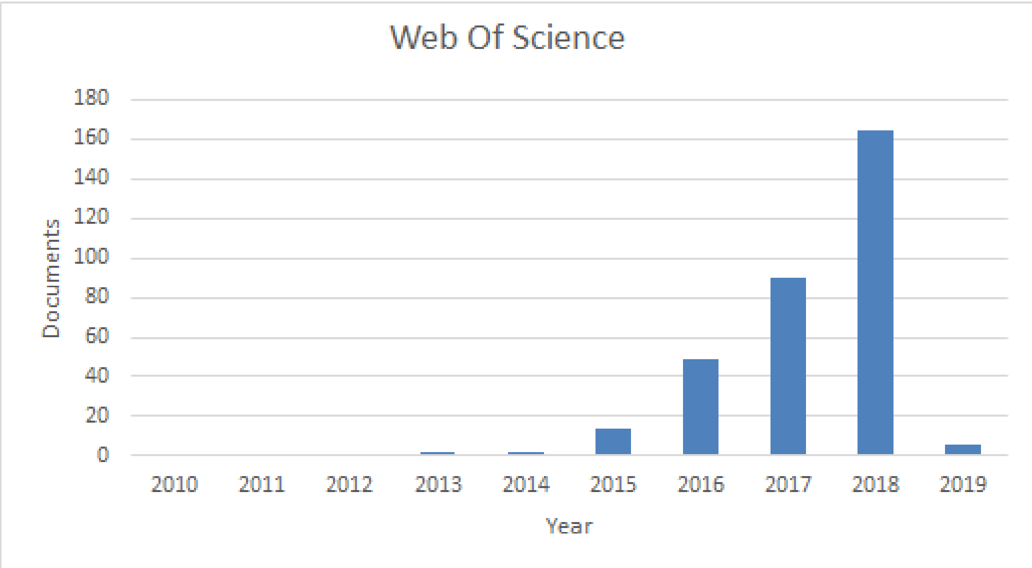


Figure 1.3: Documents per year in Web Of Science.

The graphs clearly show that the number of documents has increased exponentially since 2013 and the trend does not seem to change in the first two months of 2019. This results are simply explained by two historical facts:

2011 The term "Industry 4.0" was revived at the Hannover Fair by a working group, headed by Siegfried Dais (Robert Bosch GmbH) and Henning Kagermann (German Academy of Science and Engineering).

2013 At the Hannover Fair, the final report of the Working Group "Industry 4.0" was presented.

1.1.2 Bibliometric analysis

One of the objectives of this thesis is to find a right and safety way to follow for the implementation of the concept of "Industry 4.0" in a SME. Consequently, to achieve this kind of goal, it is chosen to firstly analyze what it has been done until now. A solution to this problem could be to read many articles, but every author has a different point of view and they usually uses the idea of others to create its own, so with this approach it is difficult to understand what are the main "Industry 4.0" features and where the future is going. In this case to know the main followed ways in this field, a bibliometric analysis was made through SciMAT [21], a software developed in Java by a team of the University of Granada. This particular tool allows to do science mapping or bibliometric mapping, that is a spatial representation of how disciplines, fields, specialties, and documents or authors are related to one another. SciMAT was designed according to the science mapping analysis approach presented in [22], combining both performance analysis tools and science mapping tools to analyze a research field and detect and visualize its conceptual sub-domains (particular topics/themes or general thematic areas) and its thematic evolution.

The data processed by the software are the same used for the previous analysis, limit to these obtained from Web Of Science since 2013[2]. This database allows to export the raw data in Plain Text format, that perfectly fits with SciMAT input requirements. To improve the data quality, a de-duplicating process was applied (the authors keywords and the Keywords Plus were used as unit of analysis).

The main steps of the analysis are reported above:

- Words representing the same concept were grouped;
- Furthermore, some meaningless keywords in this context, such as stopwords or words with a very broad and general meaning, e.g. “SYSTEM” or “ALGORITHM”, were removed;
- After this important part of data setting, the analysis was made.

In order to analyze the most highlighting themes of the "Industry 4.0" research field, a strategic diagram is shown for the whole period (2013-2019): the volume of the spheres is proportional to the number of published documents associated with each research theme. According to the strategic

[2]There are few documents to be analyzed between 2010 and 2012

diagram shown in Figure 1.4, during this period the research pivoted on seven themes: Cyber-Physical-Systems, Cloud-Computing, Smart-grid, Innovation, Decisional-DNA, Industry-Wireless-Sensor-Networks and Supply-Chain.

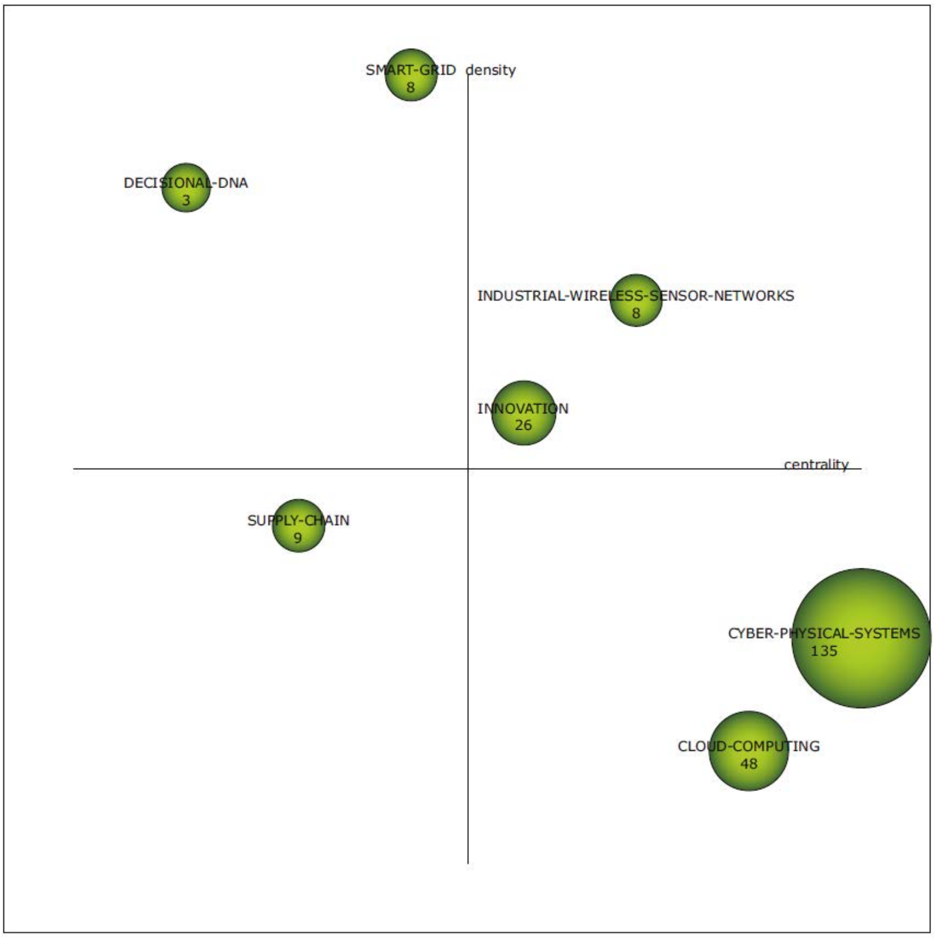
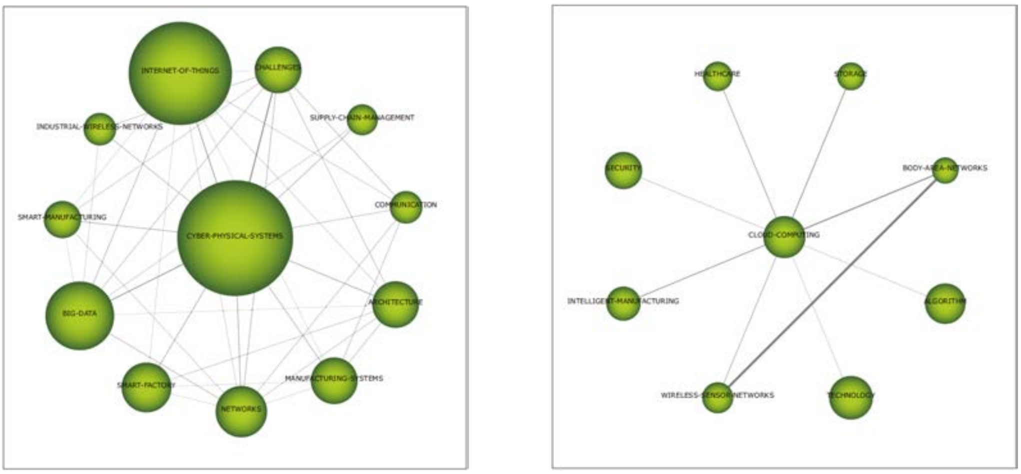


Figure 1.4: Strategic diagram for the whole period (2013-2019).

According to the performance measures, the following themes stand out (more than 100 citations): Cyber-Physical-Systems (Figure 1.5a) and Cloud-Computing (Figure 1.5b). It should be remark that both themes got great impact measures (citations and h–index), taking into account the small citation window. Concluding, the obtain results demonstrate that the most important theme of the "Industry 4.0" research field is Cyber-Physical-Systems, which is mainly related to Internet of Things, manufacturing systems and smart factories. Furthermore it is possible to notice that all these tools and systems are linked with Big Data; the reason of this interconnection can be searched within the will of using this new technology to accomplish their objectives.



(a) Theme Cyber-Physical-Systems (b) Theme Cloud

Figure 1.5: Thematic network

The results of this bibliometric analysis will be taken into account throughout the whole development process of the present work, to have an idea of what it is absolutely necessary to implement within the company to achieve the set goal.

1.2 Technological drivers of the first three industrial revolutions

In each period of industrialization, a few key technological advancements had particular impact on the increase in productivity. BRESNAHAN ET AL. refer to them as 'general purpose technologies' (GPTs), that enable new opportunities of productivity growth, but normally do not offer a ready-to-use technical solution [1]. Thereby, three technological advancements had particular impact on the increase in productivity that can be considered as industrial revolutions.

1. In the 18^{th} century, the steam engine embodies the technological breakthrough of the first industrial revolution. With the utilization of steam energy, machines were introduced into production, allowing the general mechanization of the economy. With a high degree of mechanization the economy in general became much more productive. [2]

2. One of the main technological enablers of the second industrial revolution was the widespread utilization of electricity. Electrification was a driver for mass production and had significant impact on productivity of the economy in the beginning of the 20^{th} century. [3]

3. The third industrial revolution is centered around the shift from analogue technology to digital technology and is also referred to as the digital revolution. One technological driver behind the third industrial revolution is the invention of integrated circuits that allow to increase computational power and decrease costs continuously and in an exponential manner [4]. This led to an industry wide adaptation of information technology and has a significant impact on the growth of economic performance till today. [5]

General purpose technologies, like the steam engine, electricity or information technology are generally associated with productivity growth. Yet often, a significant portion of the productivity gain is realized by the organizational innovations in companies [6]. For example, the steam engine allowed to substitute manual labor with machines, electricity allowed to transfer power to machines without line shafts, making it possible to position machinery much more freely and the invention of the integrated circuit enabled the automation of production [7], see Figure 1.6.

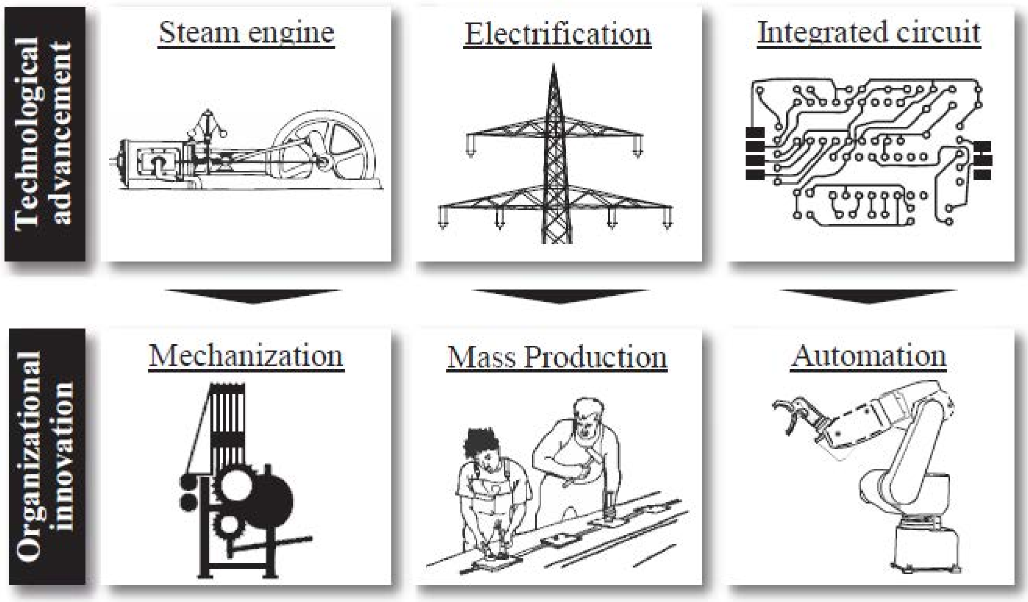


Figure 1.6: Examples for technologically induced industrial innovation.

Often, the organizational transformation cannot keep up with the pace of technological advancement, resulting in less overall productivity gain than expected [8]. This apparent discrepancy is often referred to as the productivity paradox, which was disclosed by the exponential advancement in computing power and increasing availability of information technology that did not correspond to the relatively slow growth in productivity for the whole economy but also for single companies [9]. The underlying reasons for this paradox are still open to debate, but include that the transformation of companies in order to adapt to a new technology requires not only capital investment, but also investment in acquiring the necessary knowledge and therefore takes time [10]. As a result, the productivity growth is delayed and does not correspond to the timely initialization of a new technology. Figure 1.7 displays the productivity growth for the U.S. economy and highlights the invention of the GPTs electrification and IT. As seen below, it takes considerable time for the productivity growth rate to increase after the arrival of electrification and IT. In case of the arrival of IT, a decline in productivity growth rate can be seen that could only be reversed towards the end of the millennium. [11]

However, the measured productivity does not necessarily reflect the impact on economic growth. In particular in regards to information technology, BRYNJOLFSSON identifies that organizational innovation like new processes and organizational structures result in assets that may be as much as a magnitude larger than the investment in computer technology itself

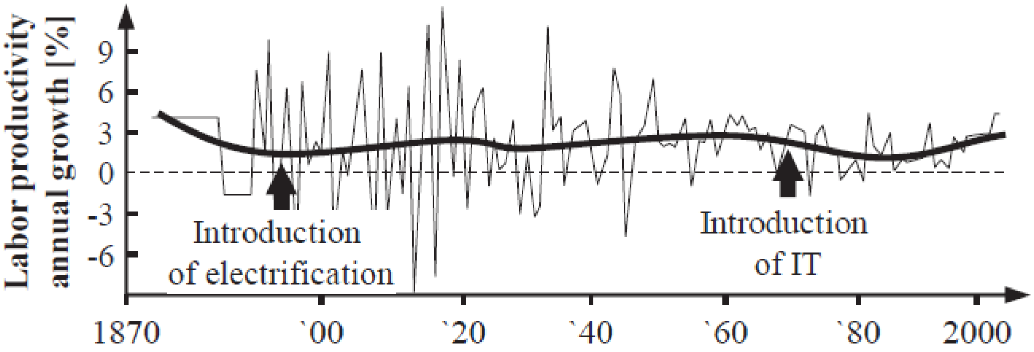


Figure 1.7: Annual growth of labour productivity, U.S. economy, 1874-2003 [11]

[6]. These findings correspond to EVANGELISTA, who finds evidence that companies who introduce both technological and organizational innovation simultaneously have a competitive advantage [12].

1.3 What is the fourth industrial revolution?

Despite of overwhelming enthusiasm and research going on for "Industry 4.0" worldwide, yet there is no standard or formal definition for it. Some of the definitions found in literature are as follows:

1. “Industrie 4.0 is the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and societal outcomes” [13];
2. “Industrie 4.0 is a new level of value chain organization and management across the life cycle of products” [14];
3. "Industrie 4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industrie 4.0, CPS monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT, CPS communicate and cooperate with each other and humans in real time. Via Internet of Services (IoS), both internal and cross organizational services are offered and utilized by participants of the value chain" [15].

Therefore from the above definitions it is evident that the *Industry 4.0* is combining of intelligent machines, systems production and processes to form a sophisticated network. Moreover it emphasizes the idea of consistent digitization and linking of all productive units in an economy and creating real world virtualization into a huge information system. *Industry 4.0* has to be integration and assimilation from smaller concepts (see figure 1.8) such as the “Cyber-physical systems (CPS)”,"Internet of things (IoT)", “Internet of services (IoS)”, “smart products” etc.

1.3.1 Objectives of *Industry 4.0* and design strategies to achieve them

The implementation of the concept of *Industry 4.0* in a company is possible only if you know a priori the objectives you want to achieve and the limits you want to set. So a literature [16] review reveals *Industry 4.0* addresses following key aspects:

- IT-enabled mass customization of manufactured products, in which production must adapt to short batches or even individual needs;

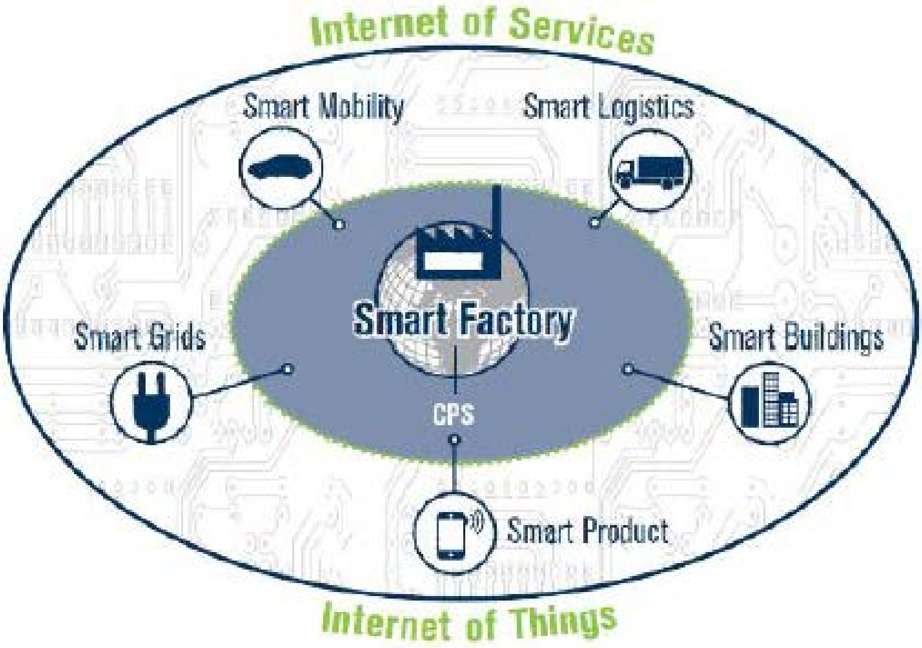


Figure 1.8: Framework for Industry 4.0 and CPS [14]

- automatic and flexible adaptation of the production chain to changing requirements;
- tracking and self-awareness of parts and products and their communication with machines and other products;
- improved human-machine interaction (HMI) paradigms, including co-existence with robots or radically new ways to interact and operate in factories;
- production optimization due to IoT-enabled communication in smart factories;
- radically new types of services and business models contributing to changing ways of interaction in the value chain.

After selecting the targets, it is necessary to derive some guidelines for achieving them. Based on the findings from the literature review [14, 15, 17] in total, six design principles can be derived from the "Industry 4.0" components:

- Interoperability: the ability of physical components, humans and Smart Factories to connect and communicate with each others;
- Virtualization: virtual copy of physical objects;
- Decentralization: the ability of components to make decisions on their own;
- Real-Time Capability: the capability to gather and analyze data in real

time;

- Service Orientation: The services of companies, CPS, and humans are available over the IoS (Internet of Services) and can be utilized by other participants.
- Modularity: flexible adaptation of Smart Factories to changing requirements by replacing or expanding individual modules.

Following exactly the previous six principles together with the results of the bibliometric analysis, during the implementation of all the industrial tools and software, it should lead us to the achievement of a functioning system.

1.3.2 Cyber-physical systems

Cyber-physical systems are all those objects, that interconnect the physical world with the world of information technology and can be referred to as the next general purpose technology (fig. 1.9), that will enable a fourth industrial revolution [14]. And this is also the reason why in the previous bibliometric analysis the words "Cyber-physical system" is resulted closely related to the *Industry 4.0* world.

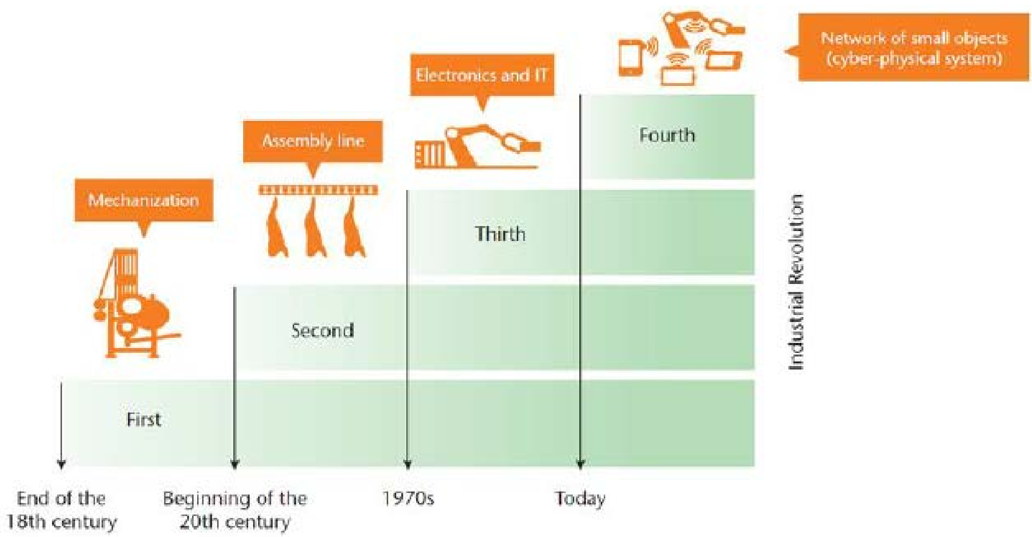


Figure 1.9: The four industrial revolutions. [16]

Cyber-physical systems are based on the further development and integration of two technologies, that both exist today and consequently all the necessary components for realizing CPS exist. The first technology, embedded systems, already operate interconnected and in cooperation with one another in closed environments. Leading examples for closed embedded systems have already been developed in the aviation and car industry [14]. The second base technology for cyber-physical systems is the pervasive interconnection of physical objects through global or local data networks, often referred to as the *Internet of Things*. With Internet of Things, objects can be uniquely identified and autonomously cooperate and interact with each other in order to reach common goals. [18] According to a report by ACATECH, cyber-physical systems can be characterized by five constitutive dimensions that lead towards "increasing openness, complexity and intelligence of systems" [19]:

- Merger of the physical and virtual world;
- Dynamic formation of system-of-systems;
- Context-dependent and autonomously operating systems;
- Cooperative systems with decentralized control;
- Extensive human-system-collaboration.

These characteristics illustrate that cyber-physical systems build the technological basis for a fundamental change in how companies and the society are organized today [20].

1.3.3 Industrial software as necessary support for CPS

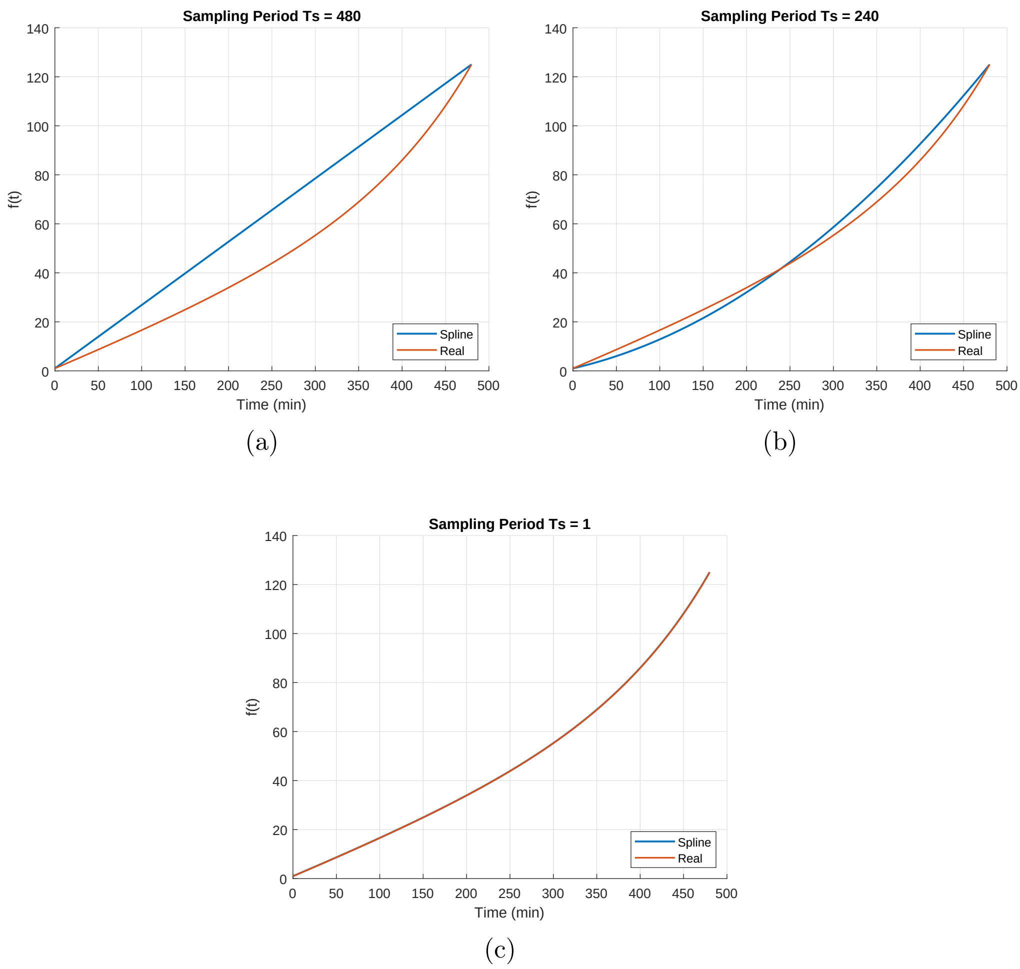
The CPS allows to translate in real-time a real world to a digital one, consequently in this manner the digital twin of the shop floor is created, but now the problem of how to use and to manage the data remains. This issue can be solved thanks to the implementation of various kind of industrial software, that communicate with the CPS through different communication protocols and they are used by the companies to manage not only the production, but also the development of a brand-new item and the administrative procedures. Consequently a good integration between these software and the CPS allows the company to follow the different activities in real-time: this is the main idea of *Industry 4.0* developed in this work. For this reason the different software and the methodologies to interconnect CPS and software will be treated in detail in the main chapter.

In this introductory section numerical results are reported as explanation of the reason why CPS are increasing the importance of industrial software and their use by companies. This analysis takes as example a particular software, but it can be also translated for each one of the others: the Manufacturing Execution System (MES) is a tool that allows to collect data from the shop-floor and to record them in a database, so that they are always available for analysis of the production by industrial managers. Before MES, the companies verified the production variables an average of one or two times a day, consequently they cannot know what was the trend of several factors during the day, but they have only a frame. The advent of the MES allowed to receive more easily and more frequently these data, but they were still constrained to the operations of shop-floor workers. In fact, for example, the operator declared the goods and scraps, the need of maintenance for a machine or tool and other process variables through a computer inside the plants. This need not only imposed limits to the process control in terms of not real-time control reached, but also the operator lost a lot of time moving from the machine to the computer. Now thanks to sensors and so CPS, the MES can have real-time information from the shop-floor and consequently allows to take a truer and more accurate look at the plant. All these improvements can be seen as the capacity to increase the sampling frequency about the analysis of the different shop-floor factors and so to decrease the error between the real function and the one build from the samples. Two functions with completely different trends are studied through a *Matlab* script in order to validate this reported theory. The results of this analysis are shown below through some plots, that demonstrate the error reduction due to the decreasing sampling period. The period considered for the analysis is 8 hours, that is often the number of hours in a working day, while the sampling periods (T_s) studied are 8 hours, 4 hours, 1 hour, 30 minutes and 1 minutes. It is chosen to use the spline as interpolation method, inasmuch it is usually more accurate than the polynomial interpolation.

First of all it is chosen a function with exponential plus linear dependence for its smooth behaviour, which coefficients are prime numbers in such a way that they are not related with sampling periods:

$$f(t) = e^{\frac{t}{119}} + \frac{t}{7} \tag{1.1}$$

Below only the graphs about $T_s = 1$, 240 and 480 minutes are reported, because they are the most meaningful for this case. Those plots (Fig. 1.10) show graphically the difference between the real curve and the interpolated one: how can be seen in Figure 1.10a in the case of only two sample points there is a big difference between the two curves, while in the case where the function is analyzed every minutes (Fig. 1.10c) the two curves are less or more superimposed. The two plots not reported here show a similar behaviour to the Figure 1.10c and this is due to the smooth curve that represents an exponential dependence.



(a) (b) (c)

Figure 1.10: Graphic visualization about the difference between real and interpolated curves.

As second set of results it is chosen to report something that shows clearly the decreasing of error due to the increasing of the sampling frequency. Consequently for each one of the previous sampling periods, it was calculated the absolute error between the real curve and the interpolated one: the two curves was evaluated every 0.1 minutes to obtain this and the result was a vector with 4800 elements. Now to have a single value that represents the error for each sampling period, it is chosen to calculate the norm of the error vector through the following equation:

$$||E(t)|| = \sqrt{\frac{\int_0^{T_{tot}} E(t)^2 dt}{T_{tot}}}, \tag{1.2}$$

but $E(t)$ is a point-defined function, so the integral can be calculated like a summation of rectangles with the same width $\Delta t = 0.1$ minutes:

$$||\vec{E}(t)|| = \sqrt{\frac{\sum_{i=1}^{n} E_i^2 \Delta t}{n\Delta t}} = \sqrt{\frac{\sum_{i=1}^{4800} E_i^2}{4800}} \tag{1.3}$$

Below are reported a table and a logarithmic plot that show the results previously described (Fig. 1.11). It can be seen that the error decrease with the increasing of the sampling frequency as expected and it is practically zero for a sampling period of 1 minutes. Furthermore it is important to notice a big error ($||E|| = 1.6575E + 01$) between the real and interpolated curves about the sampling period of 480 minutes, that is the one representing the production analyis before the advent of MES in the companies.

$T_s(min)$	$\|\|E\|\|$
1	$3.1227E-10$
30	$9.2395E-04$
60	$1.6098E-02$
240	$3.8288E+00$
480	$1.6575E+01$

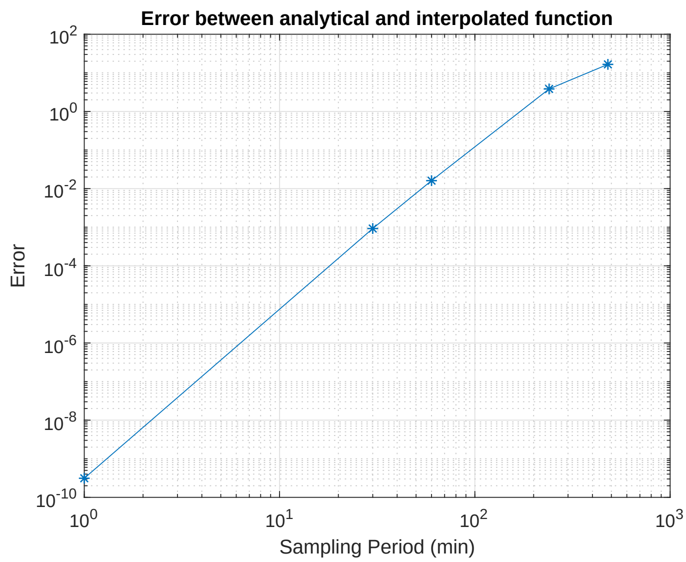
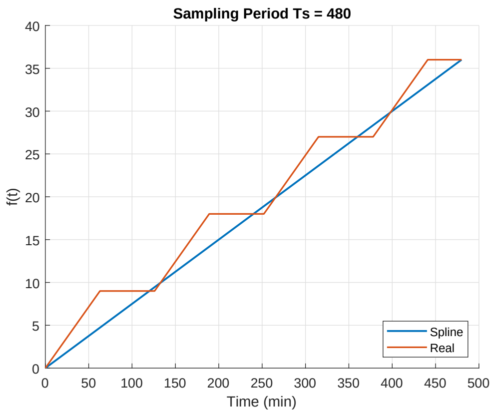
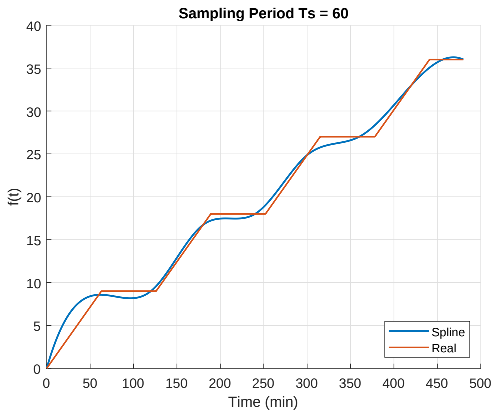


Figure 1.11: Error comparison between the different sampling periods.

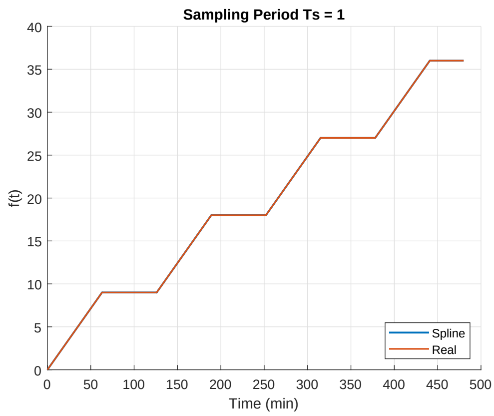
The second example studied concerns a segmented curve, that is an alternate join of two kind of functions: a ramp with angular coefficient equal to 0.1429 and a constant function. The choice of this function is due to its possible trend similarity with some shop-floor factors and to study a completely different curve from the previous one. For this example, the plots about $T_s =$ 1, 60 and 480 minutes are more meaningful and so they are reported below (Fig.1.12).



(a)



(b)



(c)

Figure 1.12: Graphic visualization about the difference between real and interpolated curves.

Like in the first analyzed function, the present one shows an error that decrease with the increasing of the sampling frequency, but in a much less clear way (Fig. 1.13). Probably this is due to the more linear trend of the function, that allows the interpolated curve to remain near the real function also only with two sample points. Furthermore this is also the reason why the errors calculated for the two sampling period of 480 and 240 minutes are equal: the sample point taken at $t = 240min$ is part of the line that join the two sample point taken with the major sampling period.

$T_s(min)$	$\|\|E\|\|$
1	$14998E-3$
30	$2.2988E-01$
60	$8.7445E-01$
240	$1.9784E+00$
480	$1.9784E+00$

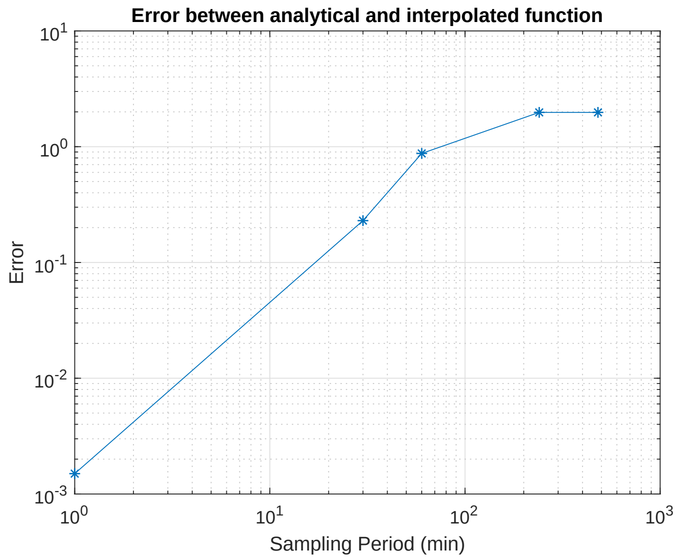


Figure 1.13: Error comparison between the different sampling periods.

If in this section it has been reported a more theoretical validation thanks to the graphs above, the same plots will be reported regarding true shop-floor factors at the end of the case study as results and validation of the objectives of the present work.

Chapter 2

Tools and software of *Industry 4.0*

The reach the objectives carried out by the *Industry 4.0* concept and to allows CPS In the years from the advent of the IT systems into the factories to the birth of "Industry 4.0" concept, many industries had tried to translate all the manufacturing operations on paper to digital one. Consequently there has been a huge software development to try to digitalize the different types of operations.[1] Below some software examples, developed during these years, are listed:

- CAD: Computer-Aided Design
- CAM: Computer-Aided Machining
- PLM: Product Lifecycle Management
- MES: Manufacturing Execution System
- ERP: Enterprise Resource Planning
- MRP 1: Material Requirements Planning
- MRP 2: Manufacturing Resource Planning
- PDM: Product Data Management
- SCM: Supply Chain Management

Think about implementing all this software in one thesis project is impossible, so in this work only some software will be explained and implemented in the case study, however more IT topics as possible will be treated. The order in which they will be presented, it is the same with which they are used by companies during the process of creating the finished product: starting from the PLM, which follows the product from the creation of the new idea to the

[1]This process started directly from the companies that developed their own software suited to their needs. Like CATIA, a CAD software, developed in Dassault Aviation to speed up the airplane design phase and now one of the most known and used CAD in the world.

sales phase included, continuing with the ERP, which is the integrated management of core business processes, and finishing with the MES, specialized in manufacturing operations.

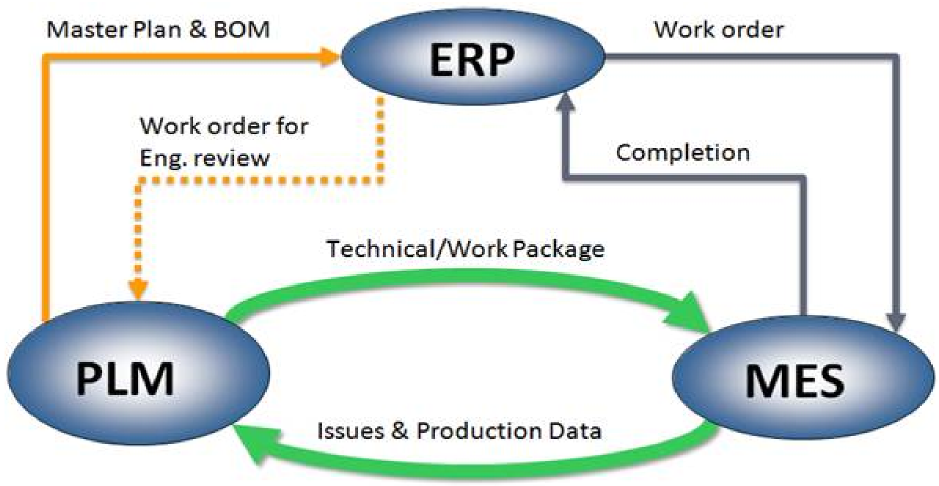


Figure 2.1: Industrial software framework adopted in this work.

As can be seen from Figure 2.1, for the success of the "industry 4.0" project it is essential an appropriate link between the main software, not only their customization. This consists in two type of connection:

Machine to Software (M2S) Achieved thanks to the use of different Communication Protocols.

Software to Software (S2S) Achieved thanks to the use of Cloud Computing technologies.

These links will be presented with their associated issues, after the presentation of the three already cited tools.

2.1 Product Lifecycle Management software

Anything that is produced and offered to the market is a product, and each product has a life cycle. Lifecycle management is one of the major challenges in modern complex technical products development and production, in fact its appliances allow significantly reduce costs and improve product. The main objective of lifecycle management is the effective implementation of programs and performance requirements specified in product development and minimizing the life cycle costs. Manufacturers use PLM for managing PPR (Product, process and resource) data, therefore Bill of Material, Bill of process and Bill of resources are considered as three main structures of a PLM system. Bill of Material (BoM) is a product structure that clarifies different parts and assemblies of a product. Bill of Process (BoP) is a structure that shows different processes and their relationships for manufacturing a product and Bill of Resource (BoR) is a factory and resources structures which are needed for producing a product. These three information structures prepare connection points for linking virtual models to the PLM system.[24]

2.1.1 Phases of product lifecycle and corresponding technologies

Many software solutions have been developed to organize and integrate the different phases of a product's lifecycle. PLM should not be seen as a single software product but a collection of software tools and working methods integrated together to address either single stages of the lifecycle or connect different tasks or manage the whole process. Some software providers cover the whole PLM range while others single niche application. Some applications can span many fields of PLM with different modules within the same data model. An overview of the fields within PLM is covered here. It should be noted however that the simple classifications do not always fit exactly, many areas overlap and many software products cover more than one area or do not fit easily into one category. It should also not be forgotten that one of the main goals of PLM is to collect knowledge that can be reused for other projects and to coordinate simultaneous concurrent development of many products. It is about business processes, people and methods as much as software application solutions. Although PLM is mainly associated with engineering tasks it also involves marketing activities such as product portfolio management (PPM), particularly with regards to new product development (NPD). There are several life-cycle models in industry to consider, but most are rather similar. What follows below is one possible life-cycle model; while it emphasizes hardware-oriented products, similar phases would describe any form of product or service, including non-technical or software-based products:

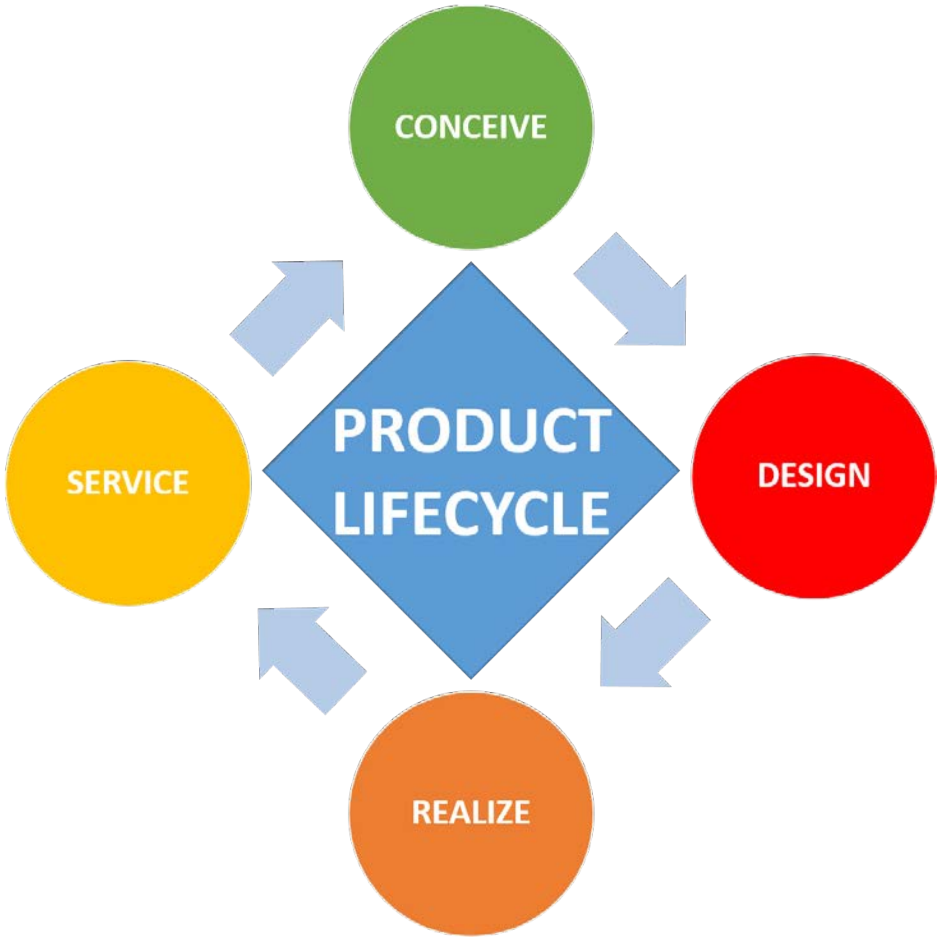


Figure 2.2: Product Lifecycle phases.

Phase 1: Conceive

Imagine, specify, plan, innovate.

The first stage is the definition of the product requirements based on customer, company, market and regulatory bodies' viewpoints. From this specification, the major technical parameters of the product can be defined. In parallel, the initial concept design work is performed defining the aesthetics of the product together with its main functional aspects. Many different media are used for these processes, from pencil and paper to clay models to 3D CAID computer-aided industrial design software.

In some concepts, the investment of resources into research or analysis-of-options may be included in the conception phase – e.g. bringing the technology to a level of maturity sufficient to move to the next phase. However, life-cycle engineering is iterative. It is always possible that something does not work well in any phase enough to back up into a prior phase – perhaps all the way back to conception or research.

Phase 2: Design

Describe, define, develop, test, analyze and validate.

This is where the detailed design and development of the product's form starts, progressing to prototype testing, through pilot release to full product launch. It can also involve redesign and ramp for improvement to existing products as well as planned obsolescence.[17] The main tool used for design and development is CAD. This can be simple 2D drawing / drafting or 3D parametric feature based solid/surface modeling. Such software includes technology such as Hybrid Modeling, Reverse Engineering, KBE (knowledge-based engineering), NDT (Nondestructive testing), and Assembly construction.
This step covers many engineering disciplines including: mechanical, electrical, electronic, software (embedded), and domain-specific, such as architectural, aerospace, automotive, ... Along with the actual creation of geometry there is the analysis of the components and product assemblies. Simulation, validation and optimization tasks are carried out using CAE (computer-aided engineering) software either integrated in the CAD package or stand-alone. These are used to perform tasks such as:- Stress analysis, FEA (finite element analysis); kinematics; computational fluid dynamics (CFD); and mechanical event simulation (MES). CAQ (computer-aided quality) is used for tasks such as Dimensional tolerance (engineering) analysis. Another task performed at this stage is the sourcing of bought out components, possibly with the aid of procurement systems.

Phase 3: Realize

Manufacture, make, build, procure, produce, sell and deliver.

Once the design of the product's components is complete, the method of manufacturing is defined. This includes CAD tasks such as tool design; including creation of CNC Machining instructions for the product's parts as well as creation of specific tools to manufacture those parts, using integrated or separate CAM (computer-aided manufacturing) software. This will also involve analysis tools for process simulation of operations such as casting, molding, and die-press forming. Once the manufacturing method has been identified CPM comes into play. This involves CAPE (Computer Aided Production Engineering) or CAP/CAPP (Computer Aided production planning) tools for carrying out factory, plant and facility layout and production simulation e.g. press-line simulation, industrial ergonomics, as well as tool selection management. Once components are manufactured, their geometrical form and size can be checked against the original CAD data with the use of computer-aided inspection equipment and software. Parallel to the engineering tasks, sales product configuration and marketing documentation work take place. This could include transferring engineering data (geometry and part list data) to a web based sales configurator and other desktop publishing systems.

Phase 4: Service

Use, operate, maintain, support, sustain, phase-out, retire, recycle and disposal.

The final phase of the lifecycle involves managing "in-service" information. This can include providing customers and service engineers with the support and information required for repair and maintenance, as well as waste management or recycling. This can involve the use of tools such as Maintenance, Repair and Operations Management (MRO) software. There is an end-of-life to every product. Whether it be disposal or destruction of material objects or information, this needs to be carefully considered since it may be legislated and hence not free from ramifications.

Operational Upgrades.

During the operational phase, a product owner may discover components and consumables which have reached individual end of life and for which there are Diminishing Manufacturing Sources or Material Shortages (DMSMS), or that the existing product can be enhanced for a wider or emerging user market easier or at less cost than a full redesign. This modernization approach often extends the product life cycle and delays end of life disposal.

2.1.2 PLM modules

As described in the previous section all the product lifecycle phases can be translated into different PLM modules, that compete and collaborate in product development; these can be categorized as follows:

Product Data Management Management of technical documentation (CAD / CAM / CAE) and project documentation (documents related to technical material of products); often includes a document lifecycle management in parallel with the definition of the main work processes related to the production of the same (see Workflow management).

Product Structure Management Management of the bill of materials (BOM).

Configuration management Management of variants and production lots.

Change Management Management of changes in one or more entities that describe the product.

Workflow Management Business data flow management tool.

Catalog Library Management of standardized components and standard parts (bolts, screws, resistors, etc).

Supply Chain Management Management of data exchange with supplier.

The implementation of one or more modules in a PLM system depends on the degree of integration that you want to give to the production process.

2.1.3 PLM benefits

Implementing product lifecycle management can deliver a number of benefits. Among these are a reduction in the time taken to bring products to market, along improved product quality and reliability.
In the early stages of a project prototyping costs can be reduced and savings can be made by reusing data gleaned from earlier projects. PLM can be used as a framework for product optimization, this in turn can improve forecasting and cut material costs by reducing waste. Because it integrates engineering workflows, PLM can produce savings and can generate ongoing documentation to help prove compliance with industry standards.
If extended out into the supply chain PLM can maximise the benefits of collaboration with suppliers and offer subcontracted manufacturers access to a central product record. At the other end of the process it can lead to more accurate generation of quotes, the ability to identify possible sales opportunities, and help to manage seasonal variations in demand.

2.2 Enterprise Resource Planning

The early 1990s witnessed a trend where every organization (including in the manufacturing sector) wanted to be productive and develop competitive advantage through cast leadership effectively utilizing resources from the support department. The organizations observed that to meet their corporate objectives, there should be effective utilization of resources not only in the production department but also in support departments. Business processes have to take care of products and services delivered to not only the external customers but also to internal customers. For the first time, the concept of an internal customer was introduced to address seamless information flow between departments. At an organizational (also known as enterprise) level, this application would help management take fast and effective decisions. For these types of needs, ERP was born.
ERP integrates the business processes of department functions and departments into one unified system. In this integrated system, different components of software and hardware take care of different business processes. The business processes are grouped into different models and different components of ERP are designed in such a way that each software component can take care of independent models. All these models are finally integrated to give the organization unified views. The basic concept behind using this unified system is the usage of the organization or enterprise database. Figure 2.3 explains this unified database.

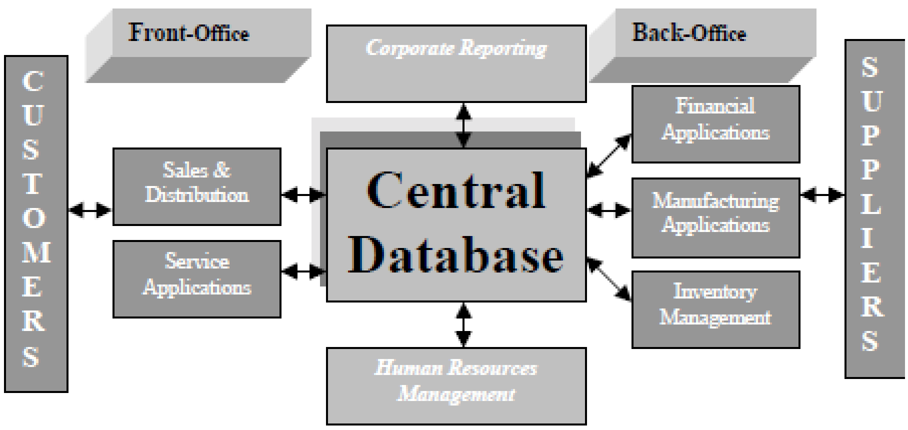


Figure 2.3: ERP system concept.

2.2.1 ERP modules

ERP as an application consists of different modules. Each module typically takes care of one function. Thus, there will be different modules such as: finance asset management; materials management; production management; project management; quality management; maintenance management, sales and distribution; etc. These modules usually cater to one function or department of an organization. The ERPs can also have different packages for different industries. These packages are meant for providing solutions for specific industries alone, such as process industry, gas, steel, automobile, textile, cement, banking, finance, etc. In all these packages, the functional modules take care of one function only. However, these functional modules can be integrated later on depending on the scope of the implementation.

2.2.2 ERP benefits

The significance of ERP lies in its many benefits. The most fundamental advantage of ERP is that the integration of a myriad of business processes saves time and expense. Management can make decisions faster and with fewer errors. Data becomes visible across the organization. Tasks that benefit from this integration include:[25]

- Sales forecasting, which allows inventory optimization;
- Chronological history of every transaction through relevant data compilation in every area of operation;
- Order tracking, from acceptance through fulfillment;
- Revenue tracking, from invoice through cash receipt;
- Matching purchase orders (what was ordered), inventory receipts (what arrived), and costing (what the vendor invoiced).

ERP systems centralize business data, which:

- Eliminates the need to synchronize changes between multiple systems—consolidation of finance, marketing, sales, human resource, and manufacturing applications;
- Brings legitimacy and transparency to each bit of statistical data;
- Facilitates standard product naming/coding;
- Provides a comprehensive enterprise view (no "islands of information"), making real–time information available to management anywhere, anytime to make proper decisions;
- Protects sensitive data by consolidating multiple security systems into a single structure.[26]

2.3 Manufacturing Execution System

Manufacturing Execution Systems are IT tools commonly deployed in companies involved in traditional manufacturing. A MES enables information exchange between the organizational level, commonly supported by an Enterprise Resource Planning (ERP), and the control systems for the shop-floor, usually consisting in several, different, highly customized software applications [27]. A schematic of MES positioning in the framework of information tools supporting manufacturing is provided in Figure 2.4.

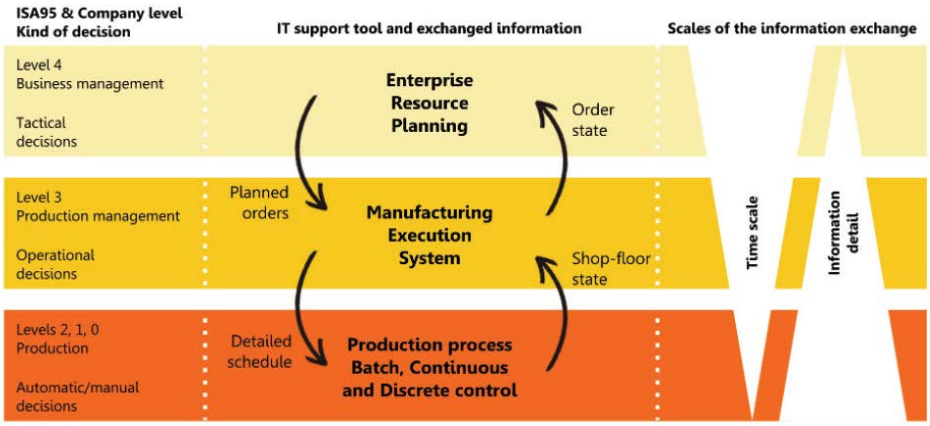


Figure 2.4: MES positioning within an industrial framework.

MES were initially deployed in industries focused in the fields of chemistry and pharmaceutics; then, the spread of such systems increased, but for long time this tool has been considered useful only for large industries. In the early 2000s, it was understood that the benefits provided by a MES can profitably support even smaller companies [28]. The tasks in charge of a MES are defined in the standards ISA 95 [29] and IEC 62264 [30]. A MES has two principal purposes. First, the system has to deal with the top-down data flow: the requirements and the necessities provided by the organizational level must be transformed into an optimal sequence planning meeting such targets. This sequence must be identified by best exploiting the available resources (such as staff, machines, materials, inventory) and taking into account the constraints of the process, such as processing and setup times, and workstations capacity. The second aim of a MES is to manage the bottom-up data flow. Data concerning process performance and product quality can be gathered at the shop-floor level; the role of MES is to collect such data, analyze them through appropriate mathematical techniques, and extract a synthetic information to provide the business level with an exhaustive picture of the current state of the process. Possibly, the analysis should be performed in real-time, in order to make decisions to control the process with the necessary rapidity. Recently, the development of low-cost, small, easily available sensors led to a great diffusion of monitoring systems to assess product quality and process performance, and to support the improvement of production process.

2.3.1 MES functional areas

Over the years, international standards and models have refined the scope of such systems in terms of activities. The ISA 95 model includes the following 11 MES functions:

- **Data collection and acquisition.** Allow the input of all information during production, manually and/or automatically.
- **Scheduling.** Provide a global view of the planned production orders and their production routing including electronic job cards.
- **Staff management.** Manage the necessary skills and authorizations for people, products and/or operations.
- **Resource Management.** Define and track the status of each resource associated with producing the production unit (production tools, machines, breakdowns, material shortage, etc.).
- **Production tracking and dispatch.** Manage the bidirectional flow of production data in real time between the ERP and the workshop.
- **Product traceability and genealogy.** Associate a final part or batch with all its manufacturing data from the raw material to the component assembly.
- **Quality management.** Manage the quality of manufacturing processes and units including quality deviations and exceptions. This function can be integrated directly into the MES software or can use external software such as SPC software and NCMS (non-conformance management system).
- **Process management.** Provide process routing and operational sequencing including full traceability.
- **Performance Analysis.** Consolidate data to calculate the key performance indicators such as Right first time (RFT), Rework, Scrap, Process capability (Cpk), Overall equipment effectiveness (OEE), Opportunities, etc.
- **Document Management.** Make available to the operator at the correct time the documents (instructions, drawings, notes) necessary to carry out their work.

- **Maintenance management.** Optimize the planning of preventive maintenance operations to reduce the impact on manufacturing.

All of these functions occur at different levels of the workshop to meet the needs of each stakeholder in the production process.

2.3.2 MES benefits

- **Increase visibility across the manufacturing network**
  Paper, spreadsheets, standalone databases, measuring systems and SCADA systems are no longer able to provide the data required to drive today's manufacturing enterprise. MES software replaces these fragmented systems to seamlessly connect the top floor and the shop floor, creating an unbroken thread of critical data across all manufacturing operations. MES software delivers:
  - Critical analysis in real-time, such as performance and quality indicators, displayed in a highly visual graphic format that mimics the process;
  - Operator empowerment with the tools to react faster when issues arise;
  - Benchmarking of machines, production lines, production runs, plants and drive improvement.
- **Reduce operational costs**
  MES enables increased control on all production inputs:
  - Direct labour costs: the MES monitors the machines and progress of jobs and alerts operatives when needed, so operator time is released for other tasks, saving direct labour costs;
  - Indirect labour costs: operations data is automatically collected from the machines and equipment, improving accuracy and saving hours of operator time;
  - Material costs: real-time process control optimizes the quantity of material used to meet specifications; meanwhile real-time production counting can prevent over-making;
  - Energy costs: constant automated monitoring of energy usage by all plant equipment will quickly help identify faults and drive optimization of equipment utilization.
- **Drive efficiencies**
  MES supports performance improvement plans:
  - Throughput and asset utilization: with accurate downtime data -

  when, where and for how long - improving machine / line / plant performance;
  - Change-overs: MES alerts key personnel when a job is nearly completed; with the scheduling functionality the MES software supports better planning as well as reaction to unplanned events such as material shortage or equipment breakdown;
  - Cycle-time: the MES software tracks OEE (overall equipment effectiveness), enabling operations personnel to focus on cycle-time improvement activities based on accurate information.
- **Improve agility and flexibility**
  MES increases competitiveness through real-time visibility of manufacturing operations:
  - Fastest New Product Introduction (NPI);
  - Smoother integration of new processes, factories and personnel;
  - Greater integration with the supply chain.
- **Standardize operations and enforce best practice**
  MES software provides a foundation for benchmarking and improvement in the manufacturing industry:
  - Routings and workflows enforce the process and ensure control;
  - Integration of the MES with machines and equipment removes the need for manual data collection, increasing accuracy and security;
  - Dashboards show real-time performance of shifts, production lines and plants.
- **Improve regulatory compliance**
  Quality Assurance and Control is often dealt with by departmental applications but it is best when it can be integrated within MES to improve:
  - Conformance;
  - Responsiveness;
  - Traceability;
  - Compliance;
  - Overall quality metrics.
- **Leverage MES for the Digital Transformation of the manufacturing enterprise**
  If your organisation's manufacturing sites are running multiple legacy applications, then consolidating them within a single well supported platform will bring many benefits:
  - Consolidate multiple legacy applications across manufacturing sites:

simpler infrastructure will give you better control over manufacturing IT;

- Reduce direct costs: IT resources are no longer needed to maintain home-grown applications;
- Material cost: elimination of paper on the shop floor and physical storage space;
- Host the MES software in the corporate data center or in the cloud;
- Ensure business continuity with an out of the box MES application, built on standard technologies and supported worldwide.

2.4 Industrial Communication Networks

An industrial communication network is a backbone for any automation system architecture as it has been providing a powerful means of data exchange, data controllability, and flexibility to connect various devices. With the use of proprietary digital communication networks in industries over the past decade led to improve end-to-end digital signal accuracy and integrity. These networks, which can be either LAN (Local Area Network, which is used in a limited area) or WAN (Wide Area Network which is used as global system) enabled to communicate vast amounts of data using a limited number of channels. Industrial networking also led to the implementation of various communication protocols between digital controllers, field devices, various automation related software tools and also to external systems. As the industrial automation systems become complex and large with more number of automation devices on control floor, today, the trend is toward Open Systems Interconnection (OSI) standards that permits to interconnect and communicate any pair of automation devices reliably irrespective of the manufacturer. OPC UA is the main communication protocol capable of doing this and it will be discussed after a brief introduction to the Industrial Networks Level.

2.4.1 Hierarchical Levels in Industrial Communication Networks

In a manufacturing or process industry, the information or data flows from field level to enterprise level (bottom-to-top) and vice-versa. Different levels have to handle different requirements of a particular level. So it is obvious that no single communication network address requirements needed by each level. Hence different levels may use different network based on the requirements such as data volume, data transmission, data security, etc. Based on the functionality, industrial communication networks are classified into three general levels (see Figure 2.5):

Device Level

This lowest level consists of field devices such as sensors and actuators of processes and machines. The task of this level is to transfer the information between these devices and technical process elements such as PLCs. Nowadays, fieldbus technology is the most sophisticated communication network used in field level as it facilitates distributed control among various smart field devices and controller. This is a bidirectional communication system in

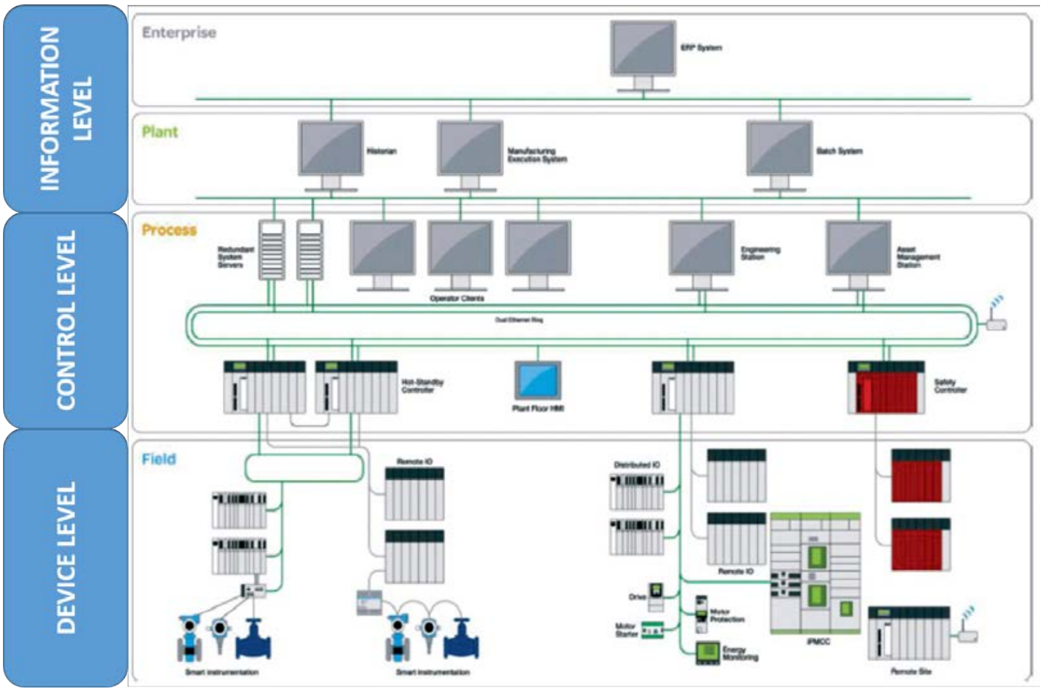


Figure 2.5: The Industrial Communication Networks.

which many variables are taken care by single transmission. Different types of fieldbuses include HART, ControlNet, DeviceNet, CAN Bus, Profibus, and Foundation Field Bus.

Control Level

This level consists of industrial controllers such as PLCs, distributed control units, and computer systems. The tasks of this level include configuring automation devices, loading of program data and process variables data, adjusting set variables, supervising control, displaying variables data on HMIs, historical archiving, etc. The Ethernet with TCP/IP protocol is mostly used as control level network to connect control units with computers. In addition, this network acts as a control bus to coordinate and synchronize between various controller units.

Information Level

This is the top level of the industrial automation system which gathers the information from its lower level. It deals with large volumes of data that are neither in constant use or time critical. Large scale networks are exists in this level. So Ethernet WANs are commonly used as information level networks for factory planning and management information exchange. Sometimes these networks may connect to other industrial networks via gateways.

The main industrial management software as PLM, MES and ERP are part of this level, in fact this level will communicate directly with the company database, which can be on cloud or on premise.

2.4.2 OPC-UA

In traditional automation, low level production facilities are integrated into the ICT in a manual and rarely standardized way. To connect field devices with higher systems of the automation pyramid, interfaces/drivers have to be carried out specifically for each different device in the machine layer. To facilitate the workflow of embedding devices into the ICT, standard interfaces or data protocol conventions are used to enable plug-and-play or – in terms of the manufacturing area – plug-and-produce capabilities, which work similar to the connection of devices in computational environments. Thus, in the beginning of the 1990s, manufacturing enterprises and members of the automation industry attempted to carry out a standard interface that was based on the Windows NT standard as most widespread operating system throughout all companies. This Operating System (OS) provides the OLE technology to interconnect multiple applications on the OS. The aim of the manufacturing companies was to establish similar approaches for connecting field devices with control systems of the automation layer. In 1995, a task force of big companies and automation providers like Siemens, Rockwell Automation, General Electric and ABB came up with the OLE for Process Control (OPC) standard, which uses the Distributed Component Object Model (DCOM) [31] for the linking of production facilities. The central specification of this approach is the OPC Data Access (OPC DA) specification and has been published in 1996 [32]. By standardizing the access to data in automation systems, it is possible to embed driver or interface specific information directly into the field devices. This approach enables plug-and-produce capabilities without manually configuring each device. The basic communication functionalities of OPC DA are based on the server-client principle. The OPC Server reads and propagates data from field level or from other data generating devices. In terms of building an OPC network, the OPC Client creates an instance of the server. This server represents a single device or a group of data sources (Figure 2.6).

The OPCItems represent concrete objects, e.g. sensors in an automation system. These can be grouped to OPCGroups for similar items. The OPCServer represents these items and propagates single or aggregated data into automa-

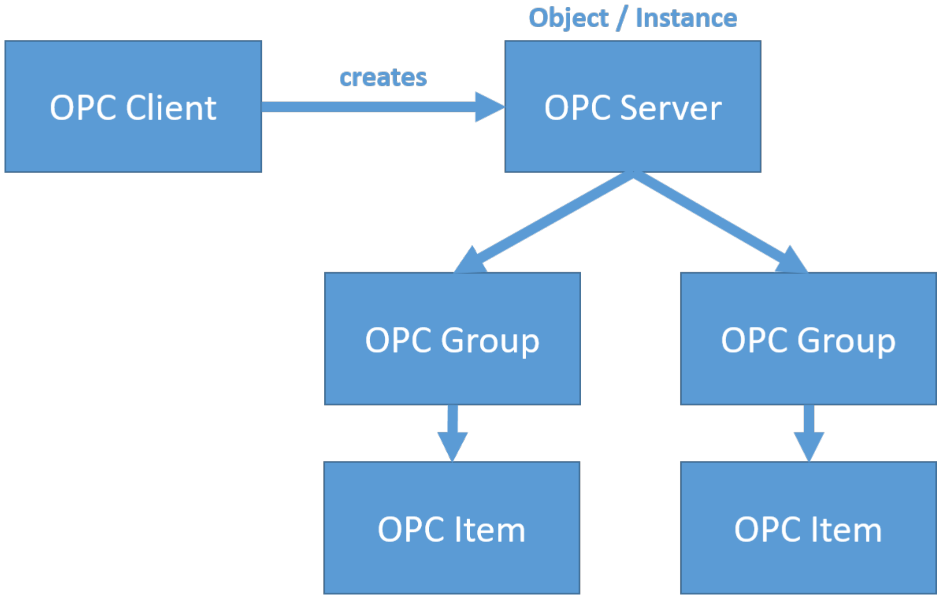


Figure 2.6: OPC Server-Client principle and item organization.

tion systems. OPC Servers can store information, whereas OPC Clients read and redistribute these information. Besides, every OPC Client can also function as an OPC Server. Due to the success of this approach, the industrial users demanded for additional functionalities for the OPC standard, necessary for a full migration of the automation environment. These demands resulted in two additional OPC specifications, the OPC Alarms & Events (OPC A&E) and the OPC Historical Data Access (OPC HDA) specification in 1999 and 2001. The OPC A&E specification provides services to trigger realtime actions based on events or critical system states that could be harmful to the process or to the automation systems. The OPC HDA specification provides functionalities to access data from previous processes for data acquisition purposes. The success of OPC in the 1990s was mainly due to the high performance of the DCOM technology and due to the robustness of the resulting automation system [32]. However, the composition of OPC-based automation systems is rather rigid and hierarchical. Another drawback of the OPC standard is the lack of communication capabilities in networks as the DCOM standard cannot be properly configured to work with firewalls. As a result, the OPC consortium figured out ways to communicate over internet based systems, accordingly publishing the OPC XML-DA standard, which enables the propagation of OPC-based information via web services [33]. However, OPC XML-DA turned out to be comparatively slow, which is mainly due to the high overhead of information that has to be integrated in each XML message for each piece of information sent between

OPC servers and clients. Due to the resulting interoperability problems of classical OPC solutions, and due to the dependency on Windows-based systems and bad configurability characteristics in terms of industrial networks, the demand for a modernized version of OPC rose up from the industry. As a consequence, the OPC Unified Architecture (OPC-UA) standard had been carried out, which attempts to combine all specifications of the OPC Classic standard, and to extend their functionalities while enabling platform independence and interoperability. One major functionality of OPC-UA is the possibility to configure lightweight and quick connections over the internet. As OPC-UA is not solely based on DCOM, the communication is performed over network borders and firewalls. This new approach solves major security problems and allows data exchange between distributed systems, as an encapsulation of system devices into a dedicated network, which is – unlike to OPC Classic – not necessary when using OPC-UA [34]. By providing abstract services, OPC-UA delivers basic functionalities to create a service-oriented architecture (SOA) of the automation system. OPC-UA integrates different specifications of OPC into a single set of services. Thus, components and automation networks based on OPC Classic can theoretically be integrated into OPC-UA networks. Another advantage of OPC-UA is the configurability of the new standard. The OPC-UA specification only specifies the message format of the information that is send. Unlike to OPC Classic, OPC-UA does not specify an API [34]. Hence, the user of the OPC-UA server is able to use or implement an API of his personal preference. All communication in the OPC-UA standard is performed using the Communication Stack. There is a client-side and a server-side communication stack. Both communication stack APIs can be developed in individual programming languages, as long as their concepts support the technology mapping given by the OPC-UA specification [34]. The described configurability of the OPC-UA application programming interface provides the user with a freedom of choice in terms of the technology or the programming language that is used to access the information in OPC-UA networks. This way, OPC-UA delivers a flexible usability in different environments and for different purposes. This availability is linked to several advantages:

- The application or the purpose of an information system determines the properties of the OPC-UA communication stack API, e.g. whether the application is complex or lightweight for the usage in small embedded devices.

- The communication with OPC-UA network can be integrated into existing enterprise communication systems.
- Tool interoperability with other systems or components of the factory is guaranteed as the programming language is of free choice. This enables the embedding of OPC-UA systems in business process, e.g. data integration chains.

The advantages of OPC-UA are able to address challenges that are introduced by the Industry 4.0. Thus, many scenarios that are in the scope of the fourth industrial revolution can be realized, if automation systems are fully equipped with UA capable devices and according infrastructures. The embedding of OPC-UA into industrial environments is the first step towards the goals of the Industry 4.0, however there are many more challenges to meet besides technical and syntactical heterogeneity in industrial production. However, existing production and automation systems are still in use of traditional automation systems, e.g. based on OPC or other rigid interface standards. Most manufacturers do not want to change their entire automation system or simply cannot take the risk of quitting a running system. This results in a demand of embedding devices like sensors or automation components that are still based on traditional interfaces into an infrastructure that is designed according to the OPC-UA specification.

2.5 Big Data storing

What has been said until now can be summarized in a single sentence: "The factory will no longer exist only as a physical entity, but each of its elements will have a digital twin". Consequently this digitalization requires the storage and management of a huge amount of data, known as the problem of Big Data. Large companies have always stored data on internal servers and employees worked via VPN to access it even from offsite. This was possible for them because they had no problem in some onerous initial investment, but if we talk about SMEs it could be expensive to spend large amounts of money on an internal infrastructure. Moreover it would become obsolete in a few years due to the speed with which the IT sector is developing and a new investment would be needed. If in the last few years we talk about Industry 4.0 even for SMEs, it is much due to the birth and growth of cloud computing.

2.5.1 Cloud computing

Cloud computing is a significant shift from the conventional way companies think about IT resources that can be utilized for remote monitoring services. It brings together many benefits such as reliability, global scale, performance, speed, and cost. The term cloud computing is used here to refer to a model for allowing users to access all their applications and services from anywhere, anytime, on the Internet, because the information is stored on the server provided for cloud computing services and not on the user's devices. There are several types of services models depending on the kind of resources delivered via them as illustrates in Figure 2.7. Services, platforms, and infrastructure can be quickly provided and deployed with less administrative effort or service provider interaction.

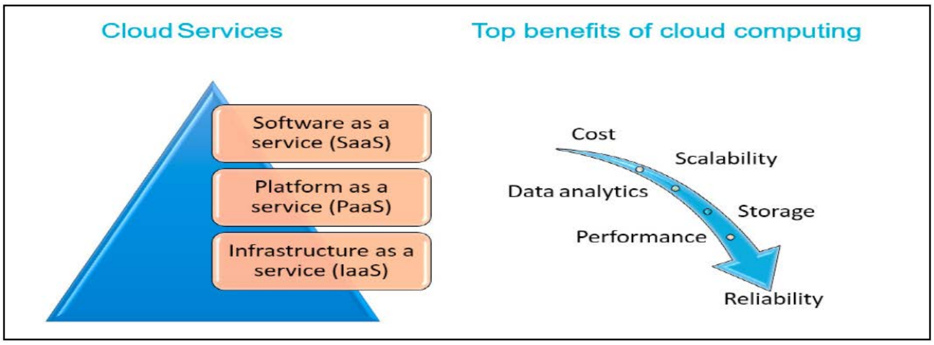


Figure 2.7: Types of Cloud services and top benefits.

Cloud computing affords a suitable means for accessing real-time maintenance data anywhere in the world accessible via simple devices for example smartphones, tablets or PC. Cloud computing architecture can be divided into three categories: Firstly, IaaS which provides infrastructure services and capabilities to deploy and run software in general, for instance, physical computers, virtual machines, networks, storage devices or a combination of these devices. Secondly, PaaS plays a vital role in providing capabilities for application development and deployment in Cloud. Finally, SaaS provides the necessary applications and infrastructure services from the service provider such as Application Program Interface (API). Nowadays, there are several IoT cloud platforms available that provide several operational benefits to industries especially the IoT. Among these platforms are Google Cloud Platform, IBM Watson, Microsoft Azure Cloud, and Amazon Web Services. These platforms provide many benefits such as an option to deploy IoT applications in order to evaluate, monitor, and analyse performance in cloud manufacturing systems. Moreover, they can be used to publish data to a back-end message broker and also to receive control messages from other devices or IoT applications.

2.5.2 On-premise or cloud

Technology changes rapidly, with smaller devices providing more computing power than ever. As the speed of development continues to increase, businesses are faced with the seemingly simple question of which platform to adopt for their next set of systems. Cloud-based productivity software has expanded rapidly over the last decade, and 93 percent of enterprise businesses already use some cloud-based system.

When looking at the pros and cons of cloud vs. on-premise solutions, everything starts with an understanding of how these two models differ:

On-Premise solutions When looking at an on-premise solution, you are committing to local ownership of your data, hardware, and software. Everything is run on machines in your facility with no third-party access.

Cloud solutions With a cloud deployment, the vendor hosts all of your information and offers access through a web portal. You can turn off the server room and leave the management to a third-party. This enables more mobility and flexibility of use for cloud-based software options.

A lot of business have started the move to the cloud due to perceived cost savings. After all, cloud adoption usually has a significantly lower entry cost. Most cloud platforms bill as a recurring monthly expense with no initial capital outlay. The cost of an on-premise solution can be very high to start, with much lower operating costs. Some calculators put the total cost of ownership (TOC) at approximately the same at 10 years out. Of course, for that cost comparison to matter, on-premise solutions must stay relevant for an entire decade, an increasingly difficult challenge to meet as technology advances at an exponential rate. Plus, many experts put the TOC for on-premise much higher, adding in hidden costs and operational figures that do not exist with a cloud provider.

Advantages and disadvantages of Services

Pros to On-Premise:

- One time expense: for some business models, it is easier to justify a one-time investment in hardware. Keeping operating costs low can free up cash and keep a business running in the black. Over time, an on-premise solution may even wind up offering cost savings.
- Security stays in-house: highly regulated industries can have major barriers for cloud systems, making on-premise the only option. For example, banks in Saudi Arabia are limited to on-premise solutions specifically due to security concerns.
- Fully customizable options: while cloud solutions offer out-of-the-box functionality, on-premise allows you to customize your software to provide all of the information and applications you need at your fingertips.
- Controlled rollout: cloud systems allow nearly instant rollout and implementation, but all of that is in the hands of the vendor. With on-premise solutions, you can control when, where and how you implement the changes. This lets you prioritize certain departments and arrange training schedules.

Pros to the Cloud:

- Predictable expenses: even if on-premise solutions were less expensive, the steady and predictable cost of cloud solutions means no sudden, large, capital outlay that can strain the budget in an upgrade year.
- Outsource security risks: depending on your industry, moving the security requirements to a third party can be a big stress release. After all, data breaches happen, and they can be very costly for a business. When that responsibility is in the hands of the vendor, individual businesses have one less headache. Also, smaller businesses get the benefit of enterprise-level security by working with an enterprise partner.
- Great out-of-the-box functionality: cloud solutions are ready to work from the day you adopt these platforms. Continuous updates mean your software is always current and compatible with new releases, and you do not struggle with a lot of unplanned downtimes.
- Fast and smooth rollout: no hardware means no long rollout times before you can start using this solution. There is no delay during physical installation, and no waiting for software customization.

Chapter 3

Case Study

The study carried out in the previous chapters has been necessary to understand what are the cutting-edge technologies within the "Industry 4.0" world and how it is possible to link them in an appropriate and useful way. Thanks to this research, now a real case of implementation in a company, that is oriented to an itself digitalization, can be taken on. The choice of the company examined is the results of two major considerations:

- first of all the company should be a customer of Global Informatica Srl, which allowed the present work and gave the software necessary for its development;
- moreover it is not possible to think of implementing a full "Industry 4.0" project in a few months in a company totally free of digitalization.

Following these reasons, there were only two possible companies and the choice was the result of a preliminary analysis of the two different subjects to understand the implementation time of the project. So as first approach it was necessary to analyze how the company works, what is already installed about machines, communication technologies and which are the goals required and achievable. This preliminary part is treated only for the examined company in the following section.

3.1 Preliminary analysis

The firm, from now referred to X, is a Small Medium Enterprise leader in the production of hydraulic components and it is localized with two manufacturing departments in the north-east of Italy. As most of the SME it has specialized in the manufacture of products by specific customer request, which design is carried out in its own departments thanks to qualified personnel equipped with Computer-aided design and engineering software. Its need to monitor all the industrial process through an appropriated information system is partly due to this kind of production: if in the bigger industries the profit grows due to the increase in the number of sold products, the smaller ones have to reduce predictable downtime both in the product development, thanks to the PLM, and in its production, thanks to the MES.
It is possible to split the company in three different area that use a different industrial software each one: the administration office that can manage the external orders and bring them inside the manufacturing environment facilitate by the ERP, the technical department that can follow the product development through the PLM software and the plant that can easily manage the different production orders thanks to the MES software.

3.1.1 ERP

The company had already thought to easily follow all the administrative issues through an Enterprise Resource Planning. This is due to a growing need for enterprises to control the budget with revenues and costs, also because of more restrictive laws. The software is used by X in all that concerns the manage of the Master Data (items, orders, employee, materials,...) and it will result expensive to describe all the different modules adopted by the company inside its ERP; consequently above it will be explained only the task that makes the ERP fundamental for the whole "Industry 4.0" project.

The ERP receive the order request from the customers and the first important phase requires to insert in the database as much information as possible in order to facilitate the subsequent flow of data through the other software and the plant. This procedure allows all the ERP functions to have the necessary input on which to act, but more importantly for the present study the R&D office can easily access the necessary information, as project requirements and drafts, through the PLM, which will read from the database and the shared server once implemented. Furthermore, when the MES will be installed, this communication will not remain fast and digital only at the highest levels of the company, but all the information will arrive in the plant instantaneously. Consequently one of the company problems is to have real time news about the order progress and to monitor the idle time for process improvement.

3.1.2 Machinery

In the present study the machines and their CNC/PLC are treated only about the interconnection between them and the higher level through the communication system, considering them as data source for MES and where the part program, created by the engineering office, has to arrive through PLM and MES.

The company machinery is very vast and consequently it was chosen to consider only the linkage of the newest machines, that are already equipped with sensors and associated PLC to send and receive signals. Despite this, the rest of the machines will contribute anyway as data source. In the table below the examined machines are listed with their IP addresses and their Computer Numerical Control description, which are essential for a right connection between MES and the machines.

ID	DESCRIPTION	PLANT	CONTROLLER
72007	Welding robot n.7	1	Fanuc Controller R-30iB
72008	Welding robot n.8	1	Fanuc Controller R-30iB
03010	Welding robot Mecome	3	Fanuc Controller R-30iB
03011	Welding robot CMM Gemini	3	Fanuc Controller R-30iB
02060	Lathe CNC- DMG MORI	3	M730UM con CELOS
02062	Lathe CNC - DMG MORI	3	M730UM con CELOS
20013	Lathe MAZAK INT. i-400	1	Mazatrol SmoothX
20014	Lathe MAZAK INT. i-400	1	Mazatrol SmoothX

Table 3.1: List of machine examined with associated controller

Once known the CNC, which has to be interfaced with MES, a research is done for every machine about the kind of communication protocols that were supported, the number of signals that can be obtained and how to send the part program to the machine. The analysis carried out has highlighted the existence of different communication protocols, like OPC-UA, OPC Classic and MT Connect, for the different machines and consequently the implementation of the various interfaces directly within the MES would have been complex. Regarding only the sending of the signal from the machines, to solve this problem it has been chosen to install an OPC server, called *KEPServer*, that is an industry connectivity platform that provides a single source of industrial automation data to all the applications and it is able to connect with all kinds of industrial communication protocol, writing the data into a MySql database. After that a procedure will be edited to load the *KEPServer* table into the MES database in a MES-readable form, in such a way that allows the software to know the data and transfer it to the higher company levels.

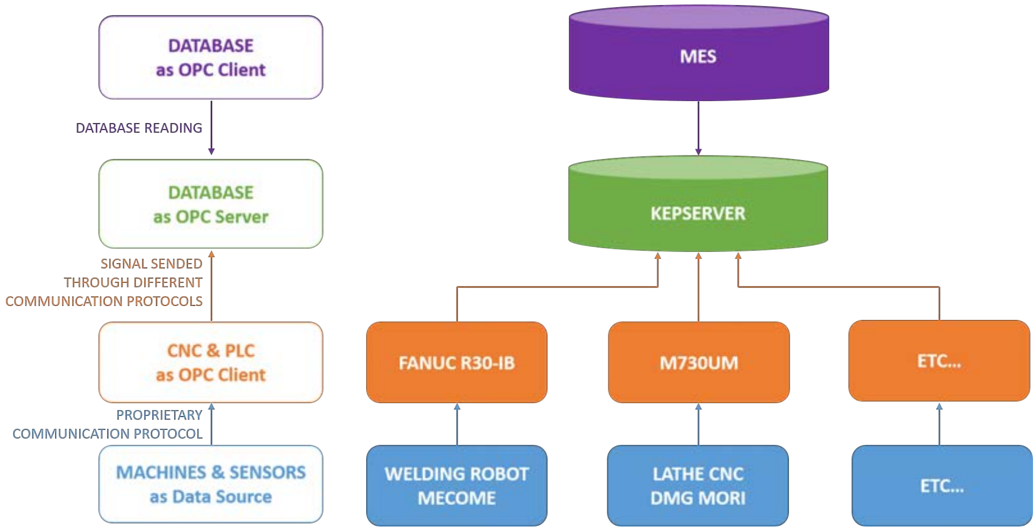


Figure 3.1: Diagram of the path of the signals from the machines to the mes.

For each machine it is created a different table, called *"MachineId_ readings"*, inside the KEPServer's database; the table fields are listed below with their meanings:

Event_name: this field identify the signal that has been read by the OPC server;

Datetime: it is necessary to capture the date and the time of the event for future analysis, that is the main objective of taking signals from machines;

Value: obviously the main field;

WorkStage: this field links the event with what the machine is doing in terms of produced item and processing typology; consequently this record allows the MES to doing every kind of statistic analysis both general and particular.

Having described the methodology with which the signals are send from the machine to the server, it is now necessary to list what signals are taken into account and for what reason. First of all the system wants to know the machine state, that can be active, idle, on setup or under maintenance, because in real time the production engineer of X must have the possibility to manage the plant, understanding if the production is going on, and because in a future analysis it is essential to have an historical events, necessary to understand what are the principal plant issues and how to solve them. The other extracted signals are the piece counter of goods, to keep track of the quantity produced, and waste, to know where it is possible to improve the plant production, and the different alerts, like overheating of mechanical parts, electrical problems and state of the tool, that are important for the worker to know how is working the machine and when stop the machine: to permit the real time communication between the machine and the worker, this kind of signals is link through the MES with a pop-up message shown in the machine monitor.

Regarding the reverse communication path, some CNCs in the examined plant can communicate only via MT Connect which is a read-only communication protocol and so the MES cannot send signals to the machines. Consequently it was chosen to worry only about sending the part program to the CNC and not other signals, but this problem will be treated in the sections below because it concerns more specifically the entire connection between PLM, ERP and MES.

3.2 Product Lifecycle Management

Since the product is developed from the idea through a 3D model, it is possible to think about the implementation of a PLM software to more easily follow the different phases of the product creation. Consequently together with the data collected by the ERP from the customer orders, also the engineering object becomes one of the first data insert within the information system.

The software used by the company is ENOVIA, a brand-new Dassault Systémes product, that allows a simple management of the product life cycle through a large numbers of applications, each one with different features and purposes (below the most used apps are treated). The potentialities of the software are also associated with the interactive web-based graphical user interface, given by the *3D-Experience* platform[1] and one of the ENOVIA's app, called *3D-Dashboard*. The possibility to quickly move itself from an application with a functionality to a different one through the blue circle in the left upper corner of the figure 3.2[2] is one of the best feature of the first one tool mentioned. The circle is divided into five interactive buttons, that each one opens a sub-menu with some app related to it (*play* in the center and *Collaboration and Social Media*, *Information Intelligence*, *Simulation* and *3D Modeling* app clockwise starting from the top) and filtered by the logged user, in fact it shows only the app associated with the user's role inside the company. The *3D-Dashboard* tool concerns the possibility to create your own graphical interface divided into some principal menus, each one corresponding to a different saved visualization, defined as *Tab*. The *Tab* is likewise split into some chosen windows (widget) with editable size, that refer to the different applications aforementioned. In the figure 3.2 it can be seen an example of visualization with three different windows: the *3D play* widget in the lower right corner, that allows to analyze the 3D model of a particular item, selected from those present inside the server, the *Collaborative Lifecycle* widget, to know on what design stage the engineering object is

[1]3DEXPERIENCE is first and foremost a collaboration platform: any information that is required in order to carry out a project will be gathered here. Whatever the time or wherever they may be, anyone participating in the project, be it the designer, the project manager or the manager, can simply share their information, acquire any necessary data and communicate with each other.

[2]For privacy reasons the images reported in the present chapter refer to a test environment, full copy of the implemented one about the procedures, but not about the data.

and to promote it to a later stage, and the *Change Action* widget, that will be explained later.

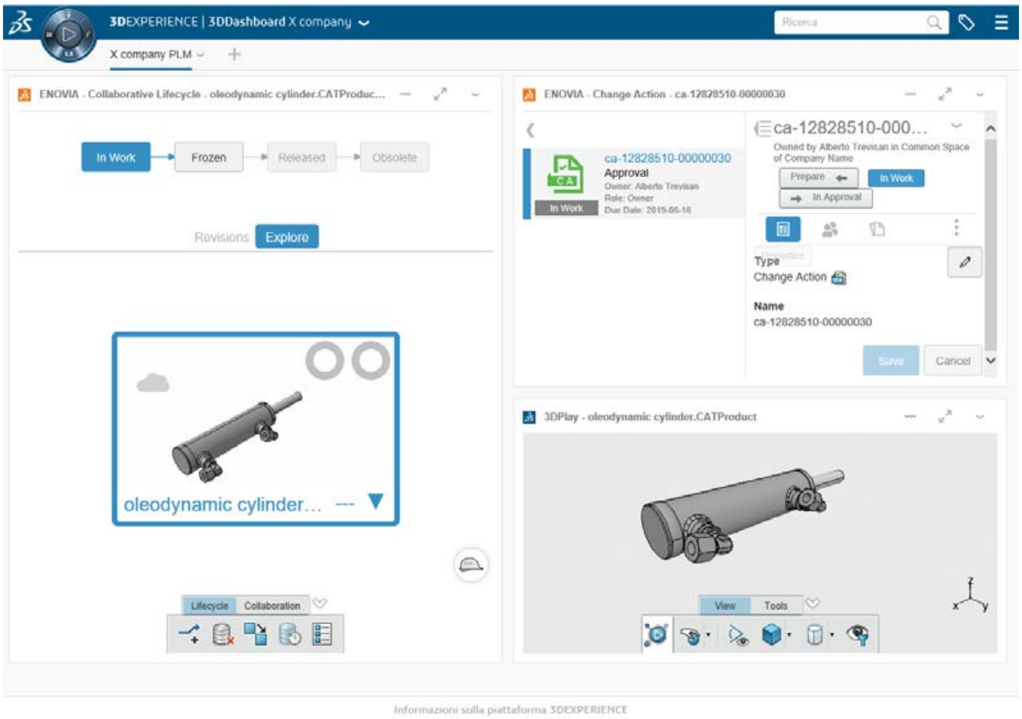


Figure 3.2: Screenshot of an ENOVIA application: 3D-Dashboard.

Below it will be reported the procedure followed by X to bring an item from the creation to the release to the ERP, detailing the app used for each particular step.

First of all it is important to keep trace inside the system of the development of a new item, also for the future stages including the production. Consequently the designer through the *Classify and Reuse* tool (see Fig.3.3) can easily create the product data and he can link the CAD model, the 2D drawing and eventually some documents with specifications for quality and production to this engineering object; so that this information will follow the product in every step. The identification code is automatically generated by the PLM: the prefix is alphanumeric and is dependent on the family of the product, while the numeric part is given by a sequence in ascending order. In X an item belongs to a class due to its function and in what application it will be used; in the figure 3.3 can be seen the first level that is the library "Parti Oleodinamiche" ("Hydraulic Parts") with the two associated family "Cilindri per cestello elevatore" ("Cylinders for ladder truck") and "Cilindri per escavatore" ("Cylinders for backhoe") in the left panel and a list of engineering object of the first family mentioned with their features in the right panel.

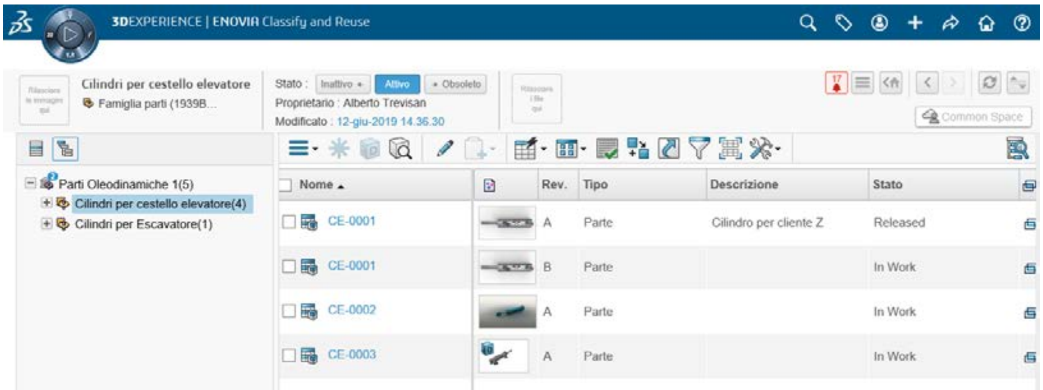


Figure 3.3: Screenshot of an ENOVIA application: Classify and Reuse.

Once created the item data and upload the CAD model, the designer promotes the object to the frozen state and consequently he generates a change order with some associated change actions through the *Change Management* app (Fig. 3.4). This step is necessary to bind the passage of the product to a later phase, before some approvals: for example the product design needs the approval of the structural engineer before passing to the state of released. In X for each change order, that takes into account a specific engineering object, there are as many change actions as files attached to that specific part because all of them have to be approved. The change action form is part into four main fields: the *information and state*, where the state of change and a main message are shown, the *basic data*, like the code, the typology, the owner and the description, the *details*, like the associated change order and the priority, the *team*, where all the people involved are shown, like the assignee, the reviewers and the followers. Once the change action is created, an email is automatically send by the software to the reviewers to inform them that there is an item, ready for release, that needs a review and then an approval.

Once the change order is approved, the state of engineering objects becomes released and automatically all the associated data are transmitted to the ERP, that maintain the encoding made by the PLM in its database and keep trace of the path of the different associated files.

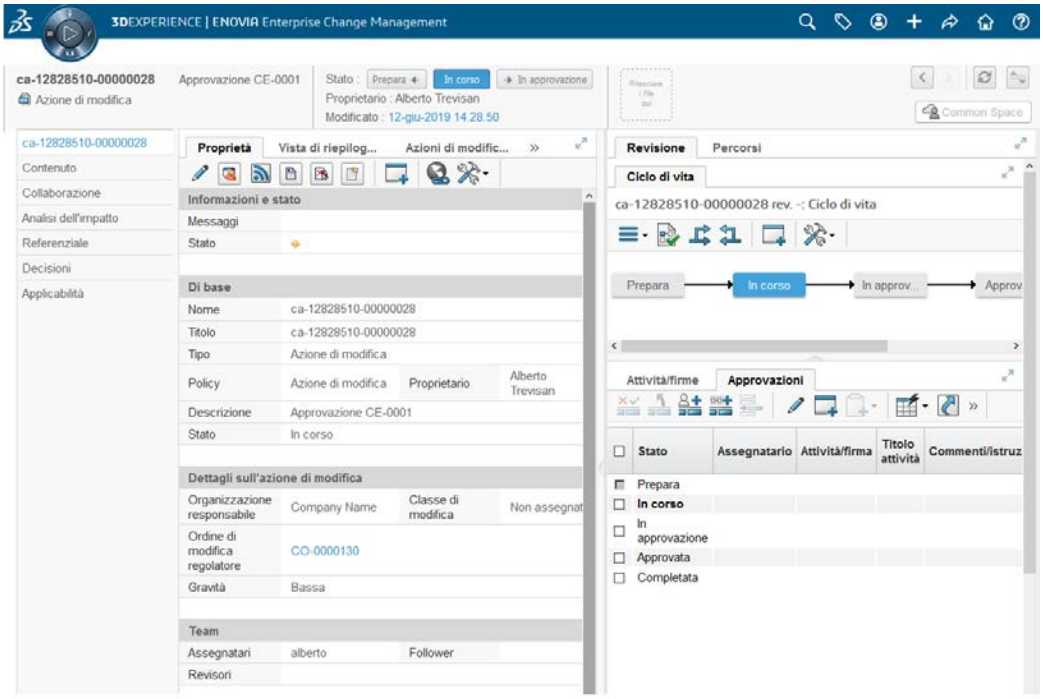


Figure 3.4: Screenshot of an ENOVIA application: Change Management.

3.3 Manufacturing Execution System

Once finished the preliminary analysis of the company, it is possible to focus attention to the implementation of the Manufacturing Execution System. The MES chosen for the study is *Opera*, made by *Opendata srl*, because it is very customizable, inasmuch it allows to modify the majority of its functions through store procedures written in MySql and Java scripts in accordance with the needs of the company. This feature, as it has been repeated several times during the study, is essential when you are trying to implement the "Industry 4.0" concept in a Small Medium Enterprise. As can be seen from the figure below (Fig. 3.5, that represents the *Opera*'s logo), *Opera* is divided into five principal modules, that are:

- ***Production***, that allows to manage, track and monitor all production activities carried out within the shop floor to allow automatic data acquisition and real-time production management (it is the only one implemented in the present study);
- ***Material***, that allows the complete management of the flow of materials (traceability) within the factory and the warehouse, allowing access to up-to-date information on the availability of material;
- ***Quality***, that allows to automatically manage, detect and monitor

quality assurance control during the production process, in order to guarantee product conformity. The controls can be performed by the operators or generated automatically by the machines in production following managed and programmed events (quantity reached, processing times, instrument calibration ... etc);

- ***Maintenance***, that allows you to manage, track and monitor all maintenance activities in order to reduce to zero the incidental failures that affect the performance of the process, in addition to improving the level of resource use and reducing maintenance costs;
- ***Device Connection***, key features of OPERA MES that allows you to communicate directly with the machines and production plants, not only to automatically detect the data relating to the production process (times, quantities produced, waste, causalized machine stops, energy consumption, process parameters, etc.), but also to provide the machines with the data necessary for the execution of the production process (part programs, recipes, instructions, etc.).

Figure 3.5: Logo of the implemented MES: Opera.

3.3.1 MES implementation

The implementation of Opera inside the company includes the following six steps: the installation of the software into a specially crafted server and its connection to a MySql database, the client installation in the on board computers of the machines through a web interface, the creation of the factory digital twin inside MES database, the preparation of the MES, so that it can communicates with the KEPserver regarding the arrival of the signals and with CNCs regarding the sending of the part program, and finally the implementation of the routine for the data transfer between MES and ERP. The first two points listed can be summarized in one operation, of which technicalities are not reported here, but only its consequences will be treated below. First of all the server and client installations create two graphical user interfaces with different utilities: the ***OperaGest*** and the ***OperaWEB*** respectively. The first is generally installed in the administrative office and allows the user to manage the Master Data, to control the plant through a digital twin of all the stuff inside the shop floor and to create some statistical analyses, such as the OEE index. Analyzing the GUI structure, as can be seen from the figure 3.6, it is divided into a main menu in the upper bar, where it is possible to move across the different modules, like the *production*, and other tools, like *KPI* to make some shop floor analysis, then there is a left panel that allows to show a specific table and lastly a right panel to go further into more detail respectively to the open table.

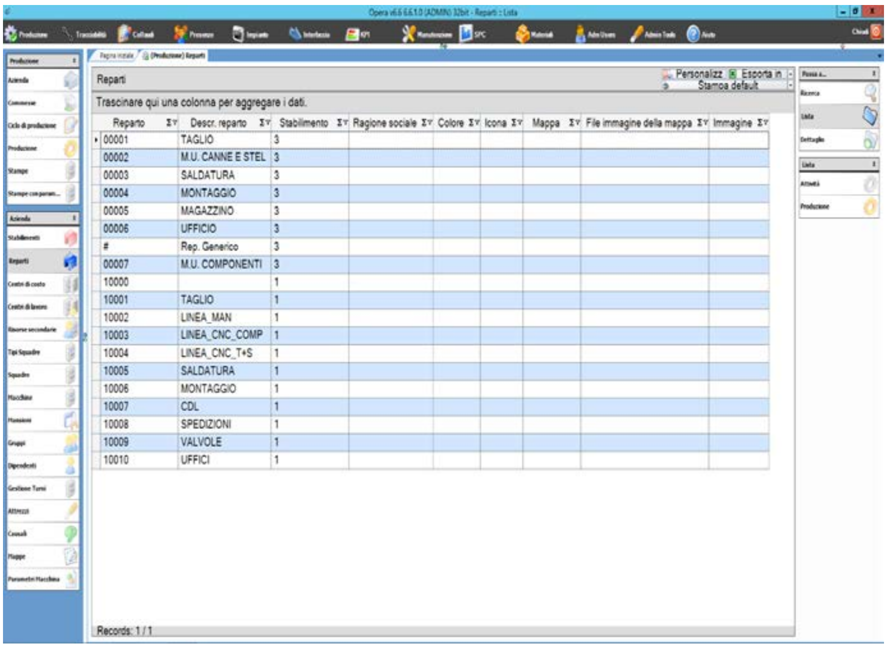


Figure 3.6: MES GUI for the production manager: OperaGest.

Instead ***OperaWEB*** is the client part installed on every linked machine and necessary to let the operators manage the different processing steps from a machine on board monitor. As can be seen from figure 3.7, the user has to report through this GUI all the operations, that he makes in the shop floor: this is the methodology used by Opera to record all the activities inside the database. The main screen is composed by some buttons, each one associated with a different work operation, that is defined inside Opera as *workflow*: once pushed the button, an associated store procedure runs reading from some database tables and a secondary screen is shown, where the operators can insert some details about the operation (for example the work stage number if it is starting a new activity or the reason for suspension of an activity). After a preliminary analysis of X's shop floor activities, it is chosen to insert the following *workflows*: Start/End Setup, Start/End Activity, Start/End Rework, Start/End Indirect Activity, Frozen/Unfrozen Activities, Hour statement, Output, Entrance/Exit Operators and Delete Machine Placements.

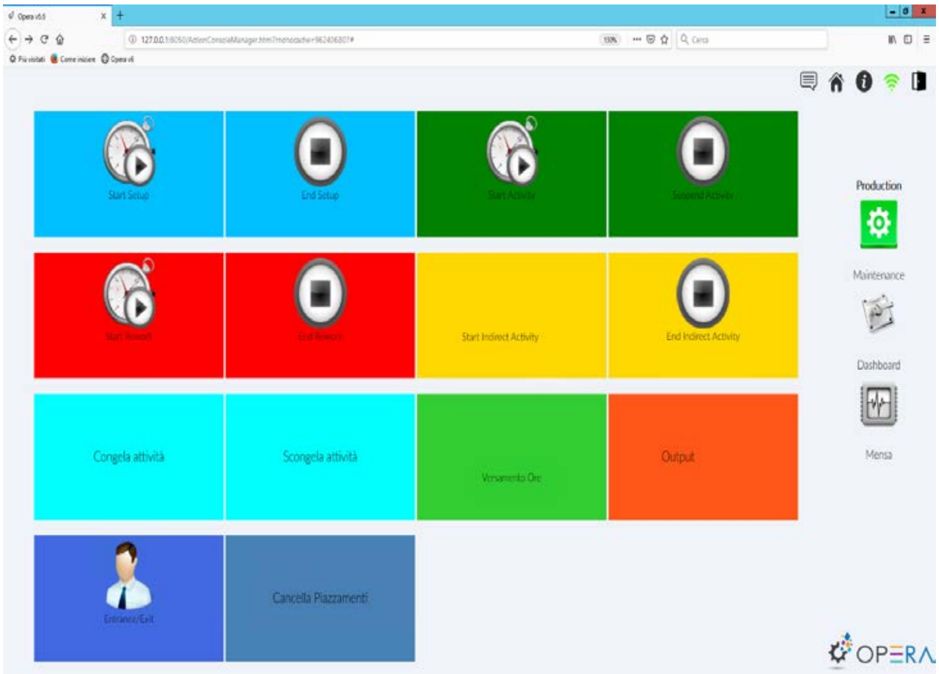


Figure 3.7: MES GUI for the operator: OperaWeb.

After the software installation, it is essential the creation of the factory digital twin through the insert into the database main tables of the several records, regarding for example the departments (Fig. 3.6), the operators and the machines with all their features. All these tables in Opera are locating inside some hierarchical trees in such a way that a record at lower levels with few details in its own table is characterized by its higher levels: the main trees are the tree of the resources (Fig. 3.8) with the plant as the highest levels and machines and operators as lowest level, the tree of the products with the family of the item as highest level and work operation as lowest level and the tree of the orders with the customers at the highest levels and the work stages at the lowest levels (the first two trees can be recorded immediately during the MES implementation stage, while the last will be directly create during the routine of data transfer between ERP and MES). This step of filling the tables is highly necessary in order that the data acquisition from the plants will be clean and orderly and every action written in the database will have a discernable subject. Furthermore if a true and correct copy is created, the analysis made by the production manager result to be more useful and realistic.

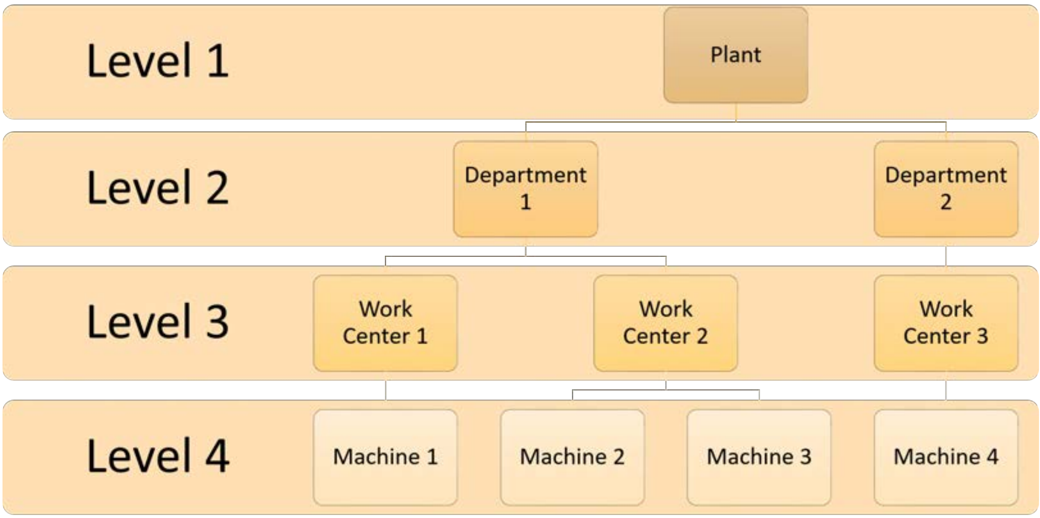


Figure 3.8: An example of hierarchical tree: Tree of resources.

Once the MES database is prepared with all the master data relative to X, it is possible to complete the link between the MES and the machines faced during the previous section. Regarding the interface between MES database and *KEPServer* database, there is a tool inside Opera, called OPC-DB, that easily allows to capture the data from an external OPC-Server and link it directly with all the involved tables in Opera: for example if a signal of machine downtime is reading from the KEPServer database, automatically the tables *machine*, *production* and *activities* are updated. In order for this procedure to take place exactly, it is necessary to indicate to Opera what are the signals that have to read and what are their functions. There are three important tables, where to insert this information: *Regs* and *Job*, used to identify a specific signal, and *Logic*, used to link the signal with a certain function (e.g. Piece Counter). In the figure 3.9 the necessary fields for the three tables are shown, taking into account an example of *"Piece Counter"* signal.

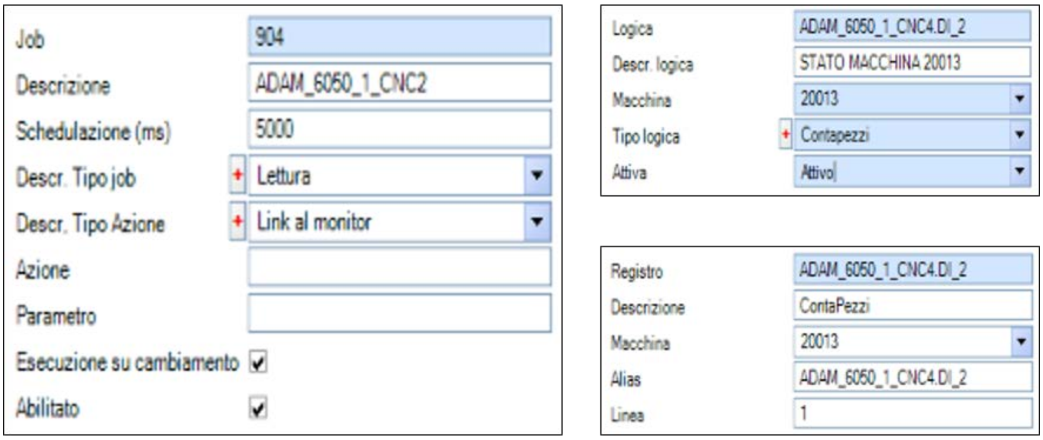


Figure 3.9: An example of a signal link to Opera: Fields of Logic, Job and Reg tables are shown for a "Piece Counter" signal.

Now opera is able to read all the signals from the machine, so that leaves only to configure the sending of the part program for a specific work stage from Opera to the machine. This process is more complex, inasmuch it requires the communication between all the industrial software treated in this study: first of all the technical department creates the PartProgram file and let the PLM manage him, that sends to the ERP the path of the file together with the bill of materials; during the data transfer from ERP to MES the aforementioned path is attached to the associated work stage; letting Opera know the file path allows to transfer the PartProgram file directly to the machine through the *workflow* "Start setup", when the associated work stage is selected by the operator; this last action automatically transfer the file from the network resource to a specific folder on the machine on board computer.

To complete the MES implementation inside the IT system of X, it is necessary to create a procedure that transfers data from the ERP to the MES, but before that an analysis has to be done about what must be sent and when. The ERP used by the company receives from the PLM the whole bill of materials and bill of processes of the different products created by the engineering department; consequently when a new customer order is reported into the ERP database, the production cycle is instantly created with the associated work stages. Considering the routine just described and the role of a Manufacturing Execution System, that has to take care only about the production, it is chosen to transfer this information to the MES database only after the scheduling of the work stages. In this way the MES receive all the information in one step and the operator finds the work stage directly visible into the machine on board monitor and ready to be launched. Obviously this procedure has to be able to manage the possible changes on the scheduling, when occurs. The procedure creates to do this consists in a planned routine that create a .csv file from the ERP database, when the state of work stage becomes "scheduled", then Opera finds the file searching in a specific folder and insert the data into its own database. A similar procedures is created to transfer data from MES to ERP, when a customer order is ready to the shipment.

3.4 Results

Different kind of results can be analyzed after the implementation of an *Industry 4.0* project inside a company, but some of those have a long-term evaluation like the production growth, the decreasing of production time or the better items quality; consequently they are not reported in the present study, but they could be object of a future analysis. Regarding the short-term results, they can be divided into two categories: one more conceptual and one with numerical data.

The first one is the totally absence of sheet of papers within the company, which means that now all the industrial processes take place inside the information system and consequently they can be always and everywhere tracked down. The input data originate from three different procedures: the cyber-physical systems collect the production data from the shop-floor, the PLM records the engineering features of the item from the CAD model and the administrative office inserts the customers orders thanks to the ERP interface. Furthermore this adopted methodology allows the operations to be executed in a faster and more accurate way. Regarding the data transmission rate, for example, before this project the production procedure arrived to the shop-floor operator through an employee that bring a sheet of paper from the office to the machinery; now, once the order is confirmed, the shop-floor operator finds instantaneously all the necessary for the production from the part program to the item specification within machine on board computer. The operations can be defined more accurate, because the filters imposed by the software not allows to make any mistakes; for example this is the case of an engineering object that, without the PLM implementation, could accidentally go into production before the necessary reviews made by the employee in charge.

The second set of results regards the full industrial real-time process control, that is the main objective of the present work. Before the implementation of the MES and its link with the machinery, in X the production factors was controlled by the plant manager one time a day in an inaccurate way through the view of where the different semi-finished items were situated inside the shop-floor. Now the production variables can be investigated at anytime in an exact way, inasmuch every stage of the production is followed by CPS, that in real-time transmit the data to the information system through the

MES. To demonstrate those results, it is chosen to show a plot (Fig. 3.10), about a single process variable (the production output), that compares the situation about the process control before and after the implementation of the different *Industry 4.0* tools. The plot takes into account the output of a specific machine (*Lathe CNC-DMG MORI with machine code 02060*) considering a single working day (*20th May 2019*): the X-axis represents the time from 8 a.m. to 17 p.m., while the Y-axis represents the sum of worked items; the sensitivity of the time domain has to be considered until the minute. The orange curve is the visualization of the real data collected by the MES, while the blue curve is a linear interpolation between the only two data, that they were collected by X before this project. As it can be seen, the two curves are totally different and consequently only now the company can perfectly know what is happening inside the shop-floor.

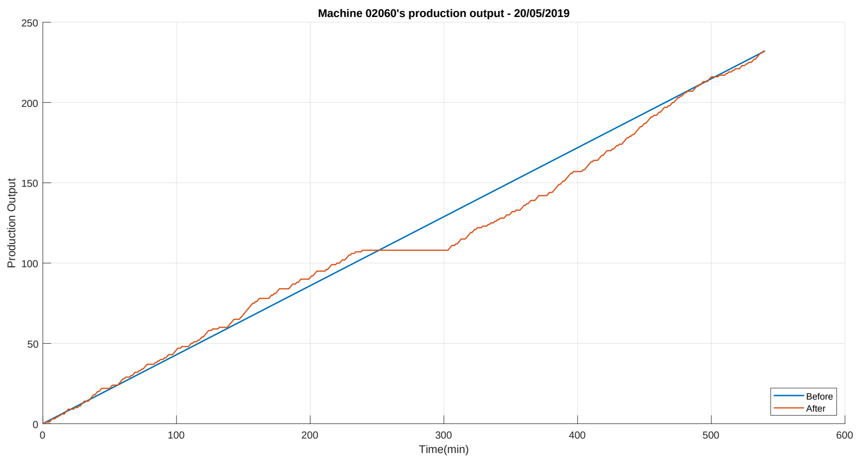


Figure 3.10: Comparison of process control before and after *Industry 4.0* project within X.

Chapter 4

Conclusion

First of all, the present study wanted to define the concept of *Industry 4.0* in a clear and ordered way through the use of tools such as bibliographic research and bibliometric analysis. It was understood that the fourth industrial revolution refers to the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and social outcomes. Once this meaning was outlined, the present work tried to go into details regarding the new technologies that are allowing this innovation. This section of the thesis starts from the explanation of cyber-physical systems and their need to be supported by specific software that can collect and analyze their data. Before moving to a real implementation in a company, some selected tools was studied more thoroughly: the features and benefits of three particular software (PLM, ERP and MES) were considered; a research was made to find out the state of art regarding the communication protocols for the S2S and M2S interconnections; the possible methods to store the Big Data was analyzed, dwelling on the advantages and disadvantages of cloud computing and on-premise services.

Once finished the first part of the work, that has the aim of presenting all the shades of *Industry 4.0*, it was tried to reach the main objective of the thesis, that is to report the improvements given by the digitalization of an industrial system in terms of analysis and management of the whole industrial process. The way used to show this was to bring the results of the implementation of a real *Industry 4.0* project in a company. This section exposes the preliminary analysis of the company, explaining in particular the software and the machinery already installed. Subsequently the several software used with the associated implemented procedures and the methodology of interconnection adopted was reported. As results, it can be seen that all the operations within the company pass through the information system and so they can be easily managed and tracked down at anytime and everywhere. Furthermore, regarding the results obtained in terms of production management, a graph was plotted to shows how the production factors can be visualized in real-time, while they were controlled once a day before the present project.

The future developments for the present study can be divided in two main categories: one regarding the completion of the case study with the connection of the entire machinery to the information system and the relocation of data from on-premise server to cloud one; instead, in terms of reported results, some of them have a long-term analysis, like the decreasing of production time or the output growth, so they could be analyzed in a few months.

Nomenclature

CAD Computer-Aided Design

CAM Computer-Aided Machining

CNC Computer Numerical Control

CPS Cyber Physical System

ERP Enterprise Resource Planning

GPT General Purpose technology

I4.0 Industry 4.0

IoS Internet of Services

IoT Internet of Things

IT Information Technology

M2S Machine to Software

MES Manufacturing Execution System

MRP1 Material Requirements Planning

MRP2 Manufacturing Resource Planning

PDM Product Data Management

PLM Product Lifecycle Management

S2S Software to Software

SCM Supply Chain Management

X Company analyzed for the case study

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