POLITECNICO DI TORINO
Master of Science in Automotive Engineering
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Industry 4.0 in Manufacturing
And it's integration with lean & six sigma

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ABSTRACT

The term Industry 4.0 refers to 4th industrial revolution in the most recent phase of industrial advancement. It is a solution which integrates cyber physical systems & IoT. This complies machines using self-optimization, self-configuration and even AI (artificial intelligence) to complete complex activities. So, in simple words, in I4.0 manufacturing ambient there will be smart production lines & intelligent devices which can interact with each other in real time and can take effective decisions.

Lean Manufacturing is a traditional method that the manufactures are using for several decades for creating a value-oriented production process by removing all non-value activities. But with increasing complexity of the operations, lean management is not well enough for fulfilling the challenges. Here comes the Industry 4.0 which by its sets of advance digital technologies can boost and improve the production while dealing with greater complexities. In this regard the combination between Lean method & Industry 4.0 approach (Lean Industry 4.0) can bring the manufacturing process the next excellence level. Recent studies show that successful implementation of lean industry 4.0 can improve conversion cost approximately 40%. In five to ten years. In this study the interplay of Lean Manufacturing & Industry 4.0 will be discussed.

On the other hand, lean six sigma which is a statistical approach to improve quality which deals with the variation in the manufacturing processes. This approach, which analyzes systematically manufacturing processes through DMAIC (Define, Measure, Analyze, Improve & Control) Phases and eventually improves product quality. The result, which is less than 3.4 defective parts per million, has made significant improvements and cost savings in many companies. Six sigma is a data driven methodology, which means data measurement is the foundation for decision. The success of six sigma depends on collection of big data and extraction of useful information from it. Industry 4.0 manufacturing solution will generate huge amount of data. This massive data sets collected by industry 4.0 technologies should be mined with powerful data analysis methods. Effective decisions can be then made by utilizing these analysis methods in each step of six sigma cycles. This study will show the application of six sigma to deal with big data of I4.0 to make faster, reliable and satisfied decisions.

Industry 4.0, Lean & Six sigma could be integrated & aligned. Together these paradigms can help manufacturer maximize efficiency & process improvement. The goal of this study is to analyze & discuss the implementation and usefulness of the traditional tools like Lean & Six sigma within I4.0 reality to make it more robust, quality oriented & confront the upcoming challenges of the future manufacturing excellence.

1. Introduction

1.1 Contextualization

Industry 4.0 (I4.0) is a term appeared first in 2011 at Hannover Fair with reference to the 4th Industrial Revolution. It is not a mere idea, but the continuous advancement of digital technology and manufacturing advancement takes us to this reality. The I4.0 was shaped by German Government and industry leaders. Industry 4.0, in the most recent phase of industrial advancement integrates cyber-physical systems and the Internet of Things into production line manufacturing. The term refers to the creation of smart factories with internet-controlled machines which can communicate to each other and can interchange data to facilitate the production.

For the last three decades Manufactures are using Lean Management (LM) to improve their business business value. LM can contribute towards the implementation of Industry 4.0 as Lean and Industry 4.0 do have a lot of similarities. To optimize their operations, manufactures need to understand the interplay between lean management and Industry 4.0. The combination of lean management and Industry 4.0 which (Lean Industry 4.0) is the most effective way to reach the next level of operational excellence. Successful implementation of Lean Industry 4.0 can reduce conversion costs considerably better than the reductions achieved by individual implementation. Each manufacturer can implement the application of Lean Industry 4.0 to address its specific challenges.

As a result of constant machine-to-machine communication, enormous amounts of information would be produced by Industry 4.0 production environment. Thus Industry 4.0 framework will require huge data collection and analysis to solve process problems. Here Six Sigma can play its role by its tools and techniques.
The approach six sigma and lean methodology aims to reach six sigma quality levels, less than 3.4 part per million defectives, by reducing variations and wastes within processes. Reaching the target depends on data collection and eventually analyzing those data to overcome quality problems. Many traditional data analysis techniques can be applied to develop quality of products and processes. These data set mined with powerful data analysis such like big data can give in depth insight which will assist to make effective decisions in each step of six sigma cycles.

Specially in measure and analyze phase this data analysis has outmost importance to make correct decisions.

1.2 Objective

The aim of this thesis is to allow an understanding of the framework, challenges and perspectives of the Industry 4.0 theme, in a global industrial perspective and how it can be accelerating by existing improvement tools like lean & six sigma.

Apart from that, the study will try to provide a guide to use lean & six sigma concepts to make faster, more reliable and satisfied decisions. Combination of this tools will finally contribute to the manufacturing processes by reducing the lead time, producing better quality products.

1.3 Organization of the report

After the first chapter of introduction and explaining the purpose of this study the second chapter The I4.0, CPS & The Manufacturing Industry will focus on the main features of Industry 4.0 in manufacturing and the technologies related to it.

In 2nd chapter, all the theoretical concept and literature study of I4.0 will be discussed. The impact of I4.0 in manufacturing industry and it's core the cyber-physical system will be elaborated. The four clusters in which the I4.0 is divided will be described and finally each technology with the several effects on process industry will be explained.

The 3rd Chapter will Discuss About the interplay between Lean Manufacturing & Industry 4.0 technologies. The pillar of lean & the five principles will be discussed in terms of Industry 4.0 components. The two way interaction will be explained deeply.

In the 4th chapter Lean six sigma & Industry 4.0 interaction will be discussed. The concept of LSS 4.0, different data mining techniques & importance of bid data will be explained. Finally data analysis techniques in different phase of Lean six sigma cycle will be shown.

2. THE I4.0, CPS &THE MANUFACTURING INDUSTRY

2.1 The I4.0

The 4th generation Industrial Revolution based on Cyber Physical System. These Cyber Physical Systems (CPS) include smart machines, storage systems and production facilities capable of autonomously exchanging information, trigger actions and can control each other.

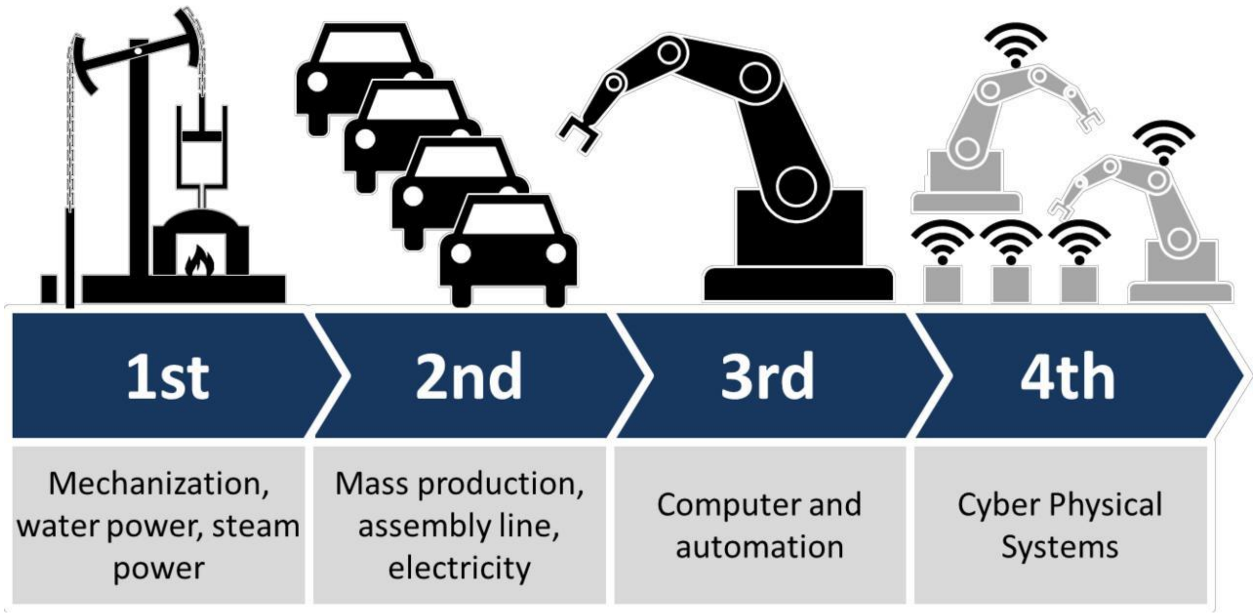


Fig. 1 industrial revolution

It is a trend of industrial automation that integrate some new production technology to improve working conditions, increase productivity and production quality of the plant. Industry 4.0 goes through the smart factory concept which consists

- Smart Production: The technology that collaborate between all elements, operators, machines and tools that present in a production.
- Smart Service: ICT technology that allow to integrate the company-suppliers-customer and the other external stakeholders.
- Smart Energy: Create more efficient systems (energy consumption) and reducing waste of energy,

2.1.1 Design Principles of I4.0

There are four design principles which support companies in implementing Industry 4.0 scenarios.

- **Interoperability:** It is the capability of machines, devices, sensors, and people to connect and communicate with each other via the Internet of Things (IoT) or the Internet of People (IoP)

- **Information Transparency:** Through inter-connectivity, operators can make effective decision by collecting immense amounts of data and information from all points in the manufacturing. The information system should be able to create a virtual copy of the physical world.

- **Decentralized Decisions:** It is the ability of CPS to work independently & make decisions on their own to perform their tasks autonomously. In case of exceptions or conflicting goals the tasks delegated to a higher level.

- **Real-Time Capability:** Smart manufacturing has the ability to collect real time data, analyze it and make decisions accordingly. It is not only market research but also to shop floor processes such as the failure of a machine. Smart objects must have the ability to identify the defect and re-delegate tasks to other operating machines. It promote flexibility and the optimization of manufacturing.

- **Technical assistance:** This is the ability of the cyber physical systems to support humans through aggregation and visualization of information for better decision-making and quick solutions to problems. It also focuses on the ability of cyber-enabled systems to physically support human resources by handling various tasks, which are considered time-consuming, harmful and exhausting to people.

2.1.2 COMPONENTS OF I4.0

With reference to academic research & publications, the most common four components related to the industry 4.0 are Cyber-Physical Systems, Internet of Things, Smart Factory, and Internet of Services.

Cyber-Physical Systems

The key to the industry4.0 is cyber physical systems (cps). IoT is the core of CPS. It can interact and collaborate with other CPS system. This is the basis of decentralization and collaboration between systems. The term **"cyber-physical systems**" emerged in 2006, coined by Helen Gill at the National Science Foundation in the US.

CPS is an integration of computation with physical processes. Embedded computers and networks monitor and control the physical processes. CPS is about the intersection, not the union, of the physical and the cyber. It is not the physical components and the computational components but we must understand their interaction.

Three phases of CPS development are:

- Identification: Unique identification is essential in production. RFID (Radio-frequency identification) is a great example of that which uses an electromagnetic field to identify a certain tag that is often attached to an object. Although it exists from many years but it still serves as a great example of how Industry 4.0 operated initially.
- The Integration of Sensors & Actuators: The integration of sensors and actuators simply means that a certain machine's movement can be controlled. Furthermore it can sense changes in the environment.
- The Development of Sensors & Actuators: Such development allowed machines to store and analyze data. Presence of multiple sensors and actuators in the CPS can be networked for the exchange of information.

The Internet of Things (IoT)

Today a cyber-physical system where machines can exchange data and can sense the changes in the environment around them sounds familiar to us. For example, Fire alarms. But the **Internet of Things** (IoT), however, is what actually has initiated I4.0.

The IoT is what enables objects and machines such as mobile phones and sensors to "communicate" with each other as well as human beings to work out solutions. This allows machines to work independently and solve problems. Of course, it's not entirely true as humans need to intervene where is a conflicting goals & strategic decision to make.

CPS can be understood as object & the IoT can be defined as a network in which CPS interact with each other through unique identification system.

The Internet of Services (IoS)

In this digital era almost all the electronic device has the feature to connect to internet & another device. Smart phones, tablets, laptops, TVs or even watches are becoming more and more interconnected. The IoS aims at creating a wrapper that simplifies all connected devices to make the most out of them by simplifying the process. Simply speaking, It is the customer's gateway to the manufacturer.

Smart Factory

The smart factory uses internet & cloud to connect with physical & virtual world. It has a seamless integration of CPS at all level. The modular construction of the factory allow flexible manufacturing. It establish communication across each machine and tool through intelligent devices.

2.1.3 The enabler's of I4 technologies

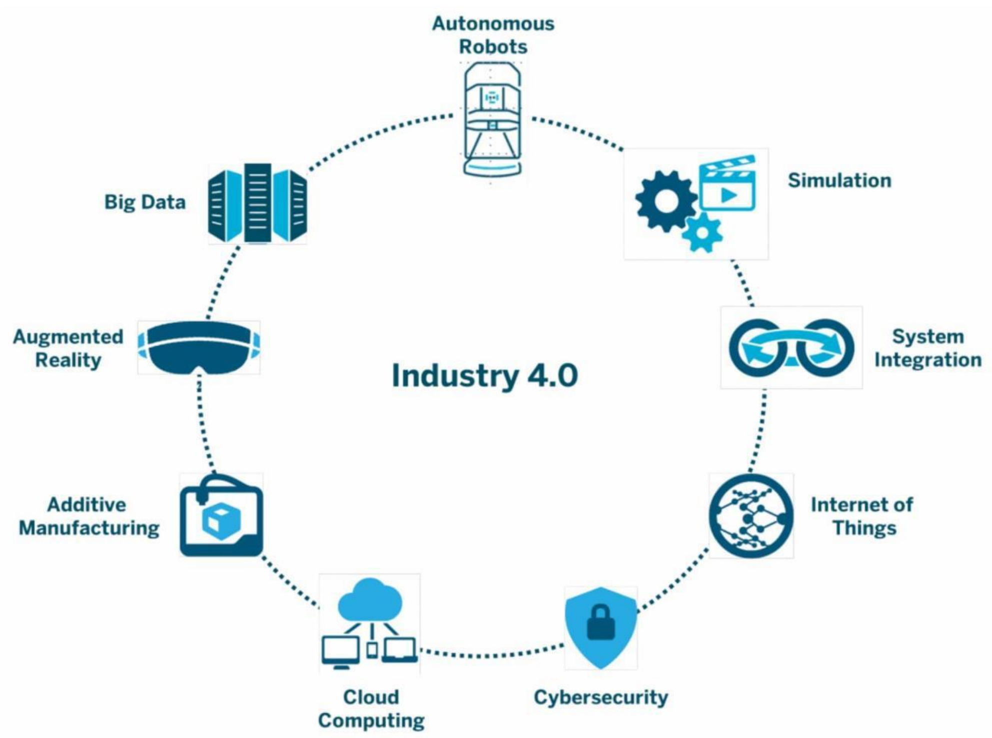


Figure 2.1 industry 4.0 enablers

- Advance manufacturing solution: interconnected and modular system allow flexibility and performance.
- Additive manufacturing: increase the efficiency.
- Augmented reality: Guide operators for daily operation, maintenance and training.
- Simulation: To optimize process.
- Horizontal and vertical integration: Exchange information among all the systems/actors in the manufacturing process.
- Industrial internet: communication or exchange information between outside & inside the company.
- Cloud: Storage & manage huge amount of data.

- Cyber-security: Due to the internal and external connection arises the need of cyber security
- Big data analytics: Big data can give important forecast and prediction through analysis of huge amount of data.

2.2 CPS IN INDUSTRY 4.0 MANUFACTURING

The manufacturing industries involve in processing of items in either producing of new commodities or in value addition.

As it was first defined, the cyber-physical systems are a network of components that are deeply interconnected existing in both, virtual and physical space. The concept cyber-physical implies a multidisciplinary knowledge of Mechatronics, cybernetics, and design (Suh, 2014). These three fields are described in following,

Mechatronics is in charge of developing machines that perform specifics tasks such as assembly arms, oil extraction machines and even space shuttles. These were unthinkable decades back. In the 3rd industrial revolution mechatronic was the main influencer.

Cybernetics are systems which capable of receiving, storing and processing information so as to use it for control (Umpleby, 2008). This is a field which study control of group of machines to fulfill different tasks. The core of cybernetics is the Internet of things (IoT).

Design and Process engineering focus on human-machine relationship through computing power, machine strength and human creativity. It allows human & machine to work together respecting safety and efficiency.

2.3 Technologies in the Industry 4.0 Manufacturing

After analyzing the following reports "How to navigate digitalization of the manufacturing sector" from McKinsey & Company (McKinsey & Company, 2015), "Industry 4.0: building your digital enterprise" from PwC (Price Water House Cooper, 2016), "Challenges and solutions for the digital transformation and use of exponential technologies" from Deloitte Digital (Deloitte digital, 2015) , and "the future of productivity and growth in manufacturing industries" from Boston Consulting Group (Boston Consulting Group , 2016), it was identified 14 technologies that represent the Industry 4.0 (Mateo Jimenez, Thesis 2017). These technologies are divided in four major clusters:

- **Automation** includes technologies that foster automation in manufacturing such like additive manufacturing (3D printing), drones, robots and autonomous vehicles.

- **Customer access** consists of technologies that accumulate information from the end user and suppliers in the supply chain of the plant. It comprises by social network, apps, websites and wearables.
- **Data analysis** composed of technologies for analyzing data such as big data analysis, routing and devices and artificial Intelligence (AI).
- **Connectivity cluster** includes technologies like cloud computing, digital products, sensors and data transmission that allow humans to gather data or connect other components.

Figure 2.2 illustrates the Industry 4.0 technologies and the four different clusters.

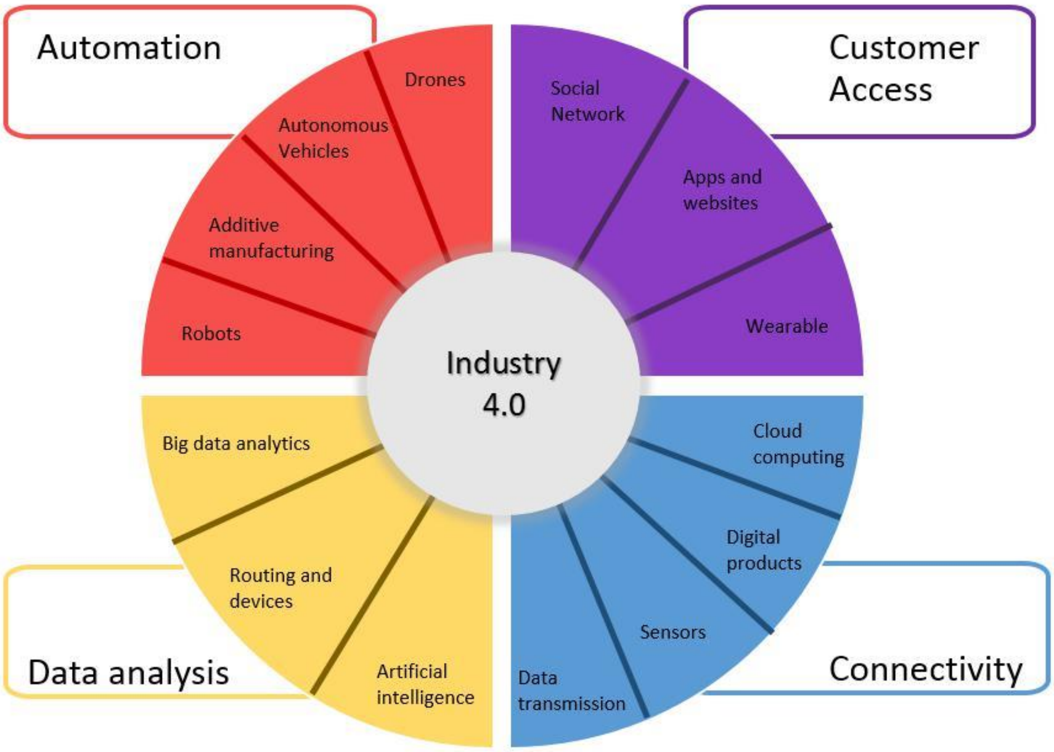


Figure 2.2 – I4.0 overview chart (BCG 2016)

Here in figure 2.3 shown that a CPS is a network and combination of different technologies and stakeholders. For example, one of the most famous CPS in the manufacturing industry are the smart assembly lines which combine the I4.0 technologies such as robots, digital Products, sensors, big data analysis and artificial intelligence to make assembly lines, which are communicating constantly by machine to machine relations (Fiat Research Center, 2016). However, before combining these technologies in a CPS, it is important to describe and explore each technology in its own context. The following section will address this topic.

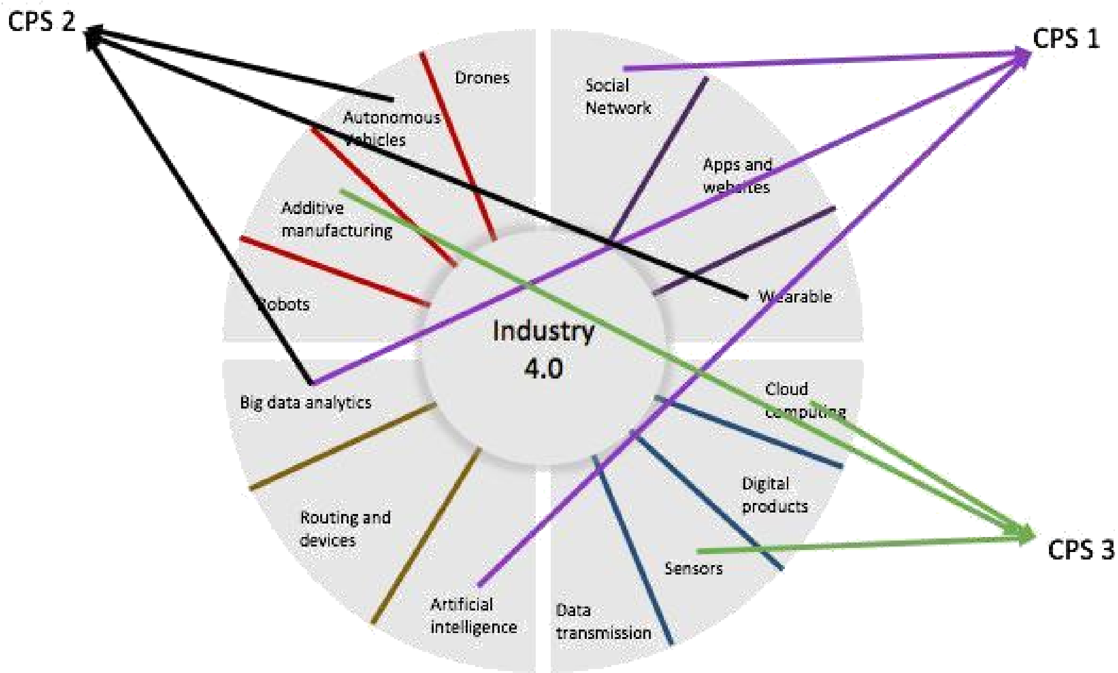


Figure 2.3-Cyber physical systems relation with i4.0 technologies

2.4 AUTOMATION

Automation is the key to manufacturers to produce the large volume of products at a low cost. Automation is a outcome of 3rd industrial revolution and these were mainly cutting machines, mechanic arms & tooling devices. As customer habits are changing so fast, so the demand on markets are putting pressure on manufacturer. Due to this reason companies can't use expensive machines that are only programmed to do one particular task. Furthermore, machines of the third industrial revolution lack of human-machine interaction (GTAI, 2016). Machines (robots & other devices) were not compatible to work together with human. Finally, the last challenge that third revolution machines are facing is the lack of decision-making process (GTAI, 2016). The industry 4.0 automation meeting this gaps.

2.4.1 I4.0 Technologies in automation

The I.40 automation technologies due to their ability of decision making, flexibility, and unsafe human-machine interaction are taking their places in the production line. Smart technologies like drones, autonomous vehicles, additive manufacturing (3D printing) or robots will make production more efficient and in long term cost effective.

DRONES

Asset management, surveillance, and mapping are the three main field where UAV’s are improving the manufacturing industry.

With the use of drones inspection and maintenance activities in the asset management field will be imrove. For example a british company Sky Futures are using drones in the oil and gas companies for aerial imagining & thermal inspection. The purpose is to replace the current inspection system in which maintenance operators inspect with ropes, lights and special equipment vessels, burners, and connections on platforms. It is safer, qualitatively better, more efficient has low down time

In security and safety field, drones can make life easier and safer for operators. UVA's can approach, film and take information about the environment in a safe & fast way. Inspection on environmental conditions, leakage or any pollution can be done remotely. Many companies are using this technology for clients that have big assets, and large territories to cover (ports and malls) for surveillance.

Finally, mapping and aerial imaging are one of the most common uses that UAV's are performing particularly in construction, mining, and energy fields. They provide important information about topography, natural resources, and environmental contamination. Such a example is the French company Red Bird which currently working with Caterpillar to deliver high performance data about topography, mining extraction profiles and surveillance.

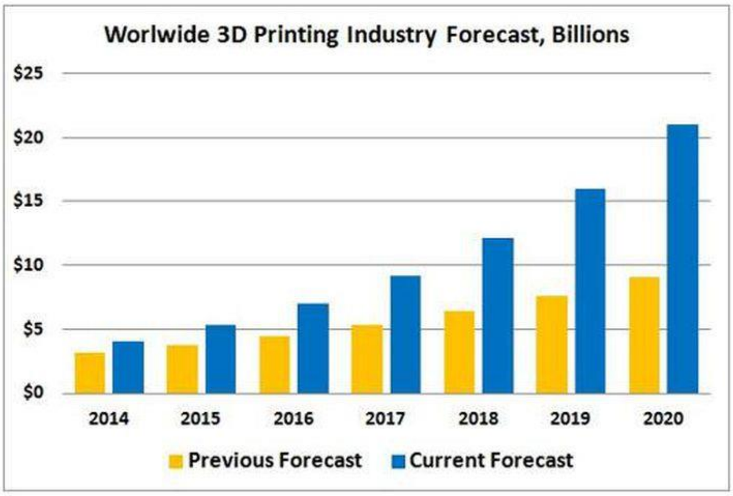
AUTONOMOUS GUIDED VEHICLES (AGV)

The main task of autonomous vehicles is basically material handling. But there is capacity gap due to precise GPS systems, poor connectivity & complex algorithm. Now car manufacturer are investing in AGV & self-driving cars for more safer & efficient operation in logistics at warehouse & road. Companies like Volkswagen, Ford, Google, Uber are already in the game.

In manufacturing AGV's will also help operators to carry materials in an efficient and self-control way. A perfect example of Industry 4.0 element is the Toru. Toru is an autonomous vehicle that has been working in DHL warehouses. It transport objects based on what clients order on the website Amazon.
Although for operations in the road, rules & regulation will need to be approved. But for the industry, it will be much easier to apply AGVs for transportation and several non-operational services.

ADDITIVE MANUFACTURING (3D PRINTING)

The application of 3D printing or additive manufacturing has been grown in recent years which is almost exponential (figure 2.3).



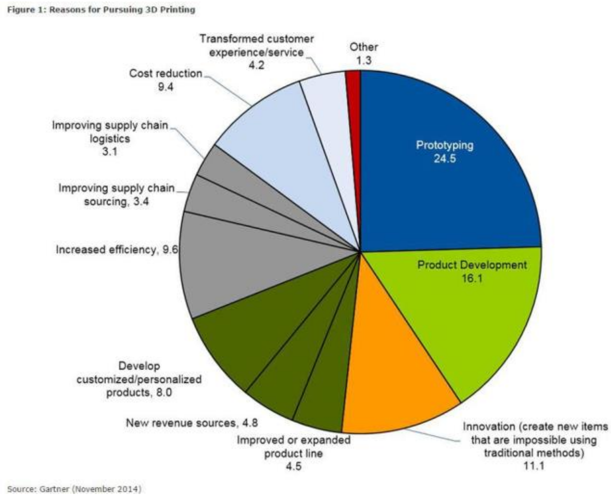


Figure 2.3: 3D printing industry forecast & reason of pursuing (Forbes & Garnter)

3D printing can develop the object within our from the cad design with outmost precision. This technology has outstanding benefits,

- **Reduction to 'Time to market':** Additive manufacturing can make the prototype within few ours from the CAD design. Normally prototype development is a very time consuming and costly process which sometimes need intervention even in the main production line.
- **Faster Customization:** Customization in traditional production system is very complex which require entire product line to change. But in additive manufacturing it's easy to modify the product with low cost and in a efficient way as the customer demand.
- **Zero Waste:** Additive manufacturing can produce components in a more efficient and cost effective way where Scrap is almost zero. Even 3D printers can go plug & produce way where the customer will be able to command through digital application where they can decide what they want, and the 3D printer starts producing.

Figure 2.4 – Exerial mass production 3D printer (Exone, 2015)

ROBOTS

Robot are controlled by computing system, made to develop certain tasks. Robots are one of the principle components of 3rd & 4th industrial revolution. The CPS in Industry 4.0 can be a group of robots that are interconnected and can perform tasks collectively. In addition they will have independent decision making and control relations.

The market for robotics is growing tremendously as we see in figure 2.5

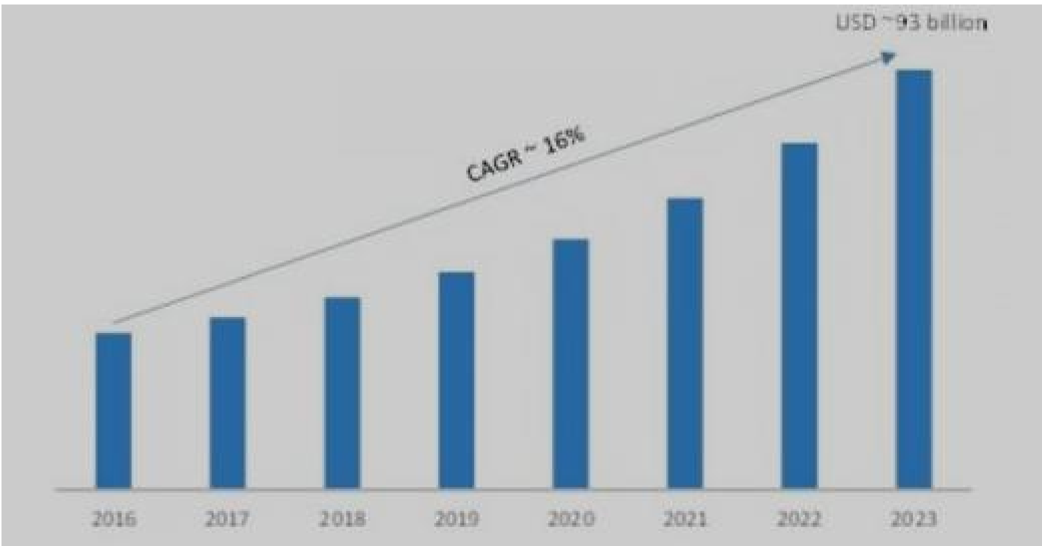


Figure 2.5: Prediction of the robotics market (reuters)

Three different categories of robots such as Soft engineer, hard engineering and services are exists today, based on the way robots work.
Soft engineering: Mainly perform simple tasks inside a human environment. For example Baxter is a robot that can do easy and repetitive task by memorizing its arm movement. These types of robots are useful in the factory for 24/7 tasks. These are cost effective, easily reprogrammed & can operate continuously. It is soft engineer because it is totally safe.

Hard engineering: These types of robot can perform hard tasks and have interconnectivity with other machines. Usually they don’t need human interaction. The Cirris series produce by the company ULC Robotics, are a group of robots that do inspection, repair, and iron joint sealing in gas pipelines. They perform the task which usually needed weeks in just few hours.

Service robots: These robots can perform all non-operational tasks such as surveillance, transportation or helping operators with their duties.

2.5 Customer Access

Digitalization has changed the way the manufacturers produce their products. Today data collected from the users through smartphones, social media & wearable device companies can understand the trend in the market. Customers have more flexibility to customize their products. This digital connection between companies and customer help production to produce objects demanded by current market situation. In this section technologies that link customers and companies will be described and explain.

2.5.1 I4.0 Technologies in customer access

The technologies described below will increase customer access, gather information about trends, needs, and new product development. Even though these technologies will not be applied directly to production but have immense implication on production line.

Social Network

Today we can't imagine a world without social networks like Facebook, Instagram or WhatsApp which are used by millions of users every day. In 2016 Facebook announced that there are 1.71 billion active accounts of which 1.17 billion are daily users (Zephoria, 2017). This is a opportunity for companies to promote & branding through this platforms. Today digital marketing is the best to to reach to potential customers and foster sells and brand image even though it doesn't have any influence in the industrial processing
These social platforms allow companies to have constant feedback about their products. They can see what customer like, don't like or believe in, allowing companies to change their production line based on customer real needs or desires.

Apps & Websites

The main reason Apps and websites technologies are developed is because of smartphones and internet connection. In the industry apps and website have various applications specially in technical support. Apps can easily fix problems from remote. In traditional way when a machine fails, the operator calls the support engineers and they need time to arrive and fix it. But through app the operator can communicate with a customer service platform in which technical support will be given with information about the state of the machine, the problem and how to solve it.

Apps & websites has huge implication also in asset management control. Through sensors machine will be able to communicate and send data to server so that the asset managers can notify the malfunctioning, and take necessary action. For example, the Siemens Industry online support app gives 24/7 technical support to the Siemens machines in such a way that the factory can reduce its downtime.

Finally, consumers with an internet connection will be able to customize their product through an app or website. This information goes directly to the shop floor in the smart factory. This pull approach reduce inventory and improve Just in Time production.

Wearables

Wearables is defined as devices or products that use sensor technology and wireless connection to interexchange information. It is a important part of IoT. Wearables are very effective for remote maintenance in production. These technologies help technician or operators find failure quickly even before it occurs and the production has stopped. Wearable devices, Apps, and sensors are combined in such a way that the sensors send information in real time about their current status. In case if the machine detects any malfunctioning, it would immediately send that information to the data center. From the data center the information is redirected to the apps. This apps or websites will notify the asset managers and technician about the status of the machine and some useful information to plan maintenance. This app will also send notification to the manufacturer of this machine. In figure 2.6 a maintenance operator using a tablet with augmented reality to solve a problem in the factory.

Figure 2.6 : Augmented reality used by BOSCH in engine maintenance

2.6 CONNECTIVITY

Connectivity is the network that links all the equipment's and machines in the factory with each other. In this field telecommunication systems like routers, the wireless device has been improving at a tremendous pace in the last decades (GTAI, 2016). Wifi & broadmand technologies are connecting millions of users. Every minute more devices are connecting to the internet and transferring more data than ever before. The analysis of the technologies that will improve the connection in the industry will be discussed in following.

2.6.1 I4.0 technologies in connectivity

Fixing a machine remotely, transforming digital products into real goods and building a digital factory that simulates the real one are some of the examples that wouldn't be possible without the technologies in the following.

Sensors

Cost effective production of sensors make Industry 4.0 real. Robot & machine can produce data through sensors. CPS collaboration share this data among different machines. Sensors collect information about ambient, temperature, time, pressure and many other important variables of production processes and can send it to all level of the company. Sensors are now key to maintenance and production process. The information given by the sensor alerts the maintenance operators about malfunctioning in the production. The process can be controlled and optimize faster by sensors.

Data Transmission

Data transmission technologies refer to the infrastructure in which data is transfer such as WIFI or Ethernet are the most used systems in which users connect to the internet. But WIFI & Ethernet work for limited amount of devices. For smart factories where thousands of machines & elements are connected other more powerful technologies such as MIMO or MU-MIMO, WiGig, Capacitance coupling, three bands and powerful routers are in use. These technologies keep constant the data transfer rate regardless the number of elements that are connected to the network. For example, WIGiG creates signal frequency that is ten times higher than the regular WIFI. The three band model is the combination of MU-MIMO and WiGiG which will allow smart factories to have many connected devices with a reliable and extremely fast data transfer. If we want to look to recent future, Ericsson is trying to develop Capacitance coupling trough which human body can transfer data from one device to another.

Digital Products

Today customers habit and choice are changing so rapidly that customize production is becoming new trend of manufacturing. Digital product is an innovative and efficient way of making customized products. It in a sense improve quality, customer service and optimizing the process line. Currently car industries are making digital products and some companies like Acer or Huawei are experimenting with this IoT technology for their smartphones.

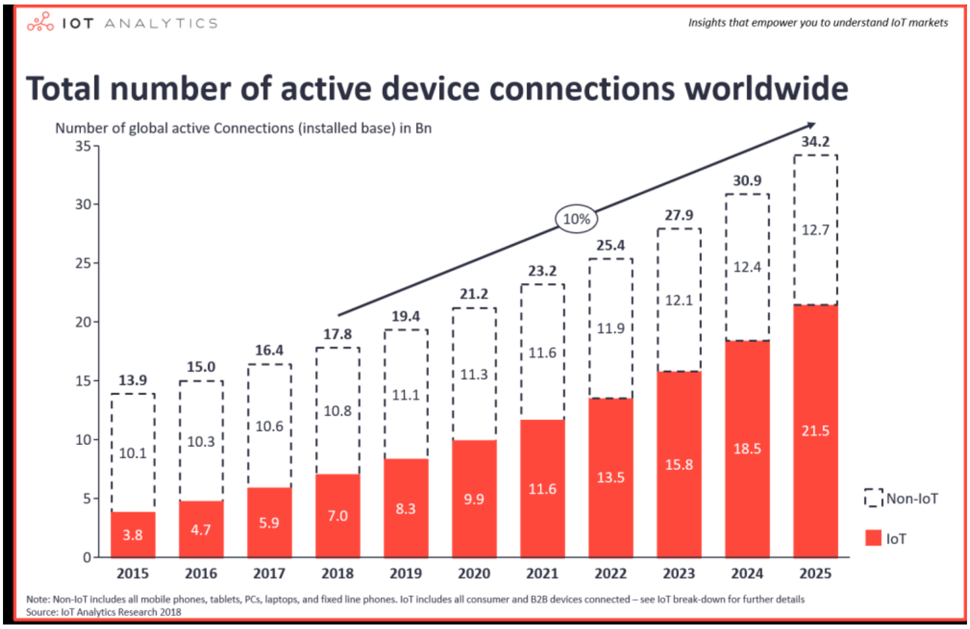


Figure2.7 – Digital products forecast

Faster penetration and tremendous increment of these digital products is shown in figure 2.7.

Cloud Computing

Cloud computing is an innovation technology to store, analyze and communicate information via internet in real time. Today's examples are Dropbox, Google Docs or Yahoo finance. For the industry, cloud computing will be vital because of following reasons:

1. CPS will use cloud computing to communicate to all stakeholder .
2. Through cloud computing platforms data analytics and simulations can be done using the resources and algorithms within it.
3. Cloud computing platforms allow to modify, visualize and share projects and deliverables
4. It improves collaboration between companies through use of data & share knowledge in an efficient manner.
5. It allows factories to store & allocate information in efficient way. Specially data filtering is very important as devices generate huge amount of data which are not important for the company.

2.7 DIGITAL DATA

Data is the core of of I4.0. In figure 2.8, it can be seen how data uses are growing each year.

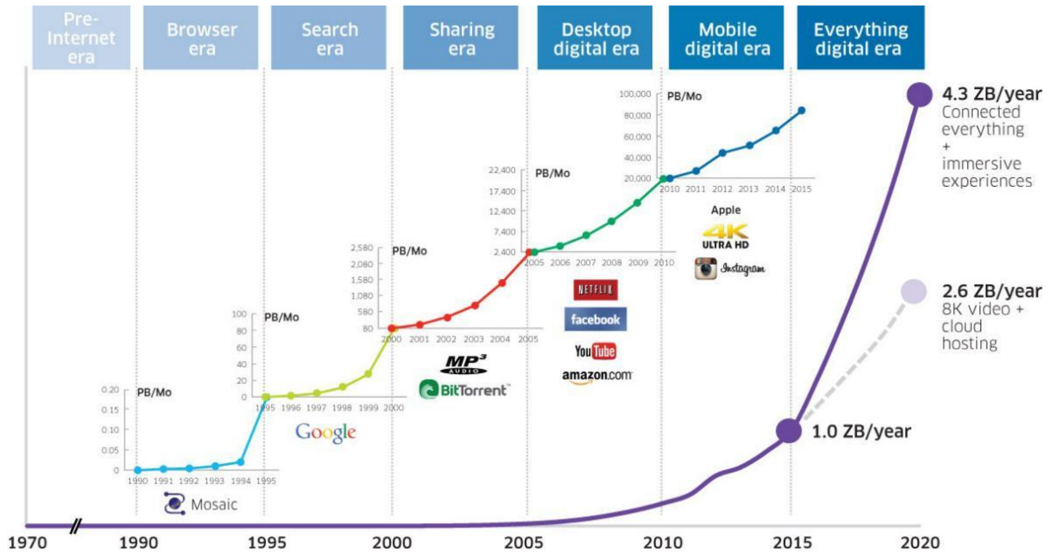


Figure 2.8 – Data forecast for 2020 (Bell labs Consulting, 2016)

Filtering, loading and analyzing of these enormous amount of data is very challenging. The following Industry 4.0 technologies process these data to get meaningful insight.

2.7.1 I4.0 Technologies in Digital Data

Data analysis techniques improve precise decision-making in short time. The following technologies are ways in which smart factories can take advantage data gathered from CPS environment to foster their sales and product quality as customer demands.

Big Data Analytics

The big data analytics (BDA) is a powerful data analysis tool which can deal with huge amount of data can't be compute with traditional computing methods. BDA uses the computing power of multiple virtual machines (Hadoop) to split data and apply categorizing, clustering and predictive algorithms to find trends, errors or other information related to the core business of the company.

There are steps to follow for BDA implementation.

- The first step is to define the data source. Main sources are as follows
  - Emails, post, texts, surveys, interviews, videos and all the digital expressions from humans are People Data.
  - Accounting and finance operations are Transaction Data.
  - Information coming from the websites are Web Data. Clicks, websites visited, time on the site are some standard data information which is useful for digital marketing.
  - All the machine to machine communication produce data that are generated from sensors which is M2M data.

- Eye scanners, finger scanners or DNA readers these security devices generate Biometric Data.

- The second step is extracting, transforming, loading and storing data. This is done by soft wares called ETL (extract, transform and load). Part of the second step is to store data which is done mainly in four different clusters depending on desired outcome. The first group is a key value; which are ways of organizing data like in dictionaries (using keywords or characters). The second is by files in which type of arrangement, data base is semi-structured. Third are relational clusters that make a network of nodes, parameters, attributes and arcs. This type of storage is especially useful for social networks analysis. Fifth is the column-oriented storage which is similar like file type but it's very efficient when each keyword has 100 or more attributes.
- Next step is to analyze data. This is the most important & hardest part of the big data analytics which requires different types of methods depending on the goal and the data. Predicting, categorizing and clustering are most common tools. Association, for instance, is an excellent categorizing analysis in which the user wants to find relations between variables. Data mining is a predictive approach used to predict and forecast behaviors. This procedure uses statistic methods to model and predicts possible scenarios. Clustering is a type of data mining, which purposes is to find a relation between clusters. Text analytics is a categorizing method that has the goal to extract information from documents.
- Finally, the visualization of data analysis result can be done in different ways such as text, graphics or forecasts which help decision making process.

Nowadays, there are different softwares, companies, and consultants that help out companies to solve their problems related to big data analytics. A great advantage of data analysis is that is allowed to reduce uncertainty in the prediction of threats or opportunities

Database Devices & Routing

Storing, transforming and analyzing in big data need speed and capacity which are conditioned by hardware and RAM. The computing power of Processors has been increased immensely in recent years. Another aspect in this database routing is that cloud computing. It allows factories to run rigorous analysis supported by on-demand virtual machines. For example, in the software Azure, the company can decide how many virtual machines they need for the analysis.

Artificial Intelligence (AI)

Artificial intelligence (AI) could be a computer program or machine that learns how to do tasks that require forms of knowledge and are usually done by humans (Russell Stuart J, 2003). In 1955 the Dartmouth project in artificial intelligence identified the seven areas in which a robot or computer program can be considered as AI (Russell Stuart J, 2003).
Some companies have been developing technologies such as Google Deep Mind project which aims to use artificial neurons networks to simulate the human brain.

The impact on the process industry is still not so flourished as AI technology is on the early development face. Moreover there are some ethical questions which need to be solved by scientist and politicians before placing in smart factories. Companies are already starting to look at the impact on different stakeholder of the business to understand its prospect.

3. Industry 4.0 & Lean Manufacturing

Manufacturers have used lean methodology for several decades. It has enhanced productivity at a great level and reduced complexity by standardizing processes, practicing continuous improvement, and empowering workers on the shop floor.

But with the increasing complexity of operations lean management itself is not sufficient to tackle the operational challenges. In this case industry 4.0 with its new digital technologies and approaches can deal with complexity and improving productivity. By using the right combination of technologies, manufacturers can boost speed, efficiency, and coordination and even facilitate self-managing factory operations.

Industry 4.0 will not make Lean obsolete, but the two manufacturing systems will generate a mutual dependency and they have their particular domain of application and combination in product variability and production volume (Sanders et al., 2017).

3.1 LEAN MANUFACTURING OVERVIEW

The term Lean Manufacturing derive from the word 'Lean' which means optimize the process as much as possible & zero waste, so to cut all non value added activities. This means using the lowest amount of resources to gain the highest level of efficiency and quality. The concept of lean manufacturing was fisrt introduced in Toyota Motor by Taiichi Ohno, the father of Toyota Production System. It was the outcome of a trial and error approach for many years, in order to find a way to survive in the mass production competitive environment.

The goals of Lean Manufacturing are customer satisfaction and profitability. Every activity must add value for the creation of the product for final customer. Value is what the customer wants to pay for. Lean methodology focus on customer value and work towards to create a perfect value creation process with minimum wastes. By eliminating wastes along the entire value chain it increase labor efficiency, space, profit and time to market.

Lean identifies seven types of wastes (Muda) connected to wasting of time, money or also resources. Seven types of waste are reported in the following table.

Table 3.1: Seven Types of Wastes (Muda) (Liker, 1996)

Type of Wastes	Description
Handling	Movement of products from a location to another or between operations
Inventory	Stock of finished goods and the work in progress (also raw materials)
Motion	Physical movement of a person while he/she is conducting an operation
Waiting	Waiting time for a product or for a machine to finish
Over-production	Producing more than what the customer asks for
Over-processing	Making operations more than what the customer requires
Defects	Reworked or rejected products due to some process errors

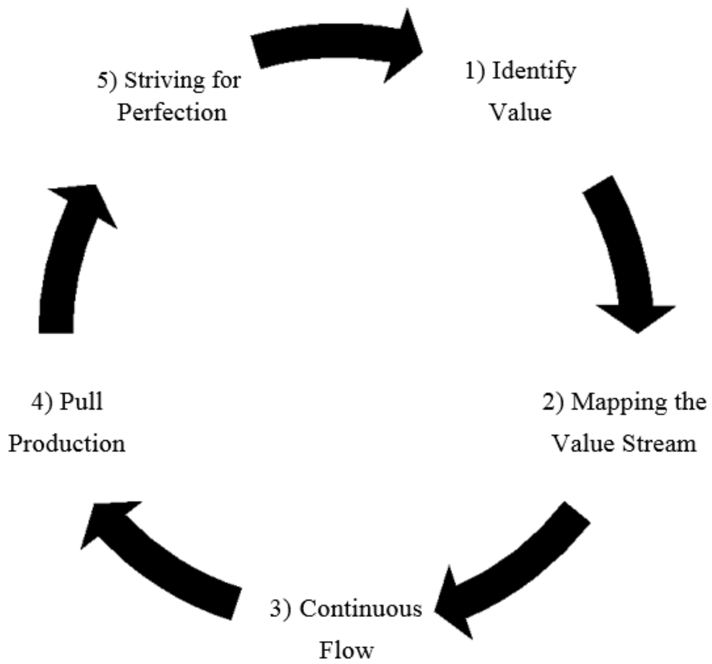
Not only Muda (waste) are critical, but also Mura and Muri must be considered. Mura is the waste of unevenness, which drives Muda. Muri creates over-burden, namely an unnecessary stress given to the employees and the processes: they are caused by Mura , lack of training, failures in the production system or wrong tools.

By preventing and reducing wastes, Lean techniques allow an organization to reach many benefits: an improved quality performance due to fewer defects and pieces reworked both in house and at customer, fewer process breakdown, more involved, empowered and satisfied employees, improved supplier relationships, lower levels of inventory and, consequently, a greater level of stock turnover with less space required. Nevertheless, Lean is not possible to implement overnight. As a matter of fact, it requires that the whole organization is committed and involved.

3.2 LEAN PRINCIPLES

The Three sources of inefficiencies *Muda*, *Mura* and *Muri* can be eliminated through five principles of Lean manufacturing. These are the reference points for process re-organization. These principles are value , identifying the value stream, continuous product flow, pull production and striving for perfection. A brief discussion of each principle is described below.

Figure 3.1: Five cycling actions for Lean implementation (Lean Enterprise Institute, 2016)



3.2.1 Value

In the process of elimination of waste 'value' is the first point. Customer does not pay for inefficiencies in the production process. Value is for what customer wants to pay & it is important to define exactly what is valuable. Companies use tools such as Brainstorming or Quality Function Deployment (QFD) to find out the value-adding activities to eliminate waste. It is necessary to reduce reworking, transporting or waiting time. The mission and the final objective of Lean is listening to the customer in order to understand what they really needs.

3.2.2 Mapping the Value Stream

After knowing what is valuable for customer the next action consists in mapping the Value Stream. Value streaming is all the necessary steps that is needed to tranfrom the raw material into final product. This value stream mapping analysis identify three different possible activities which are value-adding activities, necessary non-value adding activities which needs to be maintained or optimized, and non-value adding activities which creates waste & must be eliminated. Another important aspect of the value stream is that it is analysed from the point of view of the whole product, without looking at individual departments. Mapping the value stream aims at understanding, what effectively adds value for the customer in the process, in order to identify the process time and eliminate all the non-value-adding activities.

3.2.3 Continuous Flow

After value stream mapping when all the waste are eliminated the value added activities must be arranged in a flow without obstacles and interferences. Which is called *one-piece flow*. This flow is achieved using some tools from Kanban. Everything that reduce or stop the flow is a waste, so it has to be identified in order to be removed so the process will be uninterrupted. All shop floor station has to follow the *takt-time* to ensure the demand and time to market.

2.2.4 Pull Production

The inventory is one of the main wastes which hides many other problem and it must be eliminated. Ideally a system should produce only when pulled by the market that means the customer makes the order. Pull production can be establish using Kanban and supermarkets. Kanban is a simple and visible tool that allow to replenish the requested component, of course *called* by the external demand. In the workplace only a minimum stock level is left, and before its depletion, an instruction on the Kanban-card carried out by the operator assures a *just-in-time* replenishment. Just-in-Time means that the worker finds the right product, at right amount, at the right place, at the right time.

3.2.5 Striving for Perfection

Eliminating all the waste in the first four steps it is necessary to continue this process of perfect production. The Kaizen is the key to that. Kaizen is more an attitude than a implementation tool. Kaizen has to follow at all hierarchy of the organization, from top management to worker. A collaborative and participative environment has to be established using every ones competences & involvement in this continuous improvement process.

Achieving perfection is actually impossible. Kaizen needs a strong engineering during the planning phase and an excellent level of control over the process. It starts from the standardization of activities and processes, measures them & initiate improvement plan.

3.3 I4.0: LEAN'S NEXT LEVEL

Sanders et al. (2016) and Kolberg et al. (2017) believe that I4.0 is here because lean production can't keep up. Lean production is facing challenges as customer needs are becoming more and more complex and personalized. It is heard that I4.0 will make lean obsolete. This is due to the fact that Lean often reduced to the concept of Kaizen and the elimination of wastes. For this simplification of Lean concept this is thought that lean does not cope with the highly automated Industry 4.0 initiative.

As a matter of fact, Industry 4.0 will not make Lean obsolete, but the two manufacturing systems will generate a mutual dependency and they have their particular domain of application and combination in product variability and production volume (Sanders et al., 2017). Actually, Lean is much more than waste elimination.

Nowadays, the combination of Lean & I4.0 (lean 4.0) is essential to foster productivity. Lean can be consider as a prerequisite of Industry 4.0 since it is always important to consider and use Lean practices before automating a process to avoid costs and wastes. In this sense, the idea that Industry 4.0 will not materialize as a real revolution, but in different parts that have to be integrated into a Lean framework, is widespread in literature (Ruttimann et al., 2016; Kolberg et al., 2015; Synnes et al., 2016).

Sensors, virtual and augmented reality, AI are powerful tools, that need the correct context and domain of application in order to be exploited effectively. In other words, integrating the CPPS in Lean factory is a key challenge: it improves Lean production, making it more flexible but Lean still remains a prerequisite. Therefore, it is possible to assume that there is a mutual dependency relationship.

> *"Industry 4.0 technologies may be exactly what we need in order to create Lean supply chains and networks"*
>
> (Netland, 2015)

Lean will not fade with Industry 4.0, in particular, digital revolution can incorporate Lean. In fact, the Fourth Industrial Revolution may permit to generate the true Lean Enterprise. I4.0 allows a much deeper understanding of the customer demand and at the same time the immediate sharing of the demand data throughout complex supply chains and networks. For example, Lean with the help of I.40 technologies would be able to share real-time information in a coordinated end-to-end supply chain which will improve just-in-time production.

The current literature seems to believe that Lean management could be the most suitable strategy for a digital transformation. Industry 4.0 will allow companies to establish lean in more efficient way. For example, IoT allows to gather enormous amount of data through RFID devices or sensors & share among machines, their fundamental analysis available in Cloud lead to machines operating in full synchronization, often without the necessity for any human intervention. Value Stream Mapping that may become automatic through the usage of IoT.

Big Data is the driving force towards improvement projects especially product oriented ones (Ge and Jackson, 2018) .This role can only be achieved if talents specialized in digitalization are acquired (Chang and Yeh, 2018).

Improvements in data collection, sensors, 3-D printing, robotics will enable advanced analytics, providing a new era for established and proven methods as Lean Manufacturing. In addition, organizations will use these reinforced Lean practices to introduce a new way of working for three strategic dimensions: technical systems (processes and tools), management systems and people in terms of capabilities, skills and behavior. In this unavoidable evolution, a core role will be assumed by data, IT and connectivity that will become new value drivers. The interaction between the two paradigms reveal many opportunities for achieving synergies, leading to a prosperous implementation of future interconnected Smart Factories (Sanders et al., 2017). Industry 4.0 can be considered as a natural evolution of Lean principles.

Industry 4.0 can be thought as digitally enabled Lean (Behrendt et al., 2017). In fact sensors, more data and advanced analytics will boost the capability to solve problems and foster improvement measures for achieving higher productivity. There are few companies that are so Lean that they are completely free from wastes. Industry 4.0 can be able to optimize the value-adding areas in order to reduce wastes in the system. It would be possible just if all the products and processes are coordinated and aligned. It is visible that the implications of Industry 4.0 for the management of Lean Equipment through TPM. Industry 4.0 allows the exploitation of real time data via web-based applications, coming from machine monitoring systems in order to provide continuous feedback which helps to achieve zero breakdown goal.

Considering all this aspects, Industry 4.0 can be considered as “Lean’s next level”.

3.3 COMPATIBILITY OF LEAN & INDUSTRY 4.0

Here below a table is demonstrated showing lean tools supported by industry 4.0 technologies. (Anna C.; Anabela C.; Josè D; Pedro M. 2019)

Table 3.2 Lean tools supported by industry 4.0 technologies (Anna C.; Anabela C.; Josè D; Pedro M. 2019)

Lean Practices	Industry 4.0 Technologies									
							Other Referred Technologies			
	CPS	IoT and IIoT	Big Data and Data Analytics	Cloud	VR and AR	Robotics	3D Printing	Simulation	Video-based and 3D Models	Optimization Algorithms
VSM			x		x			x		
Standard work	x		x	x		x			x	x
Continuous improvement and wastes elimination	x	x	x	x	x	x	x	x	x	x
Andon	x									
Heijunka and production planning	x	x						x		x
Pull production	x						x			
Jidoka / Autonomation	x					x				
Kanban	x							x		
JIT	x	x					x	x		
Supermarket	x									
Milk run										x
Problem-solving and decision support	x	x	x	x	x					x
KPI	x		x					x	x	
Empowerment and involvement of workers			x							
Improved human factors					x		x			
Six Sigma	x	x	x							
TPM	x			x						
Communication and Information sharing	x	x	x	x	x	x		x	x	
Decreased operation and waiting times	x		x	x		x	x			
Decreased stocks and inventory management	x		x	x			x	x		
Increased flexibility	x		x			x		x		x

Satoglu et al. (2017) matched the typical seven Lean wastes with advanced Industry 4.0 technologies. It shows that Lean manufacturing and Industry 4.0 are not mutually exclusive; rather, “they can be seamlessly integrated with each other for successful production management” (Satoglu et al., 2017).

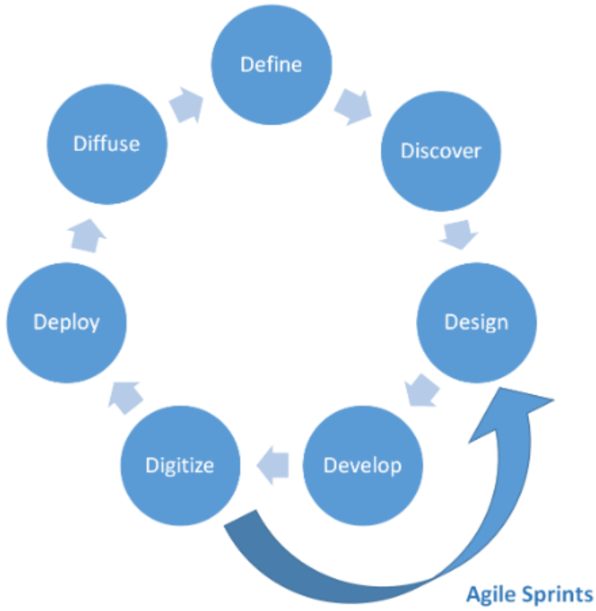
Table 3.3: Comparisons of Seven Lean Wastes and Industry 4.0 Technologies (Satoglu et al., 2017)

	Additive Manufacturing (3-D Printing)	Augmented Reality	Simulation & Virtualization	Adaptive Robotics	IoT	Data Analytics	Cloud Computing
Transportation		√	√	√		√	
Motion		√		√			√
Waiting	√		√	√	√	√	√
Inventory	√				√	√	
Unnecessary Processing	√		√	√			√
Overproduction	√				√	√	
Defectives	√	√	√	√	√	√	

According to a Lean perspective, the manufacturing layout should be converted into a Cellular manufacturing system. Besides Industry 4.0 can further reduce wastes by employing Adaptive Robotics for an enhanced parts loading-unloading and material handling. Satoglu et al. (2017) confirms the idea that Industry 4.0 Smart Technologies should be applied to "Lean activities performed successfully before automatization", validating the concept that Industry 4.0 and Lean manufacturing mutually dependent.

VSM is an excellent tool for mapping and analyzing the manufacturing process. It must be upgraded according to digitalization to improve existing operations. Lean principles and Digital Manufacturing can be integrated in I.40 VSM by analyzing huge amount of data gathered which helps to make better decision. Lean & I4.0 will complement each other, particularly the data analysis through I.40 technology will improve Lean implementation.
In this era of global competition companied have to be robust. Nicoletti (2015) in his article "Optimizing Innovation with the Lean and Digitize Innovation Process" explains how to combine Lean and Digitization to achieve a higher innovation rate, stressing the idea that this integration would lead to a greater processes improvement. As a matter of fact, the new method called 7 Ds (i.e. Define, Discover, Design, Develop, Digitize, Deploy and Diffusion) aims at adding value to customers, improving effectiveness and eliminating waste. It was investigated in several successful business cases demonstrated that Lean principles can be optimized by the use of Information technology system.

Figure 3.2: The Lean and Digitize Innovation process and its seven stages, or "the 7 Ds" (Nicoletti 2015)



It would conclude that I4.0 will support Lean production to make the manufacturing process efficient and time effective with minimum waste than competitors.

3.4.1 Lean & I4.0 Two Way Interaction Matrix

To better understand the mutuality & the evolution from Lean Manufacturing to Industry 4.0 Sanders et al. (2017) have shown a two way interaction matrix. The basic concept in building this matrix is to develop an individual two-way interaction where each interaction is rated between LM tools and I4.0 design principles. Individual rating in each cell signifies the supporting and hindering effects of Industry 4.0 design principles on LM tools in the matrix. The support that each LM tool offers to Industry 4.0 is not rated but the basic lean elements for implementing Industry 4.0 are highlighted.
Based on the TPS-House, for the construction of two way interaction matrix 14 LM tools are identified as indicated below.

Kaizen	Takt time
Total Productive Maintenance (TPM)	Value Stream Mapping (VSM)
Standardization	Heijunka (Production Smoothing)
Forms of wastes (Muda)	Autonomation
5S (sort, set in order, shine, standardize, sustain)	Andon (Visual Control)
Total Quality Management (TQM)	Poka Yoke
Kanban (JIT/Pull)	Single Minute Exchange of Dies (SMED)

Lean management tools

Six design principles are derived from independent Industry 4.0 components (CPS, IoT, IoS, Smart Factory) by means of extensive literature review to identify the central aspects of Industry 4.0

Real-Time Capability	Decentralization
Modularity	Interoperability
Service Orientation (SOA and IoS)	Virtualization

Design principles of Industry 4.0

The interdependence matrix can be formed with these lean and Industry 4.0 design principles by inserting the LM tools in vertical direction and Industry 4.0 principles in the horizontal direction (Figure 3.3). Each Industry 4.0 design principle has a benefiting effect, hindering effect or no effect on each of the LM tools. These effects are represented with scores ranging from 10 to −10.

Basically the interdependence matrix demonstrate a two-way interaction between LM and Industry 4.0 principles

- To what extent the Industry 4.0 design principles are supporting LM tools
- The basic LM tools which assist Industry 4.0 implementation (no scoring, colored blue).

The beneficiary coefficient implies the extent to which each single LM tool getting benefitted from the Industry 4.0 design principles. The calculation is done by summing up the scores for each interaction and dividing it by the total number of Industry 4.0 design principles.

Figure 3.3: Two way interaction matrix Sanders et al. (2017)

Lean Management Tools	Beneficiary Coefficient	Industry 4.0 Design Principles: Real-Time Capability	Decentralization	Modularity	Interoperability	Service Orientation (SoA and IoS)	Virtualization
Supporting Coefficient		6.6	6.1	3.1	6.2	4.7	6.1
Kaizen (PDCA)	5.3	10	5	0	10	0	7
TPM	9.5	10	10	7	10	10	10
Standardization	2.8	5	0	0	7	0	5
Forms of wastes	7.3	10	10	7	5	5	7
5S	2.5	5	7	0	3	0	0
TQM	4.7	7	7	0	7	0	7
Kanban (JIT/Pull)	7.0	10	10	5	10	0	7
Takt Time	-8.0	-7	-10	-10	-7	-7	-7
Value Stream Mapping	4.7	10	5	0	3	0	10
Heijunka (Smoothing)	7.7	10	7	5	7	10	7
Autonomation	7.0	5	10	3	10	7	7
Andon	4.0	5	7	0	5	0	7
Poka Yoke	4.7	3	8	3	7	0	7
SMED	6.0	10	3	5	10	3	5

Legend	Basic Lean Tools for Industry 4.0

Value	10	7	5	3	0	-3	-6	-7	-10
Degree of Influence	Full support	High support	Moderate support	Limited support	No impact/neutral	Limited hindrance	Moderate hindrance	High hindrance	Full hindrance
Range	9.1 to 10.0	8.1 to 9.0	3.1 to 8.0	0.1 to 3.0	0	-0.1 to -3.0	-3.1 to -8.0	-8.1 to -9.0	-9.1 to -10.0

On the other hand, supporting coefficients imply the degree of support that each Industry 4.0 design principle gives to all the LM tools. It is calculated by summing up all the values except for the fields which have no impact and dividing it by the total number of LM tools that has a score value other than 0. This is done to negate the neutral effect of LM tools on the overall score.

The blue cells signifies that they are the basic lean elements that serve as a foundation and support successful implementation of Industry 4.0.

It is clear that Takt time has the most hindrance effect. This signifies that in future smart factories the concept of takt time will be eliminated.

TPM had benefited the most from the I4.0 design principles with a score of 9.5. Since these two LM tools are lying at the opposite extremes on the scoring scale, they are considered for detailed explanation in the following. With regard to supporting coefficient, real-time capability is offering the highest support to the LM tools with a score of 6.8. Rest of the Industry 4.0 design principles are offering high to moderate support. The other way interaction (LM tools that support Industry 4.0 design principles) is highlighted in blue. It indicates the basic LM tools which are essential for successful implementation of Industry 4.0.

3.3.2 Interaction of TPM with Industry 4.0 Design Principles

It is shown in the interaction matrix that TPM receives excellent support from all the I4.0 design principles.
TPM will function more effectively in the future smart factory with assistance from Industry 4.0 techniques. The interaction of TPM and real-time capability has a score of 10 due to the fact that machine and plant conditions can be monitored in real time (e.g. energy consumption, machine breakdowns, output quality, OEE). Failure patterns can be predicted in advance and concerned personnel can be notified by means of intelligent algorithms.

Maintenance activities can be performed by augmented reality and interactive 3D trouble-shooting guidelines on smart devices. On account of such highly decentralized activities, the interaction of TPM and decentralization was awarded with a score of 10. In case of a bigger malfunction, others machines can be contacted via M2M to find their availability for taking over the workload. Alternatively, the service availability of CPS and CPPS devices in other plants can also be verified via IoS to transfer the production orders to other units. After rectification, the solution is stored into the cloud. This along with failure pattern can be communicated with other machines which can then learn the mistake and prevent it from happening again. TPM highly benefits from interoperability and service orientation principles that the score of 10 is awarded. The new spare part can be printed using 3D printer If a failure demands a part to be replaced. Parts of the machines are made modular for easy plug and play changeover, which enables maintenance replacement of the newly manufactured part. Which often do not include parts which are more complex and require precise machining. So a score of 7 is given to the TPM and modularity interaction. CPS and CPPS devices perform data collection (e.g. tool wear) and data analysis. After that the data is compared with the stored standard reference models, historical performance data and performance data of other machines in the cloud to determine the current operating state. Thus TPM and virtualization interaction is granted with a score of 10. TPM tool will serve as an important enabler for successful functioning of a connected industry.

3.3.3 Interaction of Takt Time with Industry 4.0 Design Principles

Takt time has the lowest (negative) score with I4.0 design principles. It ranges from high to full hindrance.

Decentralization has a full hindrance score of −10 owing to the fact that decision about production planning, takt time calculation is made centrally with the help of forecasted demand and product variants. So immediate and fast orders cannot be easily meet into the production with fixed takt time. Which is contradictory to the Industry 4.0 objective of decentralization and autonomy.

As production schedules, product variants and the takt time are fixed, modularity also cannot be implemented. Rapid or sudden demand fluctuations cannot be accommodated into the production line which is a complete hindrance. Data collected from the physical process cannot be used for implementing an immediate change in the production of successive products owing to limited flexibility, variants and output. Modifications can be implemented only during the next production cycle.

All these reasons above, a high hindrance (score of −7) is assigned to their interactions with takt time.

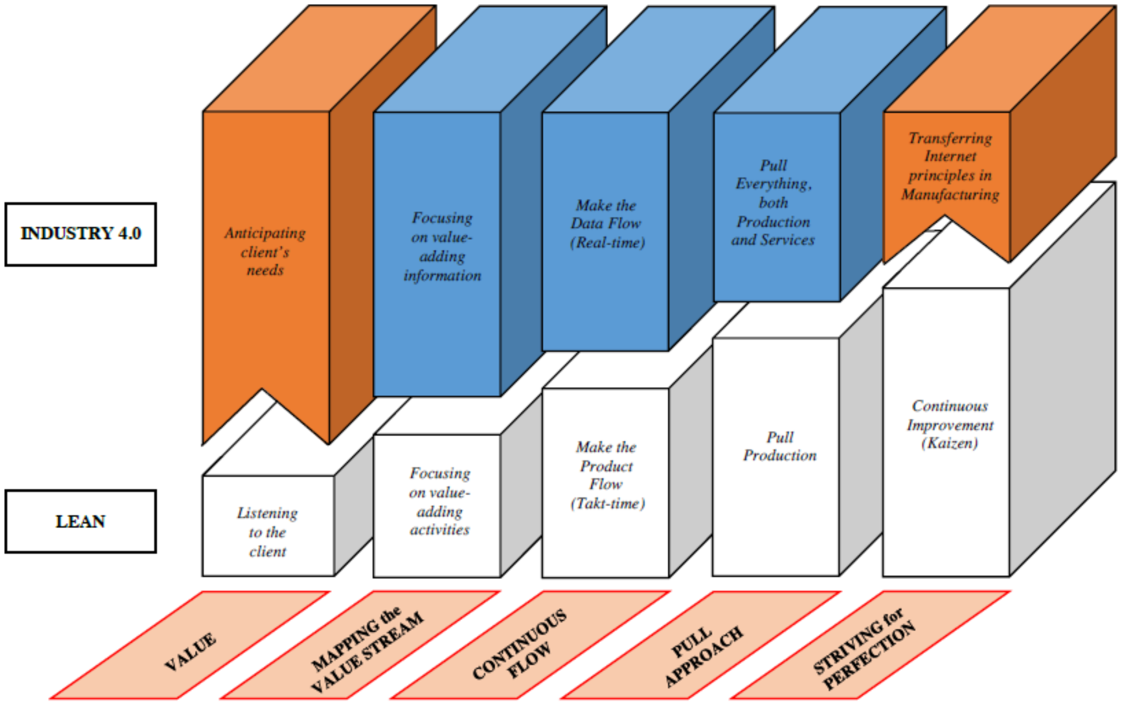
3.3.4 Basic Lean Elements for Industry 4.0 Implementation

Some of the Lean manufacturing tools interactions might have scored less with regard to the beneficiary coefficient but these tools in turn assist successful implementation and functioning of Industry 4.0 such as muda (waste).

It is very much essential, that most of the waste in the factory and entire business process must be removed before digitalization. Standardization is also equally important for achieving modularity and interoperability as all the CPS and CPPS devices in a smart factory should have a standard protocol (e.g. OPC UA) for communication. To enable Plug&Play principle for flexible interchanging machine modules different manufacturers of the module should adopt standards for integration. It is important for virtualization to maintain consistent data standards for further processing. Likewise, SMED assists Industry 4.0's target of reduced batch sizes for achieving a lot size of one by reducing the setup time. The value streamed data is fed into cloud and machines access it continuously via IoT. The present status of value stream is monitored and if there are any discrepancies, it reacts independently to solve the problem without central control.

3.5 Relation Between Five Principles of Lean & I4.0

Corporations are looking for potential connection with deeply rooted industrial philosophy like lean manufacturing with Industry 4.0. A normative model can be structured starting from the five principles of Lean Manufacturing. For each Lean principle it is required to understand the meaning behind it and how lean staisisfy it then the focus was shifted to industry 4.0.
A comparison has been tried to find how industry 4.0 would have dealt with the five principles of Lean either in sustaining perspective (malavasi schenetti, thesis, 2017). Industry 4.0 help Lean answering the same needs, there are also some points which are different, more disruptive way comparing the traditional lean paradigm.



Value

Customer first is the main moto of Lean. The Starting point of lean is value for customer. In lean manufacturing approach manufacturer has to create value for customer in a robust & faster process than competitors. This could be achieved by carefully listening to the customer and establishing robust relationship. 'The voice of customer' is the driver for value generation. In Industry 4.0 approach the process of value generation is achieved by anticipating what customer wants.
'Proactivity' is the keyword related to value in Industry 4.0. A proactive approach refers to an anticipatory in advance of a future situation. It is basically understanding in advance the future desires of the customers, in order to offer proactively valuable solutions to them.
In the era of industry 4.0 Big Data, Cloud and Internet of Things can really give the opportunity to know better the clients need by not only listening to them more precisely, but also understanding the market trends. What it is need is to analyze and interpret correctly the information contained on Data.
During last years, it has emerged a new methodology for American digital start-ups, called lean start-up, which is closed to the concept of proactivity. It uses customers feedback to support product or service creators. Through Big Data and real-time information, which are shared by customers with different sources (such as IT systems and Smart interconnected Products) the company will be able to predict their future request, disclosing new trends and arriving faster to the market. Instead of listening and participating with the final customer in the value creation process, the company will be able to know earlier what the customer will expect from the market or what he actually needs. This approach open the horizon for a new scenario, introducing a new disruptive way of creating value for the customers.

Mapping the Value Stream

Industry 4.0 supports Lean in accomplishing Value stream mapping, pull production and continuous flow by improving the situation through digitization. The second Lean principle refers to the importance of understanding and mapping the Value Stream. Once defined what is actually valuable for the customers, it is necessary to map the situation in order to make the value-adding activities, whereas the wastes have to be eliminated.

Muda, Mura and Muri are the obstacles for the manufacturer. It is essential to focus only on those activities that customer is willing to pay for. Otherwise, there will be extra-cost for the company, which cannot be requested to customers. Customers do not want to pay for inefficiencies of the system.

In industry 4.0 based on IoT, Big Data and Analytics, the focus will move from physical elements to data and information. In digitization data is the core, and so Lean principle of value-adding activities has to be converted in value-adding information.

Physical elements of the factory generate information which are spread around the digital environment. This information needs to be filtered to understand which could be used to create value for the customers. In this way, the value creation is done by those data that, once analyzed properly, could provide beneficial solutions for customers, without wastes. Industry 4.0 needs competences in identifying, managing and analysing data to create value for business processes. In fact, Data is collected everywhere, but it has to be filtered in order to have the correct information to support the right decision.

Value-adding information is essential to control and further improve the process. So it is the data which if gathered and filtered properly, the decision-making process will be fastened.

Therefore, it is possible to assume that Industry 4.0, through Smart Technologies, is an enabler of Lean since it allows not only to identify value-adding activities, but also value- adding information, that are valuable for companies in the decision-making process. Industry 4.0 supports value stream mapping, focusing to Data. The concept will remain the same, there will be only a transposition from physical to digital environment, based on Data.

Continuous Flow

In Lean manufacturing, once eliminated all those activities that to do not create value, the remaining ones must be arranged in a flow. The term ‘flow’ means the process has to be carried out without obstacles. Obstacles during the process means the wastes, the enemies of Lean. Continuous one-piece flow is the ideal arrangement of a Lean process.

The concept of a continuous flow is key in Lean philosophy that means the production must follow cycle time to fulfill customer demand. Industry 4.0 does not talk about physical entities; in turn, the focus will be on data: those value-adding information.

Make the Data Stream flow is the new, sustaining way to support Lean; at the same time, the concept of cycle time will evolve into real-time. Data and information will flow & shared around digital environment exactly at the same instant in which they are generated. With the increasing importance given to the information and data flow, Digitization will allow the complete traceability of the production. It will be possible to control and monitor the state of each component along the whole supply chain every time and everywhere. In other words, it is necessary not only to make the product but also the Data stream flow. Beside a physical flow managed by cycle-time logic, there will be a flow of data, derived by IT and factory systems, which will become valuable when managed in a continuous flow and possible to analyze in real-time.

Pull Approach

Once the activities are organized in a continuous flow, it is necessary to produce without forgetting the first key principle: the value for the customers. In doing so, the production has to be pulled exactly by the customers demand. It means when all the wastes and the interruptions are cancelled out and the process is carried out as a continuous flow, the final objective is producing only what the customer wants and at the time he wants. So, production is pulled by the customer.

In industry 4.0 the concept of pull production will evolve in the verbal expression of pull everything, where everything means exactly more than a simple physical product. What Industry 4.0 is trying to sell is more than a manufactured element. Today market trends are much closer to mass customization and service-orientation. So it is important to offer together with the product all the services related to it in order to increase the service level and customer satisfaction. In this sense pulling everything signifies pulling both production and services related.

In Industry 4.0, the pull production could be seen as the evolution of an old concept, production-based, to an enlarged service-oriented one.

In Industry 4.0 approach products are always associated to their related services and sold as if they were a unique entity. Industry 4.0 can enable the design and engineering of services based on knowledge generated through data analysis, can be used to create services that add value to the customer. Therefore, companies develop products with value-adding services, providing their customers with services that are needed. In this new business environment, "the market goal of manufacturers is not one-time product selling, but continuous profit from customers by total service solution, which can satisfy unmet customers' needs" (Lee et al., 2014). For instance, the diffusion of Industry 4.0 in manufacturing allows setting up a secure remote access to distributed assets, improving the maintenance support and creating new services associated to a product. Every time and everywhere, data coming from customers' products can be analyzed, providing them with promptly value-adding information. One great example is predictive maintenance: through a secure connection, data are collected from machines, analyzed and used to detect errors and possible failures at an early stage. Problems can be remotely identified, communicated to customers and correct, decreasing drastically the reaction time.

In this new ecosystem, customers will tend to give value more to all the services associated to a product than to product itself, pulling everything. Obviously, this actually can be considered a sustaining evolution.

Striving for Perfection

Lean strives every day for perfection by continuous improvement attitude, Kaizen. The performance of the processes is continuously improved and further wastes eliminated through Kaizen which is more an attitude than an implementation tool.

Continuous improvement means facing and solving problems every day, in a never-ending process of value creation. Everything is done in order to eliminate inefficiencies and wastes in the process, generating a continuous flow pulled by the customer. Every member of the firm from any hierarchy needs a change of mind-set, according to which this attitude for continuously trying to strive for perfection, step-by-step, is instilled and put into practice every day, in each performed activity.

With Industry 4.0, there is no more a focus on daily incremental improvements. Digital factory will be built upon the bedrock of CPS, providing disruptive innovations in Smart Factories of the future. Therefore, the concept of incremental and continuous improvement, owned by Kaizen, will be radically

overtaken. It was taken as a reference point the study of Hermann regarding the design principles of Industry 4.0 (Hermann et al., 2015) to define what could be those Internet principles to be transferred into manufacturing industry. They are identified as interoperability, virtualization, decentralization, real-time capability, service orientation and modularity. To be more precise, interoperability refers to an ecosystem in which all the elements within the plant (workpiece carriers, products and assembly stations, namely the Cyber Physical Systems) are able to communicate through open nets and semantic descriptions. Virtualization means that these elements described above in brackets are able to monitor physical processes remotely, creating a virtual copy (cf. digital twin) of the physical world.
Decentralization, in the context of Smart Factory, means that central planning and controlling is no longer needed (Schlick et al., 2014), because embedded computers enable these CPS to take decisions on their own. Real-time capability refers to data collection and analysis process already explained, which is performed in real-time. Service-orientation means that all the factory is based on a Service-oriented Architecture (SoA), according to which the services of companies, CPS and humans can be accessible and be used by other parties.

As previously mentioned for the first principle, also for this aspect an element of disruption emerges. In fact, the traditional Lean aspiration (i.e. striving for perfection) is based on Kaizen, which fosters obsessively incremental improvements every day. Therefore, Lean paradigm can be considered as totally unable to trigger radical innovations, since it is based on the idea of pursuing continuous improvements through a persistent, cyclical and committed effort. Conversely, Industry 4.0 has in its DNA a seed of radicalism; it embraces lateral and abstract thought in order to apply Smart Technologies and Solutions already successful in the Internet world (e.g. the above- mentioned principles) into manufacturing one, leading to disruptive innovations. With Industry 4.0, new business and entrepreneurial models are created, together with new products and services. To conclude, Industry 4.0 will modify radically the high-level principles (the first and the fifth) towards a digital perspective.

3.6 Lean Pillars & I4.0 in a Sustaining Perspective

To analyze the foundations and pillars of Lean paradigm towards a digital viewpoint it was decided to consider the House of Lean proposed by Liker (Liker, 2004), composed by foundations, pillars and a roof. The purpose was to find Industry 4.0 aspects related to Lean pillars and foundation in a sustaining way.
Sustaining means that a particular tool or technique of Industry 4.0 is in line with a certain Lean pillar or foundation element, and it simply reinforces it leveraging on current technologies.
The table 3.5 below For each pillar or foundation, a sustaining element for Industry 4.0 was found.

Table 3.5: Lean and Industry 4.0 in a *Sustaining* perspective

Lean Pillar/Foundation	**Sustaining I4.0**
Stable and Standardized Processes	Interoperability
Visual Management	HMI
Just in Time	Cloud Computing
Jidoka	Advanced Automation
Waste Reduction	IoT and Data Analytics

3.6.1 Stable and Standardized Processes

A stable process is necessary in order to achieve high level of digitization. It has been identified the concept of interoperability as the sustaining element between Lean and Industry 4.0.

"Interoperability is the ability of multiple systems with different hardware and software platforms, data structures, and interfaces to exchange data with minimal loss of content and functionality"

(NISO, 2004)

"The compatibility of two or more systems such that they can exchange information and data and can use the exchanged information and data without any special manipulation"

(Taylor, 2004)

So, Interoperability is the capability of an IT system to co-operate and exchange information or service with other systems, products or machines, with reliability and optimized resources. Today, customer requirements are based on a high product variability and short time to market, meaning that the production structure must be robust and flexible. Therefore, modular factory structures made of Smart Devices are necessary to overcome a rigid production process. The only way to guarantee the success of highly modular factory structures is the creation of coordinated and standardized actions between the main technology providers, integrators and end-users, by allowing the interoperability of automation technology (Weyer et al., 2015). Interoperability is for sure one of the most important aspect of Industry 4.0. It allows to overcome some traditional limitations like local-only-accessible dashboards or constraints related to scalability.

In order to highlight the importance of Interoperability, in 2015 McKinsey concluded that "The ability of IoT devices and systems to work together is critical for realizing the full value of IoT applications; without interoperability at least 40% of potential benefits cannot be realised. Adopting open standards is one way to accomplish interoperability" (McKinsey Global Institute, 2015).

Modularity is another concept that is strongly in line with Lean thinking. As Lean wants to subdivide the process in subgroups of activities easily manageable, Internet environment is built up on web modules strongly related and interconnected within each other.

Basically, the Lean philosophy attributes to standardization the merit of ensuring improvements. Standardized work consists of takt-time, the precise work sequence in which tasks have to be performed within the takt-time and the standard inventory needed to keep the process operating smoothly (SWIP). "Standardized work is far easier, cheaper, and faster to manage. It becomes increasingly easy to see the wastes of missing parts or defects" (Liker, 2004). Many documents are there to guide companies in defining and standardizing processes. Two of which documents that are common and easy to be found in production area are the Standardized Work Chart, that combine all the job elements into an effective work sequence, and Quality Check Sheets, to define the quality actions that must be performed by team members.

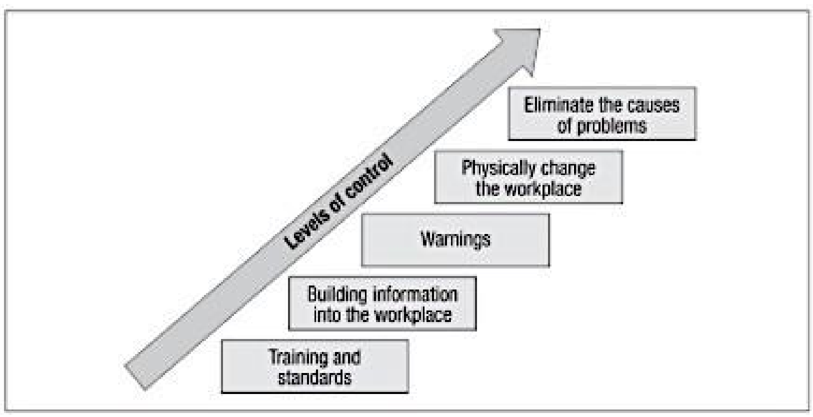
Interoperability, looking at Industry 4.0 perspective, brings with it new standards. It is considered vital across many companies since it enables businesses to catch benefits of a new technology. A real example could be Anypoint Platform by Mulesoft that helps companies to create integration and interconnection across different entities. Through a robust set of solutions, this powerful platform helps businesses creating interoperability between systems, software and applications.

3.6.2 Visual Management

To eliminate wastes and defects in Lean manufacturing everything into the shop floor must be easy to visualize during production or assembly process. In this perspective HMI (Human Machine Interface) will be a sustaining aspect for Industry 4.0 which will digitize the traditional visual management signals within the shop floor.
It is a foundation of lean manufacturing that the workplace has to be well organized and signalized to make evident each waste or defect. And it has to be standardized, without possible subjective interpretations. Through visual management, workers should have immediately the information they need. Human Machine Interface could be considered as enabler to improve Visual management practices, thereby to support them. HMI is one of the technology pillar of Industry 4.0.

On the shop floor, the main purpose of visual management should be "to give people control over the work-place" (Tapping et al., 2002; Liker, 2004). There are different levels of control that apply, as the Figure 3.6 below shows

Figure 3.6: Levels of Control (Tapping et al., 2002)



According to this, HMI will improve Visual management techniques since everything into the factory will become more visible. Starting from training process, HMI comprehends the concepts of Augmented Reality (AR) and Virtual Reality (VR). Augmented Reality allows to create an interactive combination between the real word and a computer generated world, into one seamless environment. On the other hand, VR could be defined as "a way for humans to visualise, manipulate and interact with computers and extremely complex data" (Isdale, 1998). Exploiting these technologies, an operator will be able to make training sessions for example in front of a virtual machine, simply wearing a pair of Smart Glasses. "HMI, in its simplest terms, includes any device or software that allows you to interact with a machine" (Beilke, 2015). So, these new technologies can improve the traditional Visual Management by translating the traditional techniques in a digital way.

Kanban is an integral part of Visual management. It means sign board. In an Industry 4.0 ecosystem, the traditional Kanban system becomes an Electronic Kanban system, in which all cards are electronic. In a manual Kanban system, if the card gets lost or duplicated, an issue will arise. Moreover, the signal does not get triggered until the physical card reaches the next point. Companies are increasingly adopting e-Kanban systems, in which an Electronic Kanban software can be installed on every digital device, fostering a more intuitively and paperless way of working. Electronic Kanban can be considered as an evolution of Lean Kanban cards. Conventionally, each card issued visually communicates important information and details about the order; an e-Kanban allows managers to keep track of production from any location where computer access is available, extending the set of data and details visually and instantly provided.

To conclude, it is possible to assume that Advanced HMI represents a sustaining aspect compared to Lean Manufacturing, since it will help in the process of making the whole factory more visible.

3.6.3 Just in Time

Just in time (JIT) is the second Lean pillar; JIT philosophy advocates: "producing and/or delivering only the necessary parts, within the necessary time in the necessary quantity using the minimum necessary resources" (Liker, 2004). The main goal is to improve productivity by eliminating wastes & inconsistencies. JIT is supported through Industry 4.0 by 'Cloud Computing' which will do a step-forward from JIT production to JIT information. Cloud computing, in which resources "are provided as general utilities that can be leased and released by users through the Internet in an on-demand fashion" (Zhang et al., 2010). A proper definition of cloud computing could be the one coined by The National Institute of Standards Technology.

Cloud Computing is characterized by several features, different from traditional service computing. First of all, services owned by multiple providers are located together in a single data center and the infrastructure provider makes available a pool of computing resources that can be easily assigned to different resource consumers. Moreover, any device with Internet connectivity is able to access cloud services. One of the key characteristics of cloud computing is that "computing resources can be obtained and released on the fly" (Zhang et al., 2010). This is the main reason why it is possible to consider Cloud Computing as a Lean supporting aspect. It leads to great business advantages, such as the instant access to information via mobile phone or tablet; it also gives real-time alerts in order to facilitate the decision-making process based on reliable and updated data. Indeed, data can be explored on a near-real-time basis, at scale, allowing to identify pattern and relationships, "flatten out the time to insight" (Ezell et al., 2017).

Waiting times are reduced as Cloud makes available the right information when it is needed. Hence, workers on the factory floor can view orders as they are placed, having also a clear documentation of where materials are positioned. This great possibility of having an up-to-date perspective of work to be done and suppliers in stock gives workers both tools and information they need in order to work faster. Cloud Computing also eliminate time consuming manual data entry, creating an immediate relationship with customers about order delivery times, managing better client expectations. Cloud Computing foster just in time logic towards a digital viewpoint. Data will be collected within the factory through tracking devices & sensors, by fostering their synchronization and real-time sharing in the supply chain through cloud platforms, in order to provide the right information, at the right place and at the right time.

Regarding Just in Time, Cloud Computing can be considered as a sustaining aspect. However, Industry 4.0 can also be disruptive considering another Smart Manufacturing technology, which is Additive Manufacturing. In particular, the disruption is triggered by 3D Printing that represents a new dimension for manufacturing. As a matter of fact, the great and innovative wave associated to 3D printing relies on the possibility to decrease inventories at maximum, simply manufacturing on demand.

3.6.4 Jidoka

"Automation with a human touch" (Liker, 2004) that's the meaning of Jidoka. The main goal is to free workers from machines and to perform value-added work. Advanced Automation is the feature of Industry 4.0 particularly related to this Lean aspect and it could represent an evolution of the Jidoka concept, since Co-bots and humans work together in a balanced interaction. This human machine collaboration will definitely improve the work conditions, the productivity, the quality of production and the safety.

The main idea is that, instead of replacing human workers, machines are to become their colleagues, establishing a collaborative relationship. In this work, collaboration is defined as "working jointly with others or together especially in an intellectual endeavour" (Nass et al., 1994).
As a matter of fact, co-bots come into direct contact with the workers; through sensor technology, they observe how people perform their tasks and they directly assist them with their work, without exposing humans to the risk of injury (Veloso et al., 2013). Furthermore, by observing individuals they learn from them how to cope with different issues. Co-bots are really flexible and easy to manage: the collaborative lightweight robots can be moved by a single person and easily put into action when needed.Human and machine work hand in hand in the new Industry 4.0 ecosystem.
Faults or failures of products and machines during production lead to dangerous effects on production scheduling as well as morale of the employees (Sanders et al., 2016). Quality is a key concept in a lean perspective and Jidoka forces several quality checks in order to immediately face and solve an anomaly, bearing in mind the fact that all processes should be perfectly visible. Although failures of machines are not always under control and considerable time is spent in order to identify the root cause and solve issues. In a Smart Factory, machines are all interconnected with information and communications systems and human-machine relationship can be improved and simplified. As a matter of fact, Co-bots will be able to send direct alerts and information to trained technicians, overcoming Lean practices. Therefore, "the purpose of these machines is not to eliminate jobs, but to make them easier" (Robo Global, 2015).

Referring to Industry 4.0, companies are moving towards the creation of smarter and smarter Co-bots, due to their high impact on the business. For example, one of the most famous collaborative robot is the ABB YuMi, which is a solution that allows humans and robot to cooperate creating endless possibilities. It is an innovative human-friendly dual arm robot that is able to unlock several additional automation potentials in industry. Another example is the KUKA LBR iiwa, which "uses intelligent control technology, high-performance sensors and state-of-the-art software technologies" (kuka.com), enabling new collaborative solutions in production technology. This aspect represents an important evolution since even the most difficult tasks that have previously been performed manually can be automated in a more efficient way compared to the past. Baxter by Rethink Robotics is a Co-bot able to collect data through sensors and react to problems immediately as humans do: "if workers are testing red parts and blue parts and the red tester breaks, the human worker can see this immediately and instruct a co-worker to send him just blue parts" (Lawton, 2016). Baxter will be able to do and suggest the same, being a real colleague of a human worker. Moreover, this adaptive robot is able to collect information about the performance and provide interesting data analysis.

The same is for Automated Guided Vehicle (AGV) and Laser Guided Vehicle (LGV) as well. These driverless vehicles have been used in manufacturing for the past six decades to increase efficiency in plants and warehouses. Again, in a Smart Factory they keyword is interconnectivity; so, AGVs become part of the network and not isolated automated systems. One of the best examples comes from Indeva, which has been able to generate an interconnection between AGV and KUKA robots. An AGV and a robot are able to communicate through companies Wi-Fi connection; the robot decides which function the AGV has to perform.

3.6.5 Waste Reduction

The focus of Lean manufacturing is to reduce the waste in "human effort, inventory, time to market and manufacturing space to become highly responsive to customer demand while producing world-class quality products in the most efficient and economical manner" (Todd, 2000). It is well-recognized that the basis of Lean manufacturing is the elimination of waste. A waste could be defined as "anything other than the minimum amount of equipment, materials, parts, space and time that are essential to add value to the product" (Russell et al., 1999).
Through Internet of Things, Big Data collection and Analytics, wastes will be more easily found and fixed. This is the reason why these Smart Manufacturing Technologies can be considered as supporting aspects for the approach of problem solving in waste reduction.

The connection between physical things and Internet creates the opportunity to access remote sensor data to control the physical world also from a distance. New sensors, mobile and wireless technologies are at the base of IoT evolution. However, the true business value of the IoT lies in analytics. As a matter of fact, a device can easily transmit information from a device but analytics have to be rich enough to extract meaningful insights. Sensors are able to gather data about the physical environment that have to be analysed or combined with other data in order to find patterns.
Big Data and Analytics have created one of the most profound trend in business intelligence (BI). Some people define analytics with the term exploratory analytics, to better explain this concept. As a matter of fact, through the analysis of a huge quantity of data, it is possible to discover new business facts that no one in the enterprise was able to know before. Talking about Big Data, size matters but there are two other important features: data variety and data velocity

In Lean practice related to waste management is Genchi Genbutsu, which means the Toyota practice of understanding a condition by confirming something with personal observation at the source of the condition. Lean suggests to go to the shop floor to observe the process and interact with workers to confirm data and understand the situation. Another practice strongly recommended by TPS is Five Whys, a useful approach aimed at truly investigating and solving the problem, by identifying the root cause. In Lean manufacturing, waste reduction is also pursued by eliminating inventory not required to fulfil specific customer orders and by adjusting production processes based on customer demand. In turns, reducing overproduction can help to reduce labour costs by eliminating unnecessary transfer of goods.

Industry 4.0, through IoT, Big Data and Analytics helps in supporting factory improvements in order to reduce wastes. In particular, predictive analytics are really useful when assumptions need to be made. Moyne et al. (2017) made a research on semiconductor manufacturing, which is characterized by a high level production challenges to remain profitable in a global scale. So, “waste reduction must be addressed in terms of product scrap, lost production due to high cycle and non-production times, environmental waste and general capital waste due to factors such as poor use of consumables and poor planning”. To address these challenges, specific analytics called Advanced Process Control (APC) are currently used. Of course, this example could be extended to other industries.

Basically, Analytics platforms provides useful data out of all the stored information, gathered through Smart sensors. These data are mostly utilized to improve processes performance, trying to increase the productivity level. Another practical example refers to Petroleos Mexicanos (Pemex) which began outfitting its refineries with IoT devices to measure sound vibrations. When engineers view abnormal measurements, they can go right to a piece of equipment and they are able to replace it with a low downtime.

3.7 Conclusion: Lean Industry 4.0 - Stronger together

Manufacturers seeking to optimize their process need to understand the interplay between traditional lean management and Industry 4.0. Many studies of operational excellence programs in recent years have seen companies generate valuable synergies by implementing lean management and Industry 4.0, rather than independently or sequentially. Indeed, in most cases, the integrated application of lean management and Industry 4.0 that is Lean Industry 4.0 is the most effective way to reach the next level of operational excellence. Manufacturers that have successfully deployed Lean Industry 4.0 can reduce conversion costs by as much as 40% in five to ten years considerably better than the reductions captured by the best-in-class independent deployment of lean or Industry 4.0. To capture the greatest benefits, a manufacturer must tailor the application of Lean Industry 4.0 to address its specific challenges along the supply chain and at the plant level.

4. Industry 4.0 & Lean Six Sigma

4.1 Introduction Lean Six Sigma (LSS)

Lean and Six Sigma provide two compatible problem-solving methodologies. lean typically starts with understanding the added-value for the customer, and then examining a process in detail using value stream mapping (VSM). Incremental improvements involve either eliminating waste (activities, delays, or resources) or incorporating newer technologies that didn't exist when the process was established.

When the VSM identifies a quality issue in a process step, Six Sigma provides a methodology for data driven analysis to define and quantify the types of errors. Statistical analysis is used to identify root causes and implement process improvements that reduce the errors.

Lean Six Sigma emerged initially as two different methods. Similarities and complementary features of them make it useful to use these two philosophies together. It has thus become a powerful and effective tool for sustainable operational outcomes. These two methods creating LSS are six sigma and lean manufacturing.

Six Sigma is a systematic problem-solving approach and methodology. Sigma is a statistical term for measuring how a given process deviates from perfection (Angoss Software, 2011). With six sigma, the errors in the manufacturing are reduced to the error level of 3.4 parts per million (ppm) and it is aimed to go to zero defect. Given the increasing customer expectations considerations, it is of great importance for successful companies. Six sigma asserts that this goal can be achieved if the variance in production is within a certain range. On the other hand, lean manufacturing aims to make production with value-creating operations by removing all kinds of activities that has no value from the customer's point of view. The cost is reduced by determining and eliminating all kinds of waste and so, the lead-time is shortened. The difference between lean manufacturing and six sigma is to define the basic causes of waste in different ways. While lean manufacturing claims that wastes in the processes are due to non-value added activities to the final product, the six sigma argues that wastes come from the variation in the processes. However, the common goal of both is to create a production system that meets the customer expectations most effectively by producing quality products.

LSS is a data driven methodology. It solves process variation and quality issue through define-measure-analyze-improve-control (DMAIC) approach to reach less than 3.4 part per million defectives. DMAIC is a structured method that helps solve existing problems and has proven to be one of the most effective problem-solving methods used up to now. Some of six sigma projects use DMADV cycle, also known as design for six sigma, to create new processes. The steps DMA (Define, Measure and Analyze) are similar to DMAIC but not the same. Table 4.1 below summarizes steps of six sigma both DMAIC and DMADV cycles and gives some sample activities used in the steps.

4.1 Key steps of Six Sigma for existing and new processes

Phase	Descriptions	Sample activities
Define	Define the purpose and scope of the six sigma project	Define why the project should be done
		Define the targets, goals and scopes of project
		Define the customer requirements
Measure	Measure to determine the current situation	Select the output characteristics
		Assess the performance specifications
		Establish the initial process capability
Analyze	Analyze and determine the actual causes for process improvement	Analyze the current process performance
		Monitor the potential Critical to Process (CTP)
		Analyze what resources will be needed for improvement
Improve	Improve the process by eliminating wasteful causes, removing the problem or reducing the effects of the problem	Improve idea
		Identify optimal operating conditions
		Eliminate wastes
Control	Control the improved process performance	Determine the process capability for CTPs
		Implement the process controls
		Document what you have learned
Design	Design a new process in parallel with customer needs	Develop design to meet customer needs
		Design analyze model
Verify	Confirm the truth of designed model	Create a plan for full implementation
		Validate to model

4.2 Integration of Lean Six Sigma (LSS) & I4.0: LSS 4.0

Lean Six Sigma combines two process methodologies – Lean and Six Sigma. Lean focuses primarily on eliminating waste and all non-value-adding parts of a process, with value defined as what benefits the end user.

Six Sigma offers tools and techniques that can eliminate defects and errors in a process, reducing variation and allowing for more consistency in creating quality products.

Tools and techniques found in both methods can help with Industry 4.0 processes. In industry 4.0 huge data will generate from the interaction of CPS. As LSS is a data driven approach so Big Data analytics will play the key role to improve the process. This is the pinpoint where LSS and I4.0 can be merge together to achieve next level of excellency.

Here in this study it has been tried to relate how Lean Six Sigma could be applied to accelerate the process of extracting key insights from Big Data and also how Big Data could bring new light to projects requiring the use of Lean Six Sigma. Without any kind of doubt, today integrating both LSS and Industry 4.0 is an important research field to be extensively explored.

The power of advanced analytics improves the performance of Lean Six Sigma projects: in particular the time of the data collection and the relative analysis of the phenomenon is faster. So, it allows to accelerate the so called “filters” to know in depth the process in order to highlight the root-causes which influence variations from the standard (key concept of LSS) and have to be removed to optimize the process.

In Define phase through proper data visualization tools, problems/defects in processes can be identified early on. The importance of IoT is that data can be transmitted to a smartphone or a tablet to monitor promptly deviations in the processes or products.

In Measure phase the data collection and the analysis of the data are the key points. They must represent the actual situation in the field but often a lot of information is lost and a question on data integrity arises.

Through Industry 4.0 it is easier to accelerate the data collection and in removing human error in collecting data. One of the key point of LSS 4.0 is the role of IoT in helping operations to be improved through processes driven by Lean Six Sigma tools through the definition of data collection system based on Predictive Analytics.

In Analyze phase the goal is the identification and the prioritization of the root causes of the problem (before) and the relative removal (after). A typical approach to the resolution of non-conformities is a strategy called Root Cause Analysis. Moreover, LSS offers some “quantitative” tools (Hypothesis Tests, Correlation Matrix, Regression Models) and some “qualitative” tools (5Whys, Fishbone) are able to describe in depth the process. In this context, the use of a IoT device can speed up the process of verifying root causes.

In Improve phase it is essential that the action plan taken is based on the removal of real root causes and it is monitored and sustained. Having easy to deploy plug and play IoT modules with relevant sensors can make it easier to monitor the CTQs through a personal computer, smartphone or tablet.

In Control phase the CTQs are monitored due to the presence of IoT sensors that should be reliable also in extreme conditions, the data should be confidential and secure, and the IoT system should be able to integrate with any operating platform or database: the interoperability is a key factor in accelerating the adoption of IoT systems. Summarizing, Lean Six Sigma and Industry 4.0 are mutually reinforcing as:

- Industry 4.0 helps collect more data in real-time throughout the entire value chain with the support of Lean Six Sigma tools.
- Lean Six Sigma empowers the operators/ owners of the processes.
- The IoT has allowed that different processes could feed in real-time a cognitive algorithm.
- Lean Six Sigma analytical tools allow to better extract key insights from Big Data.
- Lean Six Sigma 4.0 optimizes processes quickly thanks to a rapid DMAIC-roadmap and fast information systems.

The following table 4.2 represent methods used in LSS cycle both for DMAIC and DMADV

	Define	Measure	Analyze	Improve	Control	Design	Verify
Statistics	Descriptive	Descriptive, Tally chart, Z-test, Confidence intervals, Predictive	Correlation, T-test, Chi-square test, F-test, Hypothesis tests, ANOVA, Histogram, Predictive	Hypothesis tests, Multivariate Analysis		Descriptive, Predictive	Correlation, Causality
Quality Tools	Brain storming, NGT, Pareto analysis, Matrix diagram, QFD, FMEA, SIPOC, Prioritization matrix, Fishbone analysis,	Pareto analysis, Process sigma	SPC	TRIZ, DOE	FMEA, Control diagram, Standardization, SPC	QFD, DOE	
Data Mining[3]			Association Rules, Clustering, Classification	Prediction		Market Basket Analysis, Association Rules	
Big Data	Text Mining, Video Mining		Machine Learning, Decision Trees, Text Mining, Video Mining, Artificial Intelligence	Machine Learning, Artificial Intelligence	Machine Learning, Artificial Intelligence		Machine Learning, Artificial Intelligence
Process Mining	Process Discovery	Conformance checking	Process Discovery, Conformance checking	Flow diagrams, Enhancement	Flow diagrams, Conformance checking		Graphing, Visualization

[1] Descriptive includes some statistical methods such as mean, frequencies and standard deviation.
[2] Predictive includes some statistical methods such as hypothesis testing, analysis of variance and regression.
[3] Note that many DM methods are used for big data with advanced algorithms.

ANOVA: Analysis of Variance
DOE: Design of Experiments
FMEA: Failure Mode and Effects Analysis
NGT: Nominal Group Technique
QFD: Quality Function Deployment
SIPOC: Supplier, Inputs, Process, Outputs, Customers
SPC: Statistical Process Control
TRIZ: Theory of Inventive Problem Solving

Table 4.2. Methods used in LSS cycles (Onur, Omer 2018)

4.3 Relation of Lean Six Sigma (LSS) & Big Data Analytics (BDA)

LSS is the integration of two methodologies namely lean and six sigma. Six sigma complements lean in know-how to find out and address the specific business problems and application of tools in each phase of DMAIC. Lean focuses on customer value stream whereas six sigma understands the requirements of the customer and helps in implementing the policy in a structured manner (Pyzdek 2000; Salah, Rahim, and Carretero 2010).

Big data is referred to the large data sets that are often challenging to examine and investigate due to their complexity and variability (LaValle et al. 2011). The BDA can help the firms to unveil the hidden patterns, market trends, customer preferences, unknown causality and correlations between the different parameters (Kwon, Lee, and Shin 2014). Today firms have a number of distributed data sources right from their suppliers to the customers. This data is into different forms ranging from text, numeric, web logs, videos, tweets, etc. and become difficult to interpret and take the informed decision for many businesses. Therefore, BDA applications in LSS projects in firms can be viewed as a new methodology that pays-off to the firm in tangible and intangible benefits than ever before.

Since data is critical for LSS, mining data to extract meaningful results gains importance. Developing technology brings new ways to mining data because of collected large amounts of data. Data mining has effective methods for a smaller number of data. However, if data is collected automatically with sensors, big data analytics are more preferable thanks to large amount of data. In addition, process mining methods are nonignorable because LSS focuses on the quality in a process. It should not be forgotten that the point in all analytics is to use data to gain insights, not evaluate whole process. Therefore, analytics can help to confirm different LSS activities such as finding root causes and developing robust solutions. It is only a part of the LSS.

For all mining techniques data preparation and evaluation are common. Because data is mainly redundant, incomplete and inconsistent (Köksal, et al., 2011) data preprocessing step is necessary to overcome this kind of problems for developing data quality before mining. Some of data preprocessing tasks are data cleaning, data transformation, data reduction and discretization (Pyle 1999; Giudici 2003; Witten 2005). Evaluation of mining results depends on comparing different mining techniques. The technique that gives the best result is chosen to interpret. To make optimum and correct decisions, it is clear that knowledge extracted from data sets should be evaluated and interpreted correctly (Dunham 2003).

Except for mentioned in this section, statistics and quality tools used in LSS cycles contain also data-based methods. They are not described because they are more basic than mentioned mining techniques but considered during the study.

4.4 Data Mining Techniques, Big Data Analytics & Process Mining In LSS

Data mining (DM) is an data-analytic process that detects interesting, novel patterns within one or more data sets that are usually large (Nadkarni, 2016). Data mining techniques use the integrated data through large amounts of data stored in databases using statistical and mathematical techniques (Larose, 2005). They can be classified into two groups as descriptive and predictive (Han, et al., 2011). The most common types of data mining tasks used in LSS cycles:

- Association analysis discovers some rules among data. It also named as association rule mining. It tries to find frequent items and generates interesting if-then rules (Hand, et al., 2001).
- Clustering is a method of grouping data sets according to similarities between objects in

same groups and dissimilarities between objects in other groups (Rahman and Islam, 2014). Unlike classification, the class label of each group is unknown. It calculates distances between data and group center and assigns the data into the nearest group.

- Classification aims to classify a data into predefined class. Like clustering, classification technique also uses distance-based algorithms. The class label of each group is known (Talia, et al., 2016).
- Prediction associates a data to a quantitative variable and predicts the value of that variable (Talia, et al., 2016).

Another important and hot topic related to mining techniques is about **big data analytics**. One of the definition for big data is that it is based on large volumes of extensively varied data that are generated, captured, and processed at high velocity (Günther, et al. 2017). Today, different sources such as sensors, smart devices, organizations and individuals generate data at a very high rate. Gantz and Reinsel form International Data Corporation (2010) found that the created and copied data volume in the world was 1.8 zettabites (ZB), that 1 ZB equals to 1 trillion gigabyte, and it will be 35 ZB in 2020. It is estimated that this figure will double every other two years in the near future (Gantz & Reinsel, 2011). The more data the more near to perfect decisions on condition analyzing data very well. So, big data analytics and efficient methods of data mining are necessary to obtain accurate results. Since big data analytics aims to gain deeper insights into processes, it is a complement of LSS. Nowadays, there are various big data analytical techniques to gain deep insights. Many of them tests the combination of various algorithms and

technologies (Oussous, et al., 2017). In addition, data mining techniques are a part of big data analytics.

Some big data analytics that can be used in LSS cycles:

- **Machine learning** aims to objective of machine learning is to discover knowledge and make intelligent decisions (Oussous, et al., 2017). The field of machine learning emerged from within Artificial Intelligence (AI) with techniques such as neural networks (van der Aalst and Damiani, 2015). The difference between data mining and machine learning is not a clear-cut. In this study, machine learning refers to algorithms that learn without being explicitly programmed. Generally, machine learning methods are divided three groups as supervised learning, unsupervised learning, and reinforcement learning.

- **Text mining** converts large volumes of text data into meaningful summaries, which support evidence- based decision-making (Yazdizadeh and Ameri, 2015). Shortly, text mining refers to techniques that extract information from textual data such as social media sharings, emails and work orders (Gandomi and Haider, 2015). For example, details of a quality problem can be determined using the information extracted by text mining from the information technology (IT) system. The details may be timestamp, person, activity name, resource etc.

- **Video mining** analyze and extract information from video data captured by cameras. Even if the video camera is very rich about the surrounding environment, more effort must be made with advanced mining algorithms to make the videos meaningful (Bu and Chan, 2005). Although video analytics is still in its infancy compared to other types of data mining methods (Panigrahi, et al., 2010), various algorithms have already been developed for processing recorded videos. In manufacturing area, problems can observed with cameras and main causes of the problem can be detected using video mining algorithms.

Data mining and big data analytics are focus on the data-centered results. Although these results are very important, they are not sufficient to evaluate a process. **Process mining (PM)**, which yields process-centered results, helps to discover, and track real transactions by extracting information from event logs (van der Aalst, 2016). For LSS, which try to eliminate variations and wastes in a process, PM is a useful mining technique. The data collected from information systems are analyzed with PM to see whether deviations and bottlenecks are there from standard procedures with the aim of process enhancement (Rovani, et al., 2015). Therefore, quality problems in a process can be determined and solutions can be generated.

Process discovery, conformance checking and enhancement are three types of PM. Process discovery generates a process model showing flow of whole process without using any prior knowledge. The conformance checking tests by comparing event logs of the process with an existed process model whether process has a variability. In other words, it checks the conformance of the events in the logs with current the model. The goal of the enhancement is to improve a real process by using event logs by comparing the discovered model and event logs (van der Aalst, 2011).

Data mining in the narrow sense and process mining are complementary approaches that can strengthen each other. Once discovered and aligned with the event log, process models provide the basis for valuable data mining questions.

Like DM, big data does not also focus on the improvement of end-to-end processes, on contrary to PM. Data is the fuel for all analysis techniques and big data brings advantages about many tasks, one of them is quality. MapReduce and cloud technology are two example of big data analytics for PM (van der Aalst and Damiani, 2015). Big data technology often relies on MapReduce (Dean and Ghemawat, 2008), a basic computational paradigm, which has been remarkably successful in handling the heavy computational demands posed by huge data sets. Conventional process mining tools are often deployed on the process owners' premises. However, cloud-based deployment seems a natural choice for PM.

4.5 BDA Application in Different Phases of LSS

If data is analyzed well it leads to better decisions and therefore, big data offers the big prospects. Data mining, process mining and big data methods are necessary to obtain more confident and better results. BDA and data mining aim to get deeper insights into processes and it is a supplement to LSS. Hence, a framework is proposed on the application of BDA in LSS via inspiration from Moeuf et al. (2018).

Machine learning, text mining and video mining are the techniques that can be used in the define phase of LSS . Text mining translates the large data sets into a meaningful summary with the help of proof centred decision-making. Text mining includes the data from social media, emails, web logs and work orders (Gandomi and Haider 2015). Video mining investigates and mine the information about the surrounding environment and provide meaningful clues through advanced mining algorithms (Chen, Mao, and Liu 2014).

As LSS focuses on the process, therefore process mining is a mining technique of BDA for discovering and tracking the real transactions by mining the information from event logs that can help in minimize the variations and wastes in the process (Rovani et al. 2015). In the second phase of measure, the present situation is mapped with the help of confidence interval, process sigma and conformance checking. Third phase which is analyze, can use the common data mining techniques such as association analysis, clustering, classification, machine learning and prediction (Rahman and Islam 2014). Many of the BDA technologies test the arrangement of different algorithm technologies (Oussous et al. 2017).

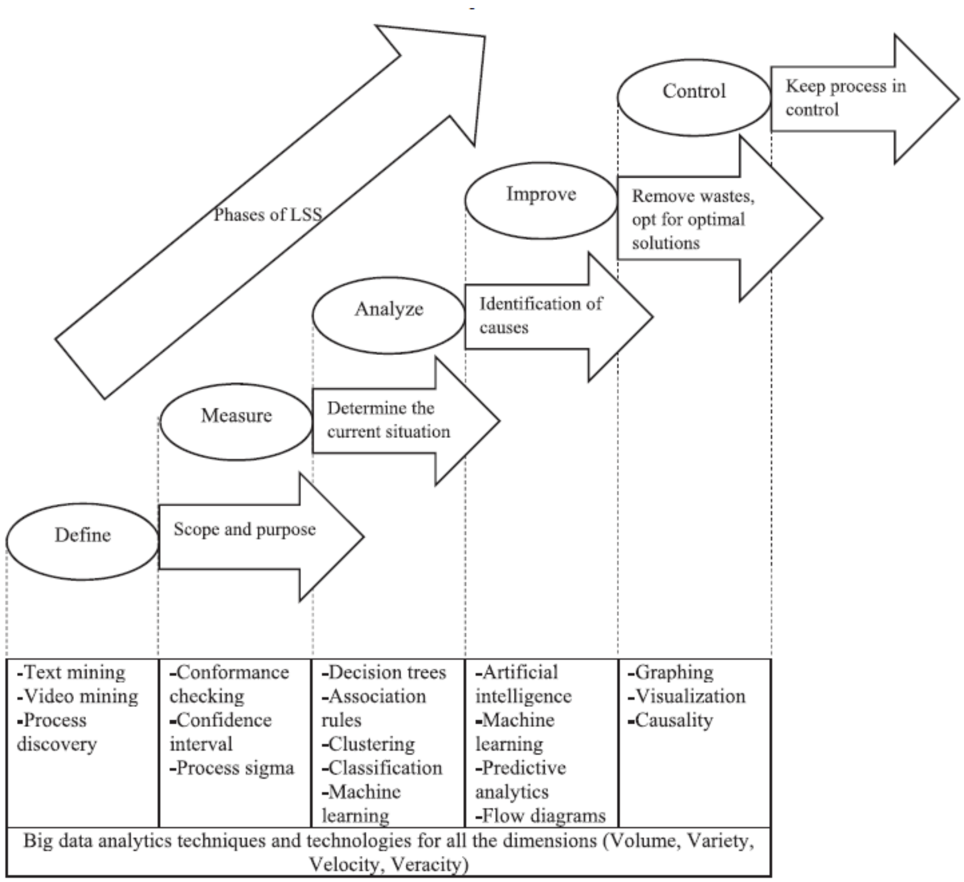


Figure 4.1: BDA application to different phases of LSS. (Shuvam, sachin 2019)

Machine learning can help to learn the pattern and make smart conclusions. Machine learning also uses artificial neural networks (van der Aalst and Damiani 2015). 4th phase Improvement includes the artificial intelligence, machine learning, predictive analytics and flow diagrams for better results and optimizing the parameters for a problem of the LSS project. In the last phase that is control and is very critical for any LSS project can be visualized by and controlled by graphics or visualization as process mining can view if there is any potential failure that can impact the improvement and optimal solution obtained in the last phase. An algorithm can also be developed to monitor the process control. Figure 4.1 describes the investigation framework phase wise and potential application of big data techniques and technologies on the basis of all dimensions (Volume, Variety, Velocity, Veracity and context to the firm).

4.6 Guide to implement LSS

In the Figure 4.2 it shows the flow diagram showing LSS stages for existing (DMAIC) and new (DMADV) process. Define phase is nearly similar for both DMAIC & DMADV cycles. Some differences exist for Measure and Analyze phase but are not remarkable.

In existing process to make better decisions for improving process, Improve phase should be used and the process must be controlled.

If it is a new process then design phases should be used and designed process is validated.

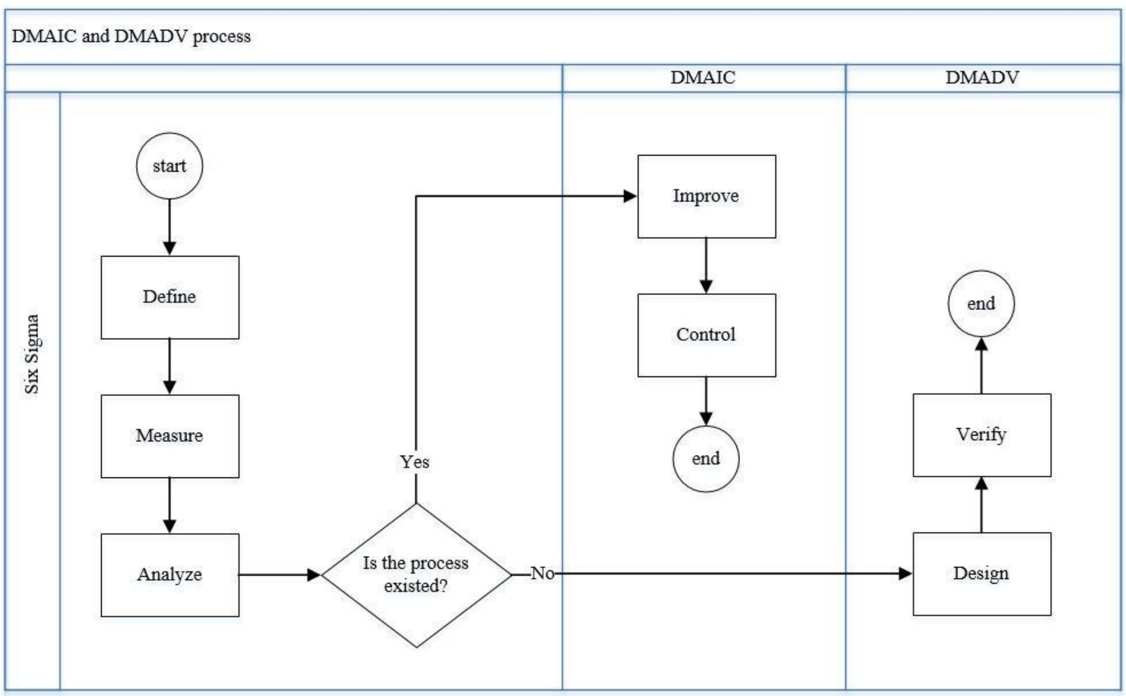


Figure 4.2. Six sigma stages for existing (DMAIC) and new (DMADV) process (Onur, Omer 2018)

4.6.1 Define

In the Define phase it is required to identify problems, process goals with respect to customer needs. Table 4.2 demonstrates some methods that can be used in this phase. For example, in DMADV cycle, brainstorming and nominal group technique are useful methods to define potential problems. After definition of problems, using prioritization matrix or pareto analysis, it is decided that which problem will be solve first (Onur, Omer 2018)

Quality function deployment (QFD) may be useful to determine process goal. For unstructured data such as text and video, big data analytics can be useful to define the problem. With process discovery, status of the process can be shown visually.

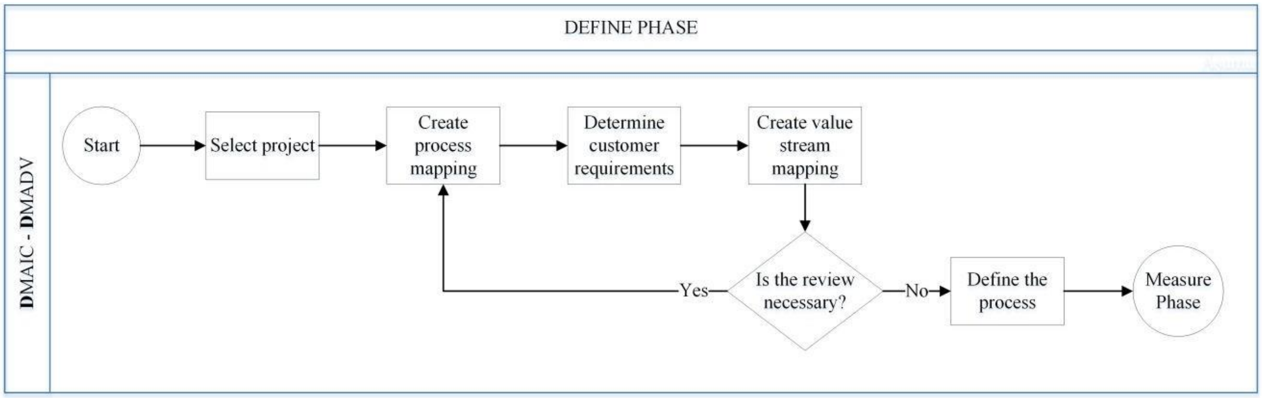


Figure 4.3. Define Phase

4.6.2 Measure Phase

One of the goals of LSS is to eliminate variations in the process. In Measure phase, ANOVA can identify the variation causing quality problems. Tally chart, descriptive and predictive statistics can be used to measure current situation of process (Onur, Omer 2018). Figure 4.4 indicates the suggested roadmap for the Measure phase

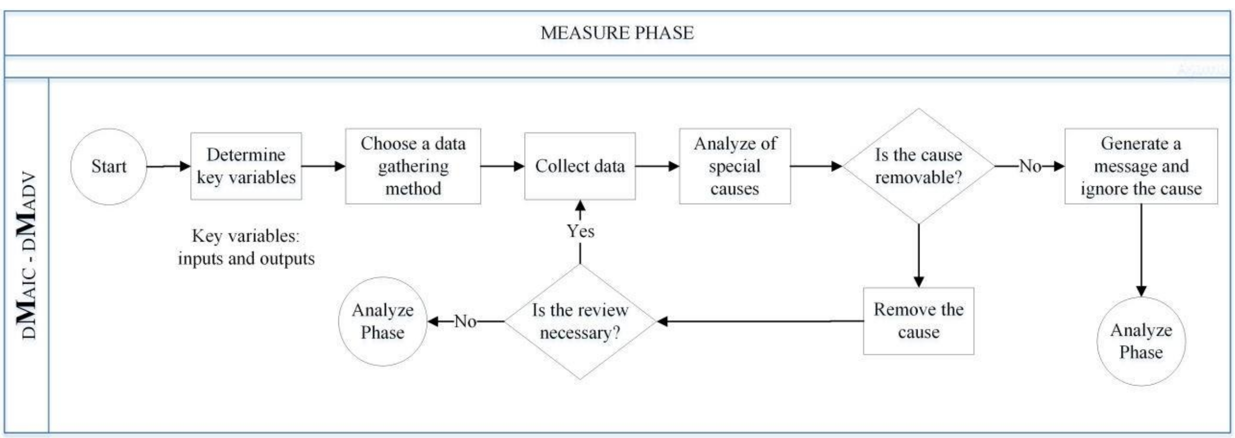


Figure 4.4. Measure Phase

4.6.3 Analyze

In the Analyze phase Data gathered in the Measure phase is used to fully understand the process. Correlation and regression analysis explain relationship between dependent and independent variables. Process competence and process performance are analyzed using SPC. Association rules, clustering and classification are the most preferred DM methods to analyze process. Machine learning algorithms can help to navigate the user without any learning effort. In addition, if the data include also timestamp, for process analysis, process discovery, a type of PM, can be more efficient technique (Onur, Omer 2018). Figure 4.5 shows suggested roadmap for the Analyze phase.

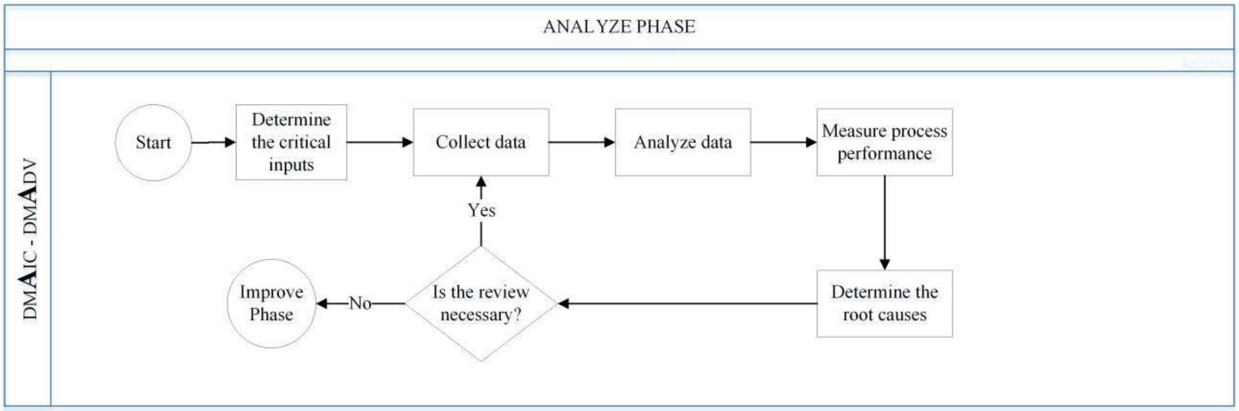


Figure 4.5. Analyze Phase

4.6.4 Improve

Clustering analysis and discriminant analysis (Multivariate statistical methods) can be used to improve the process. TRIZ for solving innovatively problems and DOE to find best parameters can be used (Onur, Omer 2018). Figure 4.6 demonstrates the suggested roadmap for the Improve phase.

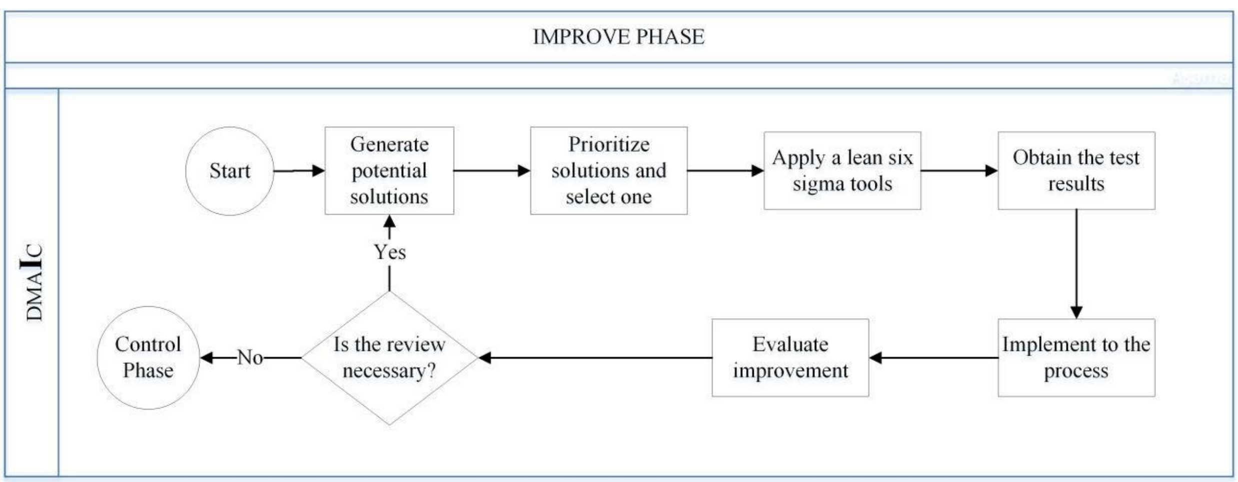


Figure 4.6. Improve Phase

4.6.5 Control

In the control phase, FMEA can be used to avoid potential risks and control diagrams to check whether the process is in control or not. An unsupervised learning algorithm can be created using machine learning techniques to give an alarm when the process is out of control. At the same time, conformance checking can be used to check created model from event logs and actual process.

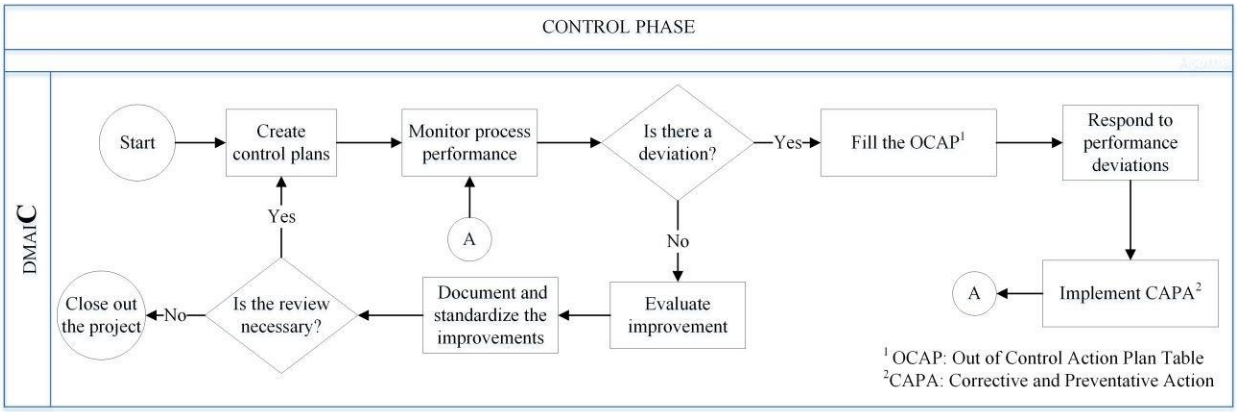


Figure 4.7. Control Phase

Figure 4.7 shows the suggested roadmap for the Control phase.

4.6.6 Design

To create a new process, in the Design phase QFD can be utilized to consider customer requirements. Descriptive and predictive statistics methods can be useful for basic information about the design. Market basket analysis and association rule mining as a DM method identifies products and content that go well together. Figure 4.8 indicates the suggested roadmap for the Design phase.

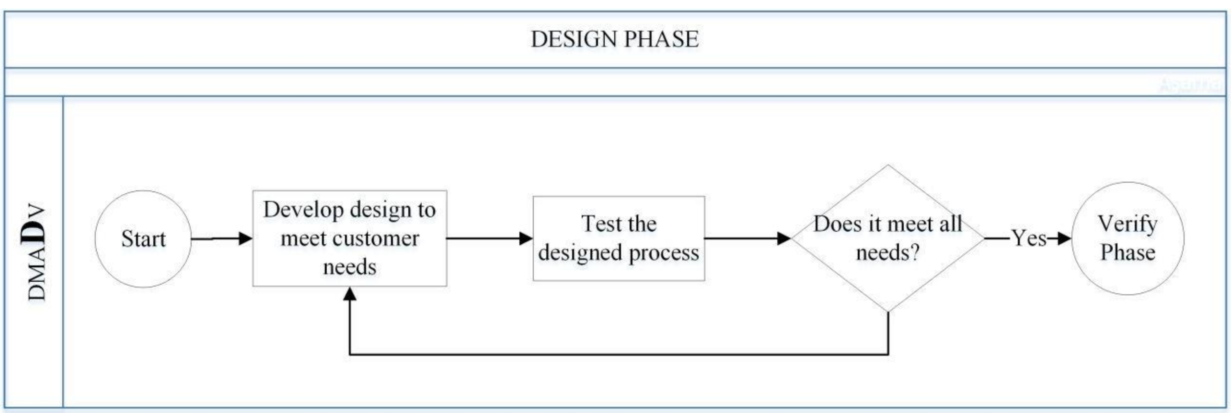


Figure 4.8. Design Phase

4.6.7 Verify

In the last step of DMADV cycle, some metrics are created to keep and a pilot run is developed to verify the new process. Results can be visualized using Graphing or Visualization as PM methods to see whether there is any potential failures affecting quality. A proper machine learning algorithm can be used like a control step to give an alarm when the process is out of control. Figure 4.9 shows the suggested roadmap for the Verify phase.

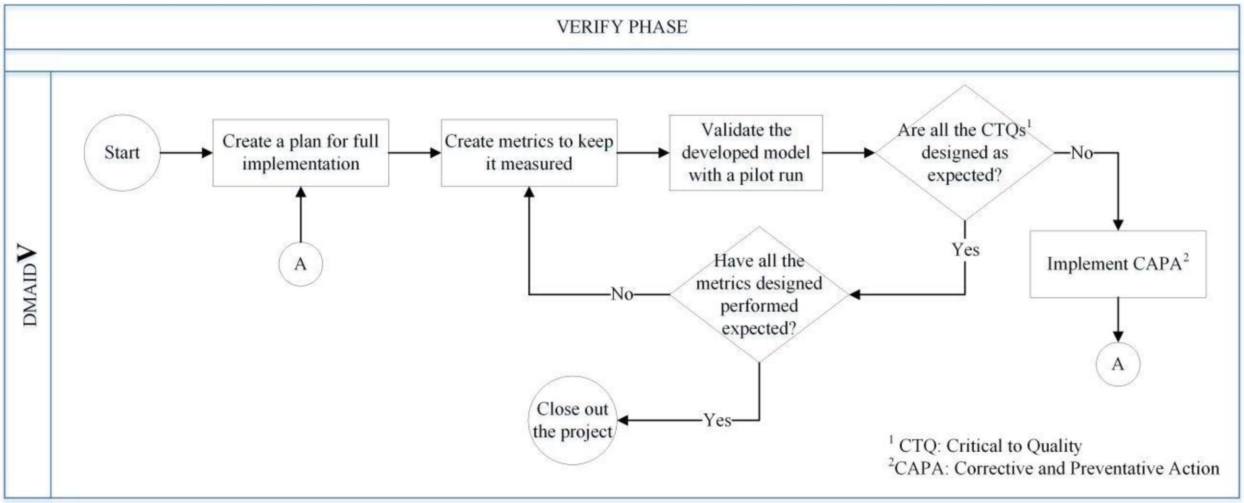


Figure 4.9. Verify Phase

4.6 Conclusion

Lean six sigma powered by industry 4.0 technologies such as cyber physical system, IoT, sensors, bid data analtics, AI and machine learning will improve application, increase visibility in problem solving, fault identification and overall efficiency improvement.
Lean six sigma has an opportunity to enhance its performance since CPS enables the communication and transmission of data from all entities of the value chain.
Lean six sigma collects data to achieve its goal. Collected data should be analyzed to make optimum and correct decisions.
Industry 4.0 technologies make possible to collect enormous amount of data. Therefore, traditional data analysis techniques are not sufficient because they require more time and cost. It is possible to benefit from advanced techniques, such as big data analytics and process mining in addition to traditional techniques to make effective decisions.
The training of the people who work in the industry 4.0 will be fundamental to succeed in the necessary cultural adaptation in this new environment, where man will work in a digital ambience, with access to data in quantities and qualities about the industrial process never seen before in the histor

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