# Looking Ahead By Looking Back

*"Understanding evolution of innovation in manufacturing"*

A thesis

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# Abstract

To understand the evolution of manufacturing and its future requires multidimensional study of different historical milestones, systems developed over a period of time and some concrete analysis amalgamated with experimental results. This thesis is about identifying major milestones in the manufacturing history and then using this information to understand the evolution of innovation process and innovative models. Further, using knowledge obtained from the study of innovation processes to understand the modern trends in manufacturing industry. Experimental analysis is performed using modern machine learning techniques like deep learning to correctly identify human facial expressions. The increasing utility of artificial intelligence was the driving force to exploit modern machine learning techniques that have proven that now decision power can be carefully delegated or shared with these intelligent systems. The Deep Learning based approach using convolutional neural network is tested on human facial expression recognition and accuracy of over 86% is achieved which is higher than other mathematical based machine learning models. These modern machine learning algorithms are also tested on numerical dataset to prove their flexibility and adaptability for different applications which can be faced in any modern day manufacturing industry. The results from this study show that these modern machine learning algorithms have outperformed old decision making methodologies due to their capacity and intelligence in learning different patterns present in the data and correspondingly helping in correct decision making. As a future recommendation, a hybrid system is proposed which is a combination of predictive as well as corrective maintenance. The proposed system is based on deep learning using convolutional neural network to predict end of life of a part.

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# Chapter 1: Craftsmanship to High-tech Production

In today's world of 21st century, where industries are looking ahead to match pace of innovation and rifeness of competitiveness, it has made businesses and industries more vulnerable and accustomed to high risks. Companies have to adapt themselves briskly with changing manufacturing trends and processes for their survival in the global market. Often, while undergoing such advancements, only current market trends are taken into consideration and this makes companies susceptible to high risk. History of manufacturing is often overlooked while planning for such innovations and important lessons which could be learned from history are often ignored. Sometimes, it is fruitful to see in the past and explore what lies in the history which can help us to move forward in present and future. It is not a bad idea to examine our future propositions and ideas with the pragmatic treasure of manufacturing history which has helped industries over centuries. In order to better comprehend and manage innovative manufacturing in the 21st century, it must be observed with care, what has led to such developments and successes in the past years of manufacturing. Often, today's operation management tight schedules, do not give leverage to thoroughly examine and test the innovative ideas before development due to forceful competition and hence, benefits of testing theory against history is unheeded. The principles and the rules, the trends and traditions, the philosophies and ideologies, the ethics and moralities of manufacturing history which has led to this industrialization glory, must have muscles to support progress of future manufacturing. Hence, the importance of manufacturing history has many manifolds and can help us to see ahead by looking back.

Manufacturing is a mechanism of converting raw material into useful products for human, economic, social or environmental benefits. From Handcrafts to high tech products, manufacturing has undergone many developments over the years and history of manufacturing is enriched with technical developments, human demands and requirements, economies of scale, geographical regions and entrepreneurship ideas. Manufacturing is a multi-dimensional effort driven by ideas, culture, needs, technology and skills. Manufacturing sector helps countries to grow and boost their economy.

### 1.1 Importance of Manufacturing

Manufacturing sectors also bring social uplift in the lives of people as it provides jobs, development and technological advancements. For many countries, manufacturing is a backbone of their economy and certain countries have their own specific areas of manufacturing specialization. According to literature, any country could be in prime, secondary or tertiary level of business with primary as first level of business before it can move to secondary and tertiary business. Primary business means countries that rely on selling of raw material and agriculture product for their economy like Pakistan and Saudi Arabia. Secondary business mean countries who are into manufacturing and industrialization to generate their money like China and India. The tertiary business mean countries who provide services to earn their wealth like England. USA appears to be in both secondary and tertiary businesses with a motion to move towards only tertiary business country.

The sole purposes of manufacturing are the value addition in merchandise and to make it more useful for human beings. Manufacturing directly affects the economies of the countries and all countries have certain regulations and targets under which manufacturing is carried out. In a free economy system, it is usually about mass production for earning maximum profits. In collectivist economy, it is predominantly directed by the government to achieve certain levels of supply and in mixed market economies, it is regulated by government at certain level. Hence, the structure of economic setup of the countries affects the protocols and trends of manufacturing. According to economists, manufacturing describes the wealth earning power of the country and whereas services are believed to be wealth consuming sector. Manufacturing is a key component which provides and generates employment opportunities. Manufacturing also provides the basis of national infra-structure and defines the future economic layout of a country.

In the early days, humans made what was needed for their existence, for example, they made handmade stone/bone hunting tools, and clay based cooking utensils and some tools for engraving on clays and stones. It was needs based manufacturing and there was no commonality in the products i-e, no two pieces could be manufactured exactly the same. Also, people of one region were accustomed to certain tools while others were totally unaware of those tools or skills. After that era, people were able to learn the craftsmanship and different individuals got specialized experience in making a particular product of daily use like cobblers and ornament makers. After craftsmanship, in late 16th century, the invention of machines, the concept of mass production came into existence i-e to produce many exactly the same products. The 18th Century saw the industrial revolution and it brought the planning and demand culture into the manufacturing world. The 19th and 20th century were more eventful as it saw the beginning of automation, programmable logic controllers, robots and increasing use of computers in manufacturing industry.

It should be noted that manufacturing was at different stages at different parts of the world at the same time. Also, people of different geographical regions had preferences for a certain type of industry and manufacturing. The nature of raw material availability or type of natural resources available also directed the development of certain types of industries and technology in a region. The availability of skilled labor and infrastructure also are contributing factors for a certain type of industry to grow. The flow of manufacturing industry over the years is shown in Figure 1:

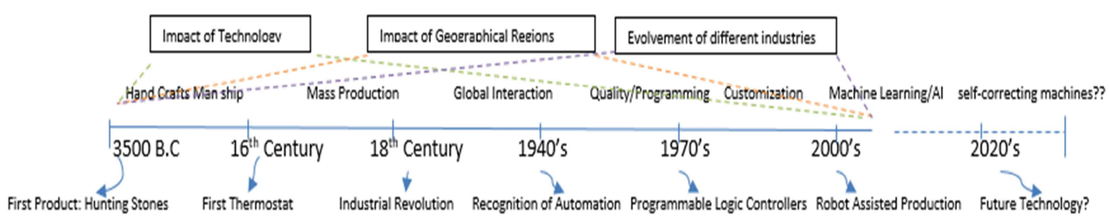


**Figure 1: History of Manufacturing and Important Milestones**

Automation is derived from the word automaton i.e. automatic control and it is a use of control system and regulated processes to operate machines used in manufacturing. The term automation is often linked to industrial production and is now considered the major part of manufacturing. The main advantage of automation is that it reduces labor, energy, waste and improves quality, precision and accuracy. Thus, automation enabled manufacturing of products that are large scale, cost effective and within time constraints.

## 1.2 Composition of Thesis

The composition of this thesis is as follows

Chapter 1: Discusses about the importance of manufacturing industry in social and economic aspects of human race. It also points out some major milestones and evolution of manufacturing industry in general.

Chapter 2: An in-depth study of history of manufacturing over centuries and important inventions of each century are discussed. It explores the main trends and indicators which led to shift of focus to a particular technology or industry in that particular century. This chapter also brings some useful information about the geographical dynamics related to evolution of manufacturing industry.

Chapter 3: This chapter outlines the innovation process and innovation models used in the industry. This chapter describes why innovation can never be an overnight accomplishment and there are always some indicators over a period of time which dictates the innovation in that area. The development of different innovative models with continuously developing technology is discussed in detail in this chapter.

Chapter 4: An approach is developed based on deep learning using convolutional neural network to explore the usefulness of machine learning in decision making and pattern recognition. A facial expression recognition task is developed using a range images. Further, traditional machine learning algorithms are also explored on credit card data.

Chapter 5: Results obtained in chapter 4 are discussed and analyzed. Usefulness and competitiveness of these artificial intelligent algorithms in decision making is explored and their increasing adaptability in manufacturing industry is explained.

Chapter 6: This chapter discusses the future recommendations based on the importance of machine learning in manufacturing in near future. Instead of traditional approach, a system is proposed for maintenance of parts in industry. This proposed system is a hybrid approach between corrective and preventive maintenance.

# Chapter 2: History of Manufacturing

It is believed that history of manufacturing dates back to the development of a wheel but actually manufacturing started way back in 3500 B.C when Sumerians and Akkadians used some sort of brush and paint for Primitive cave drawings and marking on clay tablets[1]. They also made use of stones and sharpened woods for hunting. The history of automation dates back to 16$^{th}$ century when first thermostat was first produced[2]. From manufacturing of handcrafts to today's world of modern computer controlled robotic production, manufacturing and automation have undergone interesting developments and advancements. A thorough investigation about different phases and era of manufacturing, identification of important landmarks, contributions by different geographical regions, milestones and vital breakthroughs will be interesting and helpful in understanding the path and patterns of manufacturing development history in order to predict the future course and progression of manufacturing and automation. The main theme will be to predict cutting edge technology especially in computer/robotics based automation in the coming years through assessment of current trends employed in the industry and innovation research. This study will be helpful in identifying future market trends and new technology by connecting different dots from manufacturing and automation history. The basic idea is to assess different industries with special emphasis on computer assisted automation and their value in the future. This study will also be helpful in understanding why some businesses have fallen out of the market and which other businesses are over taking them and reshaping future industries.

## 2.1 History of Manufacturing through Centuries:

The stone age or Paleolithic period is the time when human race first started to craft objects and it is believed that first item manufactured were from stone[3]. As people were migrating to better climatic and resources areas, it is a strong belief among ancient researchers that first tools produced were either war tools or agricultural instruments or may have been household artifacts but ancient writers have referred about prehistoric cave paintings in a Lascaux, France which are estimated to be around 15000 B.C[4]. They must have used some sort of pointed ornaments for engraving and some colored liquid for cave arts. So, it is safe to claim that recorded history of manufacturing dates back to as far as 15000 B.C. Sumerians in around 3500-4000 B.C were recorded to have used hammer made from stone for manufacturing. They were found to be involved in marking on clay tablets, stones and caves. The very first manufacturing products are believed to be household artifacts, hunting equipment and ornaments made from stones and wood. The very first materials used were clay, stone, gold, copper and iron [5]. The very first employed process were supposed to be hammering and casting as hammer was indeed built in very early stage of human race and casting process make largely use of just hammer. Around 5000 B.C, Sumerians, Assyrians, Hittities, Egyptian and Phoenicians were at war with each other mainly for land and water resources, so much of the development of that era is linked with war armaments. These developments in war technology then shifted to civilian needs like agriculture and construction tools[6]. Before 4000 B.C, people had started to use gold and copper in manufacturing different objects and tools. Between 3000-4000 B.C, copper casting and molding of metals had started and around this same era, manufacturing of jewelry and stamps came into existence. It is also mentioned in literature that heating of materials to mold them into different shapes had started. So, hammer and heating of metal technology had started by 3000 B.C and it is believed that these two forms the basis of manufacturing industry. Egypt and Iran are supposed to be region where these two things developed first and were particularly interested in discovering different types of materials. History evidences indicate that Middle East was at the top of the world in manufacturing mainly because of their need for advancements in military instruments, but when other regions started to take manufacturing more enthusiastically, the Middle East started to lose its technological and economic supremacy. Heating of materials for casting and joining was the first advancement in the manufacturing history and opened new horizons for manufacturing processes.

Between 3000-2000 B.C, people living at the mouth of Tigris and Euphrates river and those living in Nile valley made new inventions which raised the standard of living[7]. Bronze casting and glass beads were famous. Bronze was the significant discovery because of its hardness. The wheel was also invented around same time. Innovation of the wheel was pivotal in manufacturing as it led to the creation of carts, chariots and some transportation system and ways to transmit loads. Another main advancement was the discovery of glass and ancient history tells about glass vessels and potter's wheels were developed during that era. In that era, people also started to realize the importance of tools and started thinking about standard forms of different tools. They manufactured a Hoe tool, hammered axes and tools related to hammering and casting. It was the first time money and financial constraints started to be entangled with manufacturing. All of these materials were not readily available and there was a dire need for something which could be molded easily and hard enough to be a good replacement for stones. This was a starting point for discovery of iron and its usefulness in making manufacturing tools which still today, is the most important raw material in manufacturing industry. 2000-1000 B.C saw the era of wrought iron and extensive use of brass as brass was soft and could be used in ornaments and household artifacts. Ancient writer's point to regions of Egypt and Greece as regions where wrought iron was first used and those people started to learn to make different tools. On the other side of the world, archaeological findings indicate that there was a huge rise in the production and manufacturing sector of China. First Chinese Hysia dynasty (1800-1500 B.C) came into existence with a more organized structure[8]. The northeast part of china was more populated compared to other regions of China, so they had issues over resources. So, again, military tools were at the heart of manufacturing in China at that time.  In 500 B.C, almost 1000 different Chinese states fought with each other and when war finally ended in 221 B.C, there emerged a single huge empire which was better able to devote resources to military and manufacturing developments. Iron was at the heart of all these developments. It is worthwhile to mention here that China was the first region who specifically invested in agriculture and its tools and much of the advancement in agriculture at that time is linked with Chinese Northeastern region. Egypt and Middle East were more involved in heavy metal manufacturing while chine concentrated more on light metal molding and shaping. All of these developments in manufacturing were linked with technological advancements and economic growth.

The regions that were isolated geographically and faced far less aggression, the rate of development in manufacturing was very slow and delayed. Japan, for example, metal was first used almost about 3000 and 2000 years later compared to where it was first used in the Middle East and China respectively. The same held true for New Zealand and Australia, as they had no contact with any other region or culture for long time and hence their rate of technological development lacked behind compared to other regions of the same era.

In those eras, skills owned to build tools and ornaments were purely individual and varied hugely among different regions. There was no standard design or specification for any tools or object. Neither was any particular demand from people. It was an era of innovations as people tried to make what they needed and everyone had to make it on their own. People build things that were needed for their daily usage and requirement. Although, some people had developed better skills and became famous among their tribes for a particular type of skill. This was the root of the concept of Job Shops where there was some level of standardized work and design for certain objects.

In Greece, between 1000-1 B.C, the concept of cast iron was developed and it changed the course of manufacturing. Cast iron meant that there were chances of more standardized and replicated products. So, 1000-1 B.C holds an important milestone in the history of manufacturing as cast iron and cast steel were discovered and people started to look for ways to join iron and different materials. Ancient writers also wrote about glass pressing and blowing in that era. People were also involved in stamping of coins and welding/gluing of iron or steel. This helped them to make better or improved chisels, saws and wood working lathes. So, as indicated by literature, iron making started from middle east in the era of 1100 B.C. Around $8^{th}$ century, Roman government started to invest hugely in their military plans and hence production of war tools increased considerably. The regions which were conquered by Romans saw a rapid change in their development and Roman policy makers made a rule that major part of every region income will be devoted to strengthen their military strength. So, they invested a lot in military advancements and technology developments which paced up the rate of manufacturing in that era.

Around 300 B.C, a weaving process was invented in Japan and this brought the concept of clothing manufacturing. Clothing manufacturing were first invented in Japan, mainly in its central regions like Tokoyo and northern Kyushu[9]. The potter wheel was also invented in Japan in same time period. Japan made rapid advancements in smelting of metals technology and Japan region became famous for manufacturing of ornaments. As Japan was located far away from mainland and had a huge sea in between them and countries of mainland like China and Korea, they allocated more funds for development of sea ships. They made significant improvements in sea vessel technology and were eventually able to develop sea vessels which could travel long enough to reach main lands. China and Korea were much advanced compared to Japan at that time mainly because of geographical loneliness of Japan, so Japan started to import technology from these countries. Around the same era, it was Japans policy makers who first laid down rules that allowed copying technology from mainland countries. It was also Japan policy makers who introduced concept of subsiding in manufacturing. So, that era is important in manufacturing as concepts of technology sharing, technological plagiarism and subsiding to support manufacturing came into existence. Japan imported many different types of household utensils made of iron cast, ornaments and farm tools. Again, all of these technological advancements were linked to war and the main source of investment was in weapons. But, this era saw the transformation of advancements in war weapons manufacturing into manufacturing of goods of civil benefits.

Between 1-1000 A.D, zinc and steel were most famous materials and they were extensively being used in the manufacture of armor, steel swords, forging and coining[10]. A wide variety of materials and objects were continuously developed. But the most important milestone was the production of steel in 600-800 A.D in Asian countries. Around third century, romans eventually cut down their military expenses, which reduced the technological advancements and usage of iron. They closed many iron production centers and also reduced their investments in other manufacturing ventures. So, manufacturing faced stagnation and further cuts were made in the next two or three centuries, so that era is termed as a 'Quite Era' in manufacturing[11]. It was the era where people had specialized job shops for a particular object or tool and this started the concept of specialization in manufacture. People tried to master a specialized skill and bring improvements in the design and quality. The defense and hunting tools became increasingly famous. From the pictures and ancient historian writings, it can be deduced that people of that era also knew about etching. They were using some sort of acid or material to cut through different metals and they also had discovered to preserve things for a longer period of time. So, the era of 1000 B.C – 1000 A.D is considered to be period where specialized manufacturing had started in some form and people started to think about manufacturing in a more organized way.

So, up through 1000 A.D, the process of hammering, heating, etching, casting and glass processing were indeed developed and these led a path towards manufacturing industries. In the era 1000-1500 A.D, the concepts of blast furnace were developed which opened new horizon in manufacturing. People were involved in casting of bells, improved armory for fight and hunting, wire drawing, silver and gold smith works, sandpaper and welding of iron or steel. The Roman Empire became center of manufacturing developments and people of Roman Empire were famous for metal craftsmanship. Greece became the center for household artifacts and glass molding. So, the center was shifted from Egypt and Iran towards the Roman Empire and Greece. 1500-1600 A.D eras is famous for water power for metal working, manufacture of cast-iron cannons, hand lathe for wood, wire drawing and use of tinplate in manufacturing. As hand lathe were developed, it was a first step towards an idea of industry to manufacture products. These lathes helped to produce multiple similar objects and hence introduced standardization among products. This era saw the increased interest in the manufacture of war products like swords, canon and shields. Also, it was the era when people actually started to invest in manufacturing of products. People had developed specialized skills and started mastering them.

There was no concept of factories on or before 1500 A.D. Most things were manufactured in individual shops or in home. Most of these job shops were located in rural areas and were usually run by a craftsman. Business scale was very limited and craftsman was the owner of their shop. As mentioned earlier, Europe was the center of civilization for small manufacturing businesses. The most vital industry which was developed a little before 1500 was the printing process. But the printing process was still in a very raw shape and printing actually flourished lately in $16^{th}$ Century. Apart from printing, there existed some processes related to cloth manufacture and lathe machines, some refinement and improvement in techniques but all was very scarce and slow paced. The main material used was still stones and woods as casting or iron and other material was very expensive and was still not fully developed. The main regions were Venice, Amiens, Augsburg, Milan and Ghent. The period from 1300 to 1517 is often called 'the Renaissance' period.

In $16^{th}$ century, printing industry flourished as lathes were made of better material in that era. The Song dynasty in China is one to have first reported printing of books, printing equipment, writing tools, study chairs and tables[12]. It is around same time that proper standards of shovels, hammers, nails and metal bars came into existence. Molding hard metals and technology to heat metals for permanent deformation was developed. There were some experiments with different metals to form alloys and porcelain was discovered. This introduced further processes related to manufacturing of household items and jewelry ornaments. Still, most of the population was living in rural areas and these developments were centered in Europe. The availability of labor and raw material were big issues. Also, political instability and frequent war culture hindered the fast development of any new technology. In the start of $17^{th}$ century, rapid development and advancements were in manufacturing and industrialization was observed[13]. Romans are regarded as biggest driving force behind manufacturing in this era before the $16^{th}$ century, though they invested hugely in war technologies and very little in civil technologies. Education and infrastructure also began to develop and all of this started to bring positive change in the lives of people. Agriculture, resource mining, ornaments, clothing and household tools were important discoveries before $16^{th}$ centuries though major advancements were in war technology.

### 2.1.1 Sixteenth Century

Before the $16^{th}$ century, the development in manufacturing was very slow paced and dedicated to certain regions. The major technological innovation in $16^{th}$ century was invention of Dutch Loom. Knitting frame (1598) and ribbon frame (1604) were developed which boosted the loom industry considerably[14]. The Rolling process was invented which helped to shape roll gold, lead and other metals so that they can be molded in different shapes[15]. This era was also the starting period for drilling and boring. People started to explore drilling process to unearth the resources available underground. This was a big step attributed to this era because drilling technology later also became the source of fuel for machines. In 16th century, the more advanced methods of agriculture were developed which increased the agriculture output to a great extent. The main reason for this increase in agriculture is due to the growth of population at that time.

People had developed means to travel long distances via sea vessels, so they started import and export agricultural products as well. Previously, export and import were only limited to weapons and metal shields. American region was able to introduce many new types of crops to the world and mainly exported its crops to England and Spain. As people became more comfortable with export and import of agriculture products, this also acted as a catalyst in the trade of commercial goods. Previously, heavy manufacturing was just limited to be supported by the Government and private investors were reluctant in investing money in manufacturing, but with the discovery of porcelain and export/import business, private investors started to invest in manufacturing. America also started to export massively its precious metals to Europe and England which further spur the manufacturing industry in England and Holland. Again, regions of Europe, England and China saw huge investments in war technology and weapons still were the major portion of manufacturing. England subsidized the manufacturing of household and agricultural tools which saw the increase in the investments from private and commercial investors. With this also came a restructured form of taxes on manufacturing and Governments wanted to have their share from manufacturing in private sector. The 16th century also saw the first trend of migration among laborers to migrate to better regions in search of better living standard and job opportunities. Many people in the textile industry from central and lower Europe migrated to England because at that time, England gave better incentives to skilled labor.

Textile and agriculture became major industries along with weapon industry in 16th Century. Shipbuilding was another area which saw a lot of development. European countries, especially Spain, needed battle ships to protect its long beeches. England became the forefront region to develop one of the most advanced ships of that time. This spurred new job opportunities in England but at the same time, there were new machineries which cut down technological employment as machines started to do some of work which was previously done manually. New fields like soap, paper, glass and silk manufacturing started to take shape of industries and employed thousands of people. A new mechanical clothing machine, Gig-mills was invented which deprived many old-fashioned labor from their employment and this machine was eventually banned by Government in 1552[16]. England was the strongest in manufacturing in the whole of world in the 16$^{th}$ century and England had the largest number of employments in manufacturing.

England had most rapid rate of innovation in the whole world in 16$^{th}$ century. England is the first country to introduce the concept of patents in manufacturing. It was natural that the system of protection of invention came from England as they were growing faster in manufacturing industry and was attracting skilled labor from different parts of the world. It somehow reduced the sharing of technology to far off areas but it brought more capital gain in technological advancements.

In the 16$^{th}$ century, the concept of state factories came into existence. Previously, factories were built but usually they were of small scale or owned by some small private group apart from weapon factories which were owned by governments. Germany in 16$^{th}$ century, developed few state factories which were huge and had production in tons. This was the first time, the concept something similar to government jobs came into existence as now government had huge factories and they wanted to retain the labor to work in those factories.

Russia, under the ruler-ship of the Mongols, was heavily busy in their expansion of land and war. Russians devoted the major part of their resources to war industry to support their military adventures and hence development of manufacturing industry in Russia in 16$^{th}$ century was very slow paced. They developed advanced canons, the fast maneuvering battle sea ships and researched in the fabrication of low cost weapons through different alloys of iron[15]. China on the other hand, saw a huge growth in population and agriculture which was the main concern for them in $16^{th}$ century. Japan also had a quite $16^{th}$ century until 1543, when Portuguese ships arrived on their sea shore and introduced them with firearms. This impressed Japanese to a great deal and they researched heavily for the rest of the century in gaining this technology or even improving it. They were the first one to be able to develop more advanced forms of spring and trigger mechanism. Hence, the manufacturing of guns started at larger scale. This was the century when Japan plunged itself openly in war manufacturing.

The $16^{th}$ century is famous for agriculture, mining, services and construction. Silver was produced at large scale and mining business saw impressive growth[17]. Construction and infrastructure of manufacturing industries or factories grew rapidly specially in the later part of century. But again, war technology and weapon industry remained at the heart of all manufacturing advancements.

### 2.1.2 Seventeenth Century

England was the country which led the efforts to dominate the seventeenth century in manufacturing by introducing wide range of subsidizations for industries and protecting the rights/work environment of the workers. Due to subsidized policies and better work protection, most of the Western Europe labor and technical workforce fled to England in early seventeenth century. This helped England to grow economically which provided it with more resources financially and skilled labor. Investors started to look things on big scale and the idea of production of same items on a large scale became stronger and dominant. However, the start of seventeenth century brought a decline in manufacturing around the world and England was no different. England went into civil war between 1642-1649 and this reduced the investment in commercial and military investments which resulted in the decline in the investment for manufacturing[18]. This decline in manufacturing resulted because of the political tensions between the Kings and the British parliament and Kings being the big supporter of military manufacturing, during the seventeenth century, England was the largest producer of military armaments in the world[19]. As the civil war ended and Parliament won that civil war, it aggressively laid down policies to subsidize incentives to manufacturing to empower the businessman who could make parliament more powerful. They introduced a Cromwell’s Navigation ordinance in 1651 which was aimed to increase exports as factories were able to produce large quantities[20]. They also introduced the Corn Laws which offered rate security and insurance to agriculture sector as well. England along with Dutch was the most successful and largest producers of manufacturing goods.

The Seventeenth century also saw the most resistance by common people and by some governments against labor saving machines which made it hard for manufacturing industry to grow at a rapid pace. Seventeenth century saw the brisk advancements in technology and development of high-tech more powerful machines with certain factor of automation embedded in them. The machines started a cut on the labor required in the industries and seventeenth century became the first time where labor or human work force started to envy machines. There were large scale protests against machines across England and others part of the world. In some countries including England, there were strict restrictions on the use of new technology or machines to be used in manufacturing as a result of these protests and outrage of labor against such machines. This resulted in the decline of use of high tech machinery which affected the quality improvement factor of manufacturing in that era and labor rights were more powerful.

The Seventeenth century also saw the sense of nationalism in manufacturing. Governments introduced policies to buy and use goods manufactured in their local country. This includes 1571 law of wearing English woolen caps and use of woolen shroud made in England for deceased if someone dies in England[21]. Efforts like these attached honor and pride in manufacturing as countries started to care more about quality in their products as people started to read on items. This also made some regions a hub for specific items as goods started to get famous from certain areas or from people with specific skills living in certain specific regions of the world.

This nationalism in manufacturing also resulted in monopolies that started to control the direction and rate of production. Governments played into the hands of these monopolies as they started to provide funds for political movements and in return political people made policies which favored certain monopolies or groups.

The Navigation act was most famous event of that century which forced all ships to and from England land needed to be English[22]. This means, goods can only be transported via English ships from England and this policy was targeted at Dutch fleets as Netherlands was most efficient and advanced in terms of goods fleet[23]. It was hard to match the technology of Dutch ships and their fleet efficiency; it forced other countries like Spain, Portugal, and England to invest a lot of money in development of efficient merchant fleet. They subsidized the ship building industry, tried new materials and reduced taxes in the building of commercial ships. This resulted in two things, countries started to realize the importance of foreign trade and importance of good transport network in manufacturing. Countries understood that in order to have high financial gains, they should push exports which will eventually dictate their prosperity. Second, they apprehended that if they have to raise the manufacturing scale to a high, they must need efficient and smart transport mechanism. This lead them to invest heavily and this saw the rise of efficient ships and this was also the era of invention of motor powered cars. Another interesting phenomenon that happened in that time was the order of England government to capture Dutch sea bulk freighters to steal their technology. Dutch shipping industry was most advanced and competent in the start of $17^{th}$ century[24]. So, England literally captured their fleet in order to dismantle and try to reverse engineer to steal their technology. These were first recorded instances of international industrial spying and reverse technology. They copied their technology and invested hugely in commercial shipping and eventually were able to build ships that were as efficient as Dutch ships.

The Seventeenth century saw the most rapid advancements in the agriculture sector compared to past as metal plowing tools were invented and widely use. Better harvesters and powerful metal tools helped to irrigate tough lands which was not agricultural able in the past. In 1620's, first factory or industrial complex was developed for silk weaving at Spital fields in England mainly from groups who migrated to England from France. This raised the income from agriculture as well as manufacturing and England was the first country in introducing social welfare system in their country indicating huge financial reaps from advancements and investments in manufacturing[25].

France was the country other than England which saw the rapid advancements in the manufacturing industry. Louis XIV was the first French ruler who increased financial allocations to civilian industries and manufacturing. He realized that not only war ornaments, but financial and manufacturing supremacy would decide the course of wars in future. He subsidized industries in France and invested hugely in metal related industry. He also spent money in superior shipping yards and war ships. Russia and Germany were involved in wars within their country and were not able to focus on manufacturing. With England policy of promoting exports, there was a rise in export of goods from England to Russia. This made Russia also invest hugely in the manufacturing industry and rulers started to invest in big industries where local businessman could not invest. So, this century saw the appearance of numerous industries in Russia which was nonexistent during the sixteenth century. So, in Russia, the government owned all major manufacturing industries compared to England where industries were in the hand of private people. This resulted in different style of manufacturing, with Russian industries lacking in quality and technology and English industries dominated by entrepreneurships and smart manufacturing. In the start, Russian rulers were not interested in the shipbuilding industry but in the later part of century, they invested in the shipping industry and were even able to export ships to Europe and other countries by the end of seventeenth century and had improved their manufacturing quality.

China went through the same pattern in the seventeenth century as the start of seventeenth century saw the decline of the Ming dynasty and China soon realized that they were far behind in military weapons and civilian manufacturing compared to other parts of the world[26]. This became more evident when English ships bombarded their port in mid seventeenth century and China had no reply to the superior war craft of the English. This made them to invest largely in military and civil industries which brought technological advancements and financial stability in their region[27].

Latin America and Japan were more silent regions during the seventeenth century[28]. As America was in very early stage of manufacturing and living was still about food and natural resources, Japan started to invest more rigorously into civilian manufacturing. They had invested particularly in agriculture and metal industries. They also subsidized their industries and invented few modern agricultural ornaments and tools.

Silk production formally started in the seventeenth century and flax production became popular in Virginia. The Dutch Loom was invented in 1604 and this opened new doors for better quality clothes and this started the era of fashion and expensive clothing. Ruff was also developed which changed the course of clothing specially in England while other European countries were still stuck to traditional Spanish clothing and wearable's[29, 30].

Early automobile manufacturing companies were Panhard et Levassor, Winton, Oldsmobile, Cadillac, and Ford. First small steams car were manufactured in 1678.

Other industries that grew significantly were the production of drugs to treat people and the brewing of alcohol. Though alcohol was previously consumed on large scale but there was no proper process for its brewing. Due to this fact, earlier this had resulted in production of poisonous alcohol which killed many people in early time. It was around 1607, when first brewing factory was established in pursuit of production of safe alcohol and also on large scale[31].

Before $17^{th}$ century, the centers for industrial manufacturing were Venice, Ghent, Milan, Japan and England. The major technological advancements were ribbon frame (1604), improved pickling process, butter churns, and better ship designs, fueling mills, wind powered sawmills and better fueling mills. Germany was able to develop slitting mills and it started a trade of silk and raw wool[32].

To conclude, the first half of the seventeenth century saw the decline or hard time in manufacturing but the second half brought prosperity and brisk advancements in manufacturing across all over the world. This was the first century where there was a little decrease in the wars which resulted in the regular investments in the military manufacturing and increase in investments in commercial manufacturing and industries. Seventeenth century could be termed as a silent century for manufacturing as nothing much significant happened during this century but after seventeenth century the, manufacturing flourished exponentially and all the political, geographical settlements during seventeenth century basically paved path for all manufacturing miracles of eighteenth and nineteenth century.

### 2.1.3 Eighteenth Century

In the early part of the eighteenth century, products were still being produced in batches and had all reliance on manual labor in all parts of their production stage. The biggest step in manufacturing that is attributed to eighteenth century was that the machines started to take place of artisans. Previously, machines were developed which were used just to aid or assist labor in production processes but the eighteenth century saw the invention of machines which could do some part of job of their own without the human intervention. Machines started to produce or use some of energy to do their tasks. Steam engines and water wheel to produce energy which could power machinery were invented which opened up unlimited opportunities of production. Manufacturing started to become a little independent from labor needs and skills. Water and steam power were first sources of energy to run machines and this energy powered machines became very popular in this century. Manufacturers started to realize that skilled labor could be replaced with specialized machines and this led to a decrease in products price and cost of labor. This was probably of one the biggest steps forward in the manufacturing industry as later it paved path for more intelligent automated machines which are a hallmark of today's manufacturing industries. In today's world of the twenty first century, no one can imagine a production system which does not run on any source of energy.

An important step ahead in manufacturing which occurred in eighteenth century was the introduction, production and use of identical interchangeable parts. Eli Whitney was the person who introduced the concept of identical interchangeable parts as before no two parts could be produced identicals and always needed a lot of hand fitting in order to replace a certain part with new one. This opened up a new era of manufacturing as production now has the capability of producing two exact parts which reduced the downtime to a considerable extent and production rate was improved to a great extent.

The Eighteenth century also saw the increased use of steel in manufacturing and malleable cast iron and solid iron rods were produced which could be used for variety of purposes.

Adam Smith was a renowned Scottish philosopher and is famous for his books particularly 'The wealth of Nations'[33]. Though, he was a famous economist and moral philosopher, he gave one of the most intriguing ideas of manufacturing processes in his time. He explored and discussed the importance of phenomena that manufacturers can or should constantly reorganize their labor and divide tasks into smaller chunks which could be assigned to a smaller group of labor teams. This introduced two very important aspects of modern day manufacturing: tasks should be divided into smaller step by step tasks and there should be organized small teams for each task. Previously, production was considered a single big job and all labor was forced to accomplish that job. Dividing jobs into smaller narrower chunks allowed more systematic approach to production, introduced specialization in small tasks and then to take better advantage of labor, they could be divided into smaller teams. This meant that now these small narrow tasks could better be mastered by the workers and they can look to improve in their own local domain of their assigned tasks. This also introduced the concept of teams in the manufacturing process. Now, manufacturers could divide a problem into smaller simplified problems and try to achieve their tasks thorough solution of these smaller problems. These smaller chunks of work gave better visualization to manufacturers to vision what tasks can be completely replaced by these modern energy powered machines.

The most important development of eighteenth century probably came from the ever-great Benjamin Franklin. In lieu of his desire and efforts to control electricity, he put a kite in the thunderstorm in 1752 which enabled him to the manufacture of electric rods[34]. He realized that electricity could be used for human benefits and will be a key factor of modern manufacturing[35]. The use of electricity in manufacturing or realization of the fact that machines could be run on electricity was very limited or oblique in the eighteenth century. Steam or coal power remained at the center of energy sources for machines of that era.

Another important invention of century was the development of the cotton gin which help southern America to strengthen itself financially[36]. The cotton gin was the machine to clean cotton which could remove hundreds of seeds those plants develops. Most of the developments later in America were due to benefits reaped by the development of these machines as America later became one of the largest manufacturers of clothing and cotton products. In 1785, the first automatic flour mill was established in USA which is considered the beginning of modern day efforts to handle bulk materials[37]. Oliver Evans built this semi-automated mill which used leather belt bucket elevator, belt conveyers and other automated parts. This can be considered as first efforts to move towards automation.

As in previous centuries, the history of manufacturing revolves around the military and this century was no different. Due to latest developments in the world, rulers from Britain, Europe, China, and North America invested hugely in military developments. North America in 1710, introduced first riffles in the world which were long range and more accurate than any other military animation known at that time. Rifles became very famous in a short time and shortly became most traded and produced item in the early part of eighteenth century. It helped North America to build financial reservoirs which helped them in their development and a lot of money also flowed into civil manufacturing. Rifles and guns were first started to be manufactured in factories in the second half of eighteenth century or start of industrial revolution. The East India Company of Britain, along with the largest manufacturer of guns and rifles was also the largest buys of war largely due to their efforts to occupy south Asian sub-continent countries. This resulted in an interesting situation in gun manufacturing industry as for all other companies; the East India Company was their biggest competitor and also their potential most lucrative buyer. This thing helped in joint research in war and the gun industry was one of the most lucrative and economically stable industries of eighteenth century.

In 1712, Thomas Newcomen invented first atmospheric steam engine[38]. It was the first machine which used energy on a large scale and provided the much-needed power in the industry. Previously, moving heavy objects or building of large machines was not possible as those had to be operated by available human power. The steam engine had much larger power and this power could be used to handle very large machines and move heavy objects. So, this invention literally changed the scale of production and size of machines. Later in the century in 1783, the French were able to invent first steam Wagon and use of energy powered machines made a greater leap in transportation industry[39]. Later, French were also able to develop steam boat and use of steam to power transportation machinery became very popular and standard. Henry Cort in 1783 also invented steam roller which was used for the production of steel sheets[40]. This meant that now, steel could be shaped in the form of equal width sheets and can be transported and used easily.

Another invention of eighteenth century which later became an important material in manufacturing industry was the refinement of rubber. Importance of rubber in the production industry was realized and a lot of investment was made to produce rubber products or use rubber in different machines. In 1798, liquefaction of gas was also made possible and this introduced a new source of energy for powered machines in the years to come[41].

As machines were developing fast and countries had started to export and import products, there was a strong requirement to introduce some form of standardization in manufacturing. In this effort, first global metric system was introduced by French in 1795[42]. A lot of countries readily adopted this metric system as it helped them to understand the manufacturing needs, specifications and demands of market and trading countries.

In mid of eighteenth century, there occurred the famous landmark of manufacturing history commonly known as first industrial revolution. Though, this industrial revolution is predominantly associated with British or European countries, but in the later stages of this revolution, it also affected North America. This industrial revolution brought not only technological advancements and changes, but it also changed altogether the concept of human labor, social structure of families and thoughts of the individual. Before the mid of eighteenth century, Europe and other parts of the world were predominantly agricultural and industrial manufacturing was making very slow strides. The European and British economies were agricultural based economies and major population was living in villages. But in the same time, the European trade has expanded to all parts of the world except Antarctica and this offered them with huge market for their products. This was one of the compelling reasons for Britain and Europeans to think about an industrial based economy. Why other countries didn't join in this revolution first was because of the fact that European and British economy had become the sort of Global economy and was driving force in the market. Any such revolution was only intended to benefit the wealth of Europe and Britain, that's why other countries remained quiet during the start of this industrial revolution. Another reason given by historians about this industrial revolution was the increase in the population of the Europe. Clouds of war had reduced in the Europe and people started to have better family lives, there was a growth in the population and this required more resources and more labor jobs. Another significant reason of the rise in the population was that many skilled people with wide range of skills were travelling to Europe in search of better jobs and modern way of livings. Europe had attracted a great amount of talent from all around the world and this industrial revolution was driven by migration of skilled people to Europe.

Historians are a bit oblique about exact timing of this revolution but all of them agree that it originated in England. Compared to major part of Europe and other parts of the world, British parliament was dominatingly under the influence of corporate tycoons and capitalists, so it was natural that most suitable policies and lucrative strategies were laid down for manufacturing and industrialization. This allowed them to rapidly increase and spread trade to other parts of the world. In fact around 1780's, one third of their exports were going to North America and they also began to dominate the Indian trade. Cotton was the plant grown abundantly in America and India[43]. Most of the cotton was grown in British colonies and African slaves were also trafficked to these British colonies as it was a source of cheap labor. But, cotton needed to be spun into thread and it was done via a machine called a flying shuttle which had the capability to handle one thread at a time. In 1767, the spinning jenny was patented which was a series of combination of sixteen simple machines and could handle sixteen threads at a time. This machine which was a combination of simple machines and it could be used to replace the work of several labor was the first great hallmark of first industrial revolution[44].

The Eighteenth century will be remembered for inventions which became integral part of today's manufacturing industry. In 1724, Gabriel Fahrenheit invented the first mercury thermometer and it started the era of using sensors in production[45]. The use of sensor in production was still unknown as there was no automation or sensor driven machines. But it opened up new horizon to sense and measure different physical phenomenon. In 1761, an Englishman John Harrison invented marine chronometer for measuring longitudes and this was a huge advancement in the sea transportation[46]. In 1783, Benjamin Hanks patents it first self-winding clock. So, there was a wide spread need and desire to measure things and create a useful information[39].

The first industrial revolution predominantly happened only in England or at least the first phase entirely belonged to England. The British were very well aware of their technological, industrial, and economical dominance and wanted to make most of their head start. In lieu of this, they forbade the export of technology, machinery, and skilled workers. This helped them to earn huge benefits from the first phase of industrial revolution and their strong monopoly ensured that whatever progress or advancement took place at their colonies; it will only benefit England and its industry. As British saw enormous natural resources and potential in their colonies, they were not able to refrain themselves from exploiting these opportunities overseas. In this effort, Belgium was the first country in Europe to bag benefit of first the industrial revolution when two Englishman established machines shops in Belgium. The Belgian part was largely limited to coal, steel, and textile. France, considering its history, was expected to compete with Britain in the first industrial revolution but they were busy with their revolution and political crisis and were not able to match the British or Belgians in that era. Other European countries were also far behind to match wealth, resources and power. Countries like Germany and Holland were facing similar political ordeals and were facing internal unity issues. America and Japan were very similar in this regard and were only valued in the industrial revolution of nineteenth century.

An important invention of eighteenth century which does not became very famous at that time was the invention of Leyden jar by the E.G. von Kleist in 1724[47]. Leyden jar are considered to be very first and raw forms of today’s electrical capacitor. This was an important hallmark in production industry as it forced researchers to think about storing power to increase its strength which could be helpful in huge machines. In 1799, Alessandro Volta invented the battery which is one of the crucial milestone of today’s manufacturing industry and modern life style[48]. All of these inventions and efforts were indicative of the fact that researchers knew that electricity will lie at the heart of all manufacturing endeavors of the future world.

Eighteenth century presented this world with a lot of inventions such as in 1709, Bartolomeo introduced the piano[49]. This invention shows that people were starting to think about their quality of life and looking for means to entertain themselves. In 1722, French C Hopffer invented the fire extinguisher[50]. In 1758, Dolland invented chromatic lens[51]. One of the most widely used food commodity also bags its invention in eighteenth century when Joseph Priestley in 1767 invented carbonated water[52]. Later in 1798, the first soft drink was invented and introduced in the market. In 1774, first electric telegraph was patented which effectively meant that information or messages need not to be carried along with commodities and can be transferred at much higher pace or speed. In 1776, first submarine was invented by David Bushnell. In1780, Benjamin Franklin invented the first bifocal length eyeglasses mainly because of his own increasing impairments to see close and far objects simultaneously[53]. First Parachute was also tested in the same time when Louis demonstrated it in 1783. Safety locks were invented in 1784. Very early forms of bicycles were also seen in Scotland in 1791[54]. First ambulance was built and used in 1792. Preserving food was becoming an increased area of concern and first food preservation jar was patented by Francois Appert. There were advancement and research in the field of medical as well as vaccination for smallpox was tested in Edward Jenner in 1796. The first metal lathe was also invented in the later part of eighteenth century.

Before the industrial revolution, people were living in small houses, strenuous conditions of living existed and people had to work hard to make both ends meet. They had to grow their own food, manufacture their own house hold equipment and textile in their own small home based job shops. Industrial revolution brought great development in the lives of middle and upper class and raised their standard of living. The industrial revolution introduced factory produced goods into the market and products got cheaper and more standardized. This resulted in transformation of British and European rural areas into urban advanced industrialized areas offering many opportunities of skilled labor jobs. But the condition of poor and lower class remained the same as these factory jobs were largely underpaid and offer hazardous working condition and environment. There existed no job security especially unskilled labor was under more threat as they could easily be replaced. Child labor and abuse was on a rise and almost one fifth of the Britain textile workforce comprised of children less than fifteen years of age. Children and low class labor was forced to work long hours, exposed to notorious chemicals and children were also forced to clean parts of machines and factory waste. There was more flux of labor coming from rural areas and other parts of Europe which resulted in crowded housing and unhygienic sanity and living conditions.

To conclude, eighteenth century or more specifically industrial revolution brought technological and social and cultural changes. The major social changes involved better banking and economic solutions, first stock exchange was established in London in 1770's and first American stock exchange was formed in 1790's[55, 56]. Legislations to support industrialization uplifted British colonies and cheap factory products. There were also great advancements in agricultural industry and this helped to counter problems of hunger. Due to advancements in medical research, cure of some very deadly epidemics were found which helped to increase the life span of people. The main technological features of first industrial revolution include use of energy in machines and new form of fuels like steam power, coal, electricity, petroleum products and internal combustion engines. The new large scale machines like spinning jenny and power loom which replaced or reduced human energy and increased production. The materials like iron and steel started to replace wood and clay and other forms of materials. There were rapid advancements in the field of communication and transportation like telegraph, steam locomotive, parachute, hot air balloons, bicycle, steam ship and automobiles. But the most important development of industrial revolution was the introduction of new form of work organization known as factory system in which there was an increased division of labor and more specialization of function. This was the actual beginning of an era of mass production.

### 2.1.4 Nineteenth Century

Early part of nineteenth century is considered as the second half of first industrial revolution, in which industrialization spread from England to other parts of the world as well. The machines were briskly taking over animal and human muscle energy and factories were becoming capable of mass production. As the industrialization spread to the United States and Europe, there were series of new inventions in the nineteenth century and many of the existing machines were improved during second industrial revolution which happened in second half of nineteenth century. Advancements in petroleum and electricity introduced small and powerful motors which revolutionized the transport and production industry and both of these became major sources of energy and fuel. Advancements in Agriculture and medicine were also notable. The social and economic life of people changed considerably during the first industrial revolution but it changed dramatically during the second industrial revolution especially for people living in Europe and North America. But the nineteenth century is termed as 'age of machines' or 'century of tools', as a lot of different machines and tools were invented, the idea of machines that are composed of several different small parts and machines that can produce interchangeable parts for other machines were the highlights of nineteenth century. In terms of manufacturing, the biggest advancement was the introduction of Assembly lines in manufacturing process. Assembly lines speeded up the production rate and factories began to be more organized and task oriented. After interchangeable parts, assembly lines were a big milestone in manufacturing industry.

American manufacturing industry grew substantially in the early part of nineteenth century. The man responsible for American industrialization was Samuel Slater who worked at cotton mill in England[57]. He was intelligent and soon he became the supervisor of the mill. He was well versed with all machinery and processes involved. At that time, there was a ban on mill workers to leave country and no paper was allowed outside the mills. He slipped to New York under the disguise of a voyage and had plans in his mind. He established eight fully functional textile mills in first decade of nineteenth century around Rhode Island. A tariff laws by Congress between 1815 and 1826 safeguarded American manufacturing and textile industry from overseas competition. It helped them to grow at their own pace and allowed them room for experimentation and research. At the same time, the nature of workforce was changing as the line between skilled and unskilled worker began to grow and people were transforming into a specialized machine operator or factory workers. The advancements in agriculture were also massive as new ways of ploughing, especially the steel plow, became popular and common. Spinning cotton into the thread machine was already developed in eighteenth century but British rulers of that time prohibited export of the machine and technology to foreigner land but late eighteenth century and early nineteenth century saw some of Englishman travelling to America with plans to build the cotton textile industry in America due to large and cheap production of cotton in America at that time. Also, the labor was cheaper in America and they saw huge potential and opportunity by investing in textile mills in America and reaping the above-mentioned benefits. Eli Whitney, who became very famous for producing interchange parts for machines in eighteenth century, increased its accuracy for parts and got large orders from the American Congress as this had increased factory efficiency and decreased labor cost. In 1846, the sewing machine was developed and later enhanced by Isaac Singer which changed the clothing industry altogether. The textile products that were produced in England were cut and transformed into shirts, pants and other fashionable clothing in the Northeast of America as these regions were close to rivers which provided water energy and also easy means of transportation. In the same way, Pittsburgh was center of iron and steel industry as it had a lot of ore and coal mines. Ohio became center place for meatpacking and dairy products. This was the start of era where sources of energy and transportation were becoming prime factor in the location of industries. This is mainly due to the fact that now industries were able of mass production at high efficiency.

The most important invention of early nineteenth century was the invention of electric telegraph. In 1844, electric telegraph was successfully experimented and used in a commercial project[58]. This opened a new era of communication and people were amazed that how quickly information could be transferred over telegraph lines. This practically meant that now, along with communication being faster, the lead time from order to delivery will reduce significantly as orders can be placed or intimated over phone and messages could be transferred over electric telegraph instead of meeting and longtime taken for travelling to these meetings. A huge investment was made in rapid deployment of telegraph lines and they stretched from coast to coast. This also give a projection to journalism as information can be now communicated very fast and number of newspapers in America rose from eight to four hundred by the end of 1860.

The new factory system in which production process was divided into smaller narrow chunks of task, division of labor to carry each of these smaller task chunks and replace labor with machines where able possible to do a specific task. This factory system improved further in the nineteenth century with sense of separate departments based on the nature of the work. The concept of the assembly line was realized and factories strove for multiple assembly lines with in a same factory. Also, the concept of specialization began to become stronger as each stage of manufacturing needed specialized skilled labor and expertise. Also, the importance of research and development for industries was realized and the term 'scientist' was first used in nineteenth century. Industries started to employ people who were responsible for improvements of different steps involved in the production line. Previously, all research and inventions were done out of factories.

A textile mill in which spinning and weaving was all done by an energy driven machines was established at Massachusetts[59]. At that time, women were also a considerable part of a workforce. Though they were paid less compared to men, had to live in factory dorms and work twelve hours a day, they enjoyed more liberty and independence compared to their mothers and grandmothers. But, they were eventually replaced by Irish immigrants in late 1840's and 1860's as there was in increased flux of labor coming from overseas specially from other British colonial territories due to booming nature of American industries.

All of these inventions and outburst of machines meant that labor can be replaced easily and less demand of labor in the factories. This resulted in tension between factories owners and laborers and laborers retorted to formation of unions in order to protect their rights. First, politically recognized trade union in America was formed in 1830's and the first strike of workers in America occurred in Philadelphia in 1835. It was the time, when there felt a need for legislations about labor rights protection and work environment. The very first and prime demands of laborers were the reduction of work hours to ten hours per day and payments for labors who got injured in factory accidents.

The focus of nineteenth century which also changed the manufacturing industry was increased focus on electricity. Though, by end of eighteenth century, water, petroleum and coal emerged as main source of energy and were widely used but soon after experiments by Benjamin to use electricity for a practical purpose, there was a firm belief that electricity will be the major source of energy for machines in the future. In this regard, the first major advancement was made by Italian scientist Alessandro Volta who invented first chemical battery in 1800. This battery was majorly used to spark a plug or initiate a particular process. So, it was an important milestone for future automation based manufacturing. In 1859, French Gaston Plante invented first storage batteries and it was a major breakthrough in electric based manufacturing[60]. Now, electricity could be stored and people started to see it as source of energy and in coming years, a lot of machines were invented who solely used electricity. Dry cell batteries were developed in 1870 and Thomas Edison batteries that use alkaline rods instead of an acid was also patented at the end of nineteenth century[61]. Thomas Edison was also experimenting with other electric process like bulbs that can last longer and at much cheaper price. In 1879, he was able to successfully invent incandescent bulb which lasted longer compared to all other bulbs at that time and was also cheap. The interesting thing is that factories were the first utilizer of incandescent bulbs as it improved lighting conditioning within factories and now most of the factories could afford to continue production in the night time. An interesting phenomenon mentioned by some researchers was that bulbs also improved the quality of products produced in the factories due to better lighting conditions. Ohm’s law, one of the most basic and most widely used electric law which still lies at heart of most modern inventions was realized in nineteenth century.

There were some major breakthroughs in information sharing and communication. The biggest breakthrough was the invention of radio by Italian scientist Marconi in 1895[62]. He invented a machine which could transmit and receive radio waves. This invention was the inspiration of another great innovation of telephone by Alexander Graham Bell in 1876[63]. He was able to transmit information over electric wires and this is one of the greatest inventions ever made in human history. This effectively meant that information could be transmitted over wireless or wired network. This led to the transmission of information over continents and this opened new era of research in the field of communication. The fountain pen was also invented in 1884 and this radically changed writing[64].

There were advancements in road transportation as well. The coal powered motorcycles were developed in 1867 that was two cylinder and steam driven. American scientist Sylvester Howard Roper invented this motorcycle that had two wheels. Later in 1885, Germans introduced gas driven motorcycles[65]. The first tractor was in invented in 1892 by John Froehlich. It brought revolution in the field of agriculture as now vast fields could be ploughed very easily and this tripled the production of agriculture in America within a span of five years.

The blueprints of automobiles which resemble cars of today's world were drafted in Germany and France towards end of eighteenth and start of nineteenth century. Carl Benz, Nicolaus Otto, Gottlieb Daimler and Emile Levassor were the forefront leaders in the development of first gasoline automobiles. Bicycle mechanics from Massachusetts named J. Frank and Charles E. Duryea developed first American gasoline car in 1893[66]. They demonstrated the usefulness of their invention by winning the first automobile race in USA and then were able to sale their gasoline USA made car in 1896. This introduced a sense of urgency and opportunity of great potential to investors of that time and a lot of different groups dived into the manufacture of automobiles. The growth was so vertical that almost 30 different companies were able to sell more than 2500 motor vehicles in just over three years.

A lot of inventions were made in nineteenth century which brought revolutionized changes in the social life of the people. Jeans were invented in the nineteenth century. Coca Cola was also introduced in same century which is still one of the most selling soft drink in the world. Factory produced potato chips were introduced in 1853 and paper bags became popular after their invention in 1852. As there was a boom in construction industry especially after the increased use of steel in construction, the buildings were getting taller and taller. The first elevator was invented in 1852 and long bridges were constructed thanks to strength of steel. Vacuum cleaner was invented in 1860 which helped further to develop technology of vacuum suction and vacuum locks[67]. As the machines were getting heavier and bigger, the lubrication system was developed to reduce friction between different machines parts which greatly reduced the energy losses and exponentially increased the life of machines. Air brakes were invented which greatly improved parachute and rocket technology. Refrigerators were invented by Carl Linde which effectively prolonged the life of food and other nutrition's elements. First Camera was developed in France and first recorded image dates back to 1888 by George Eastman. Industrial manufacture of cosmetics started and coupled with advancements in clothing laid the foundation stone of today's fashion industry. Internal combustion engine, transformer and Electromagnetic theory of light radically changed the face of technology at that time.

Along with productive inventions, there was also rapid development in military technology as well. Dynamite was manufactured by Alfred Nobel in 1866 which is still one of the main components of bombs these days[68]. Rifles were also invented to in mid nineteenth century which were a huge step ahead as these greatly improved accuracy and range. Since the early dawn of guns, only round balls were used in the guns. In early nineteenth century, Minie' Balls were introduced which is effectively first form of bullets and were not round in shape. Earlier, three different components, powder, wadding and a projectile were separately loaded into a gun which is then ignited by the external spark. Eventually, in 1847, a Frenchman named M. Houiller invented full metal bullet cartridge which had all three components embedded in it.

In 1843, the first ever computer program was written by Ada Lovelace[69]. The fax machine was invented by Alexander Bain which had a huge impact on the manufacturing industry as Fax machine was only primarily used for business orders and fast communication of production plans. The rotary printing press was developed which made printing process very fast and a lot of literature was published explaining the process and inventions of that time.

All of these developments, advancement and inventions affected the social life of people to a great extent. The Nineteenth century was the time when the culture of city living was originally developed and difference between city living and village life grew substantially. A lot of people migrated from villages, other states or even from abroad to cities which were booming with industrialization at that time. This introduced an added burden on the city services of the cities and condition of services worsened by the end of nineteenth century. The factory owners were very strict in their behavior with workers. Laborers were not taken care of well, with no medical insurance, life insurance or even injury insurance. Factories used to replace slow and old workers with young and energetic workers and there was no concept of job security. Often, whole families were destined to work in a factory as wages were so low that family could not exist on a single person pay. Political and economic corruption began to corrupt societies and the difference between poor and rich grew substantially. There was a sense of anger and hate among labors for their factory owners which eventually affected the manufacturing rate or production norms to a great extent. There emerged a need of intelligent and sophisticated methods to better utilize factory workers. It was exactly the same time when fields like engineering management, work management and project management started to take shape in the operation of factories. The concept of 'scientific business management' was introduced by Frederick Winslow Taylor in 1894[70]. Many nations were looked as a source of cheap labor and factory labors didn't had many opportunities to grow in their carriers. People from other nationalities were not offered better paying jobs and there was no concrete legislation protecting the rights of poor labor. The labor was exploited throughout the nineteenth century.

### 2.1.5 Twentieth Century

Twentieth century probably saw the most rapid and radical advancements in the manufacturing industry. It will be very safe to say that twentieth century had more developments and technological milestones than the whole history of mankind. From rockets to super computers, automation to programmable logic controllers, genetics seeds to powerful anti-biotics, machine gun to laser guided bombs, computational power to machine learning, atomic power to renewable sources of energy, emails to cell phones, Kanban system of manufacturing to sophisticated six sigma manufacturing, and assembly lines to robotic assisted manufacturing, all these are hallmark of advancements and achievements of twentieth century. The inventions and technological milestones of twentieth century laid foundation of all the advancements and progress of twenty first century.

The technological development or history of manufacturing in the twentieth century can be easily divided into two distinct eras. The start of twentieth century till 1945 was dominated by two world wars which effected social, economic, and industrial developments of this time period. The second era of 1945-1999 is a hallmark of extraordinary inventions and introduction of new process and technologies in manufacturing. There is a distinct difference between manufacturing norms of early twentieth century and later part of the century. The first atomic bomb at Alamogordo, N.M in July 1945 changed the social and economic preference of the world and different countries devoted themselves for the industrial glory and different regions of power and technological supremacy emerged in twentieth century[71]. There emerged a growing fight and tension over natural resources between different nations which resulted in stress and war between different countries.

The most important milestone of manufacturing industry came in the start of twentieth century when organization of industries and manufacturing became aware of self-conscious innovation management. This effectively meant that factories and industries started to look for means and technology to improve their efficiency, production, and quality. This self-conscious motivation resulted in many small important developments which improved manufacturing to great extent and new procedures were introduced which radically changed the outlook of manufacturing at large scale.

Start of twentieth century is marked with one of the most important milestone of manufacturing industry Henry Ford and assembles line. As factories were eager to improve their efficiency, quality and reduce cost, Henry Ford introduced moving assembly lines to the manufacturing world. In lieu of this effort, Henry Ford being ambitious about manufacturing improvement announced that he wanted to build ‘a motor car for the great multitude’. The greatest hurdle at that time was the cost and time required to build one single car. As car manufacturing was a highly skilled task, specialized workers used to build different parts of the car which used to take a lot of time and efforts. Those specialized skills didn’t used to come at low price and this adds to the cost of manufacturing. Further, once a specific worker produces a part, only he was able to fit that part in the car as he used to understand the dynamics of that part better compared to other workers. This effectively meant that unless he is done with his work, nothing else can be done on the car. This used to eat up a lot of time and makes whole manufacturing process very time consuming, costly and lethargic. Also, the quality of each car was different from others as it was dependent on the skill level of the workers who have produced that car.

In 1907, Henry Ford, announced to produce the Model T, a very simple car with almost no factory options[72]. He has done that to produce very similar car which can help to reduce the cost and speed of manufacturing. People didn't have even choice of color or interior as Henry Ford wanted to reduce time by making exactly same car. Although, it reduced the cost of Model T compared to other cars, but it was still costing around $850 which was still out of reach for general public. Henry Ford and his engineers were eager to reduce the cost of car and also wanted to have mass production of the car. He and his teams observed other industries like meat packing plants at Chicago, brewing industry, flour mills and industrial bakeries and also critically evaluated their own industry and realized four important principles which could help them to achieve their goal: Interchangeable parts, division of labor, continuous flow and reduction of wasted efforts and resources.

First of the identified target was the better usefulness of interchangeable parts in the manufacturing. This meant that they needed to produce each part in exactly the same way every time so that it can be fit into any car. This meant that they needed a lot of common part which will fit into different models too in exactly the same manner. This brought them to realize that they needed to improve the part manufacturing machinery, cutting accuracy and standardization of dimensions of different parts. It was a difficult task, but once done, it could only require a low skill labor to fit that part in the car effectively eliminating the need of the highly skilled labor which used to produce each different part by hand and fit in the car. To improve the flow of work and reduce time, tasks were needed to be arranged in such a manner that as soon as a task is completed, the next scheduled task begins by minimizing the time needed for setup. This helped them to reduce the time required to manufacture a car and gave the practical demonstration of continuous work flow. In the meantime, Henry Ford and his team observed the conveyor belt used in grain mills and meat packing plants in Chicago. They realized that if they can bring work to workers instead of workers wondering around for the work, they can effectively reduce or minimize the wastage of resources or human efforts. This meant that workers will waste less time moving around and devote that time in actual manufacturing. In order to realize the division of labor goal, he divided Ford Model T 3000 different parts into 84 distinct tasks and then trained a group of workers for each specialized task. It means that a specific group of workers needed to do just one step in the production. In an effort to improve process further, Henry Ford invited Frederick Taylor, the inventor of the concept 'scientific management' to do movement and time analysis of his production and to determine the steady speed at which work should execute and exact patterns of movements by the workers to accomplish task at that speed. He came up with a speed in which rope pulls a car chassis at a rate of six feet per minute while workers perform their specific task on the car chassis.

After continuous efforts, fine tuning, determined testing and critical analysis, after 5 year on Dec 1, 1913 Henry ford introduced the concept moving assembly lines to the manufacturing world[73]. With his efforts and this new concept of assembly lines, he was able to reduce the manufacturing time of Model T from 12 hours to two hours and 30 mins. He was also able to reduce the cost of car from $850 to $300 and make it available to masses of general public. Ford was able to manufacturing at a record pace and radically changed the manufacturing process of number of industries. In February 1914, he also introduced mechanized belt which added some sort of automation in the process.

Another remarkable contribution of Henry Ford which is not much talked about in published literature is that he raised the wages of the employees to $5 per day. He introduced this competitive wages as he believed that happy worker can dedicate his time more efficiently and can produce better results. This is one the prime lessons to be learnt from Henry Ford as pay can increase the efficiency of workers. Also, he was of the view that if he will raise the wages of employee's, then in turn they themselves will become potential buys of his car and this will also improve their loyalty to Ford.

**Figure 2. First ever Car of Henry Ford in 1896**

**Figure 3. First draft of famous Model T in 1908**

**Figure 4. Henry Ford Assembly line in 1913**

Shortly after the concept of automation became popular in manufacturing, there was an important milestone in the production world. Programmable logic controllers were introduced and rapidly became very popular. It was the first instance when a same physical hardware or machine can be used for a wide variety of task and their work solely based on the logics implemented at the industry. Before the advent of programmable logic controllers, the most famous control units or switches used in the industry were relays. Most relays had a motor and coil and make use electromagnetic concepts to turn the motor with magnetic resonance produced when electrical current is applied through the coil. Relays were primarily used as switches and were employed to implement and control different logics and valve operations. So, in any manufacturing industry, there are usually a lot of machines with different motors and valves and they were needed to be controlled in a specific logical pattern to get the desired results. This effectively meant that hundred and thousands of relays were used in the industry to perform a specific task or to produce a specific task. All of the relays were needed to be hard wired and in the right order inside the control panel to perform any task in desired manner. This led to a lot of problem faced by manufacturing industry of that time as these relays worked on electromagnetic principle, which means that very often, they can fail. Contact failures were very hard to diagnose and happened very frequently which make diagnosis of any error in a control panel hard and time consuming. Also, if there is a change in the logic, all of these hard wires were needed to be rewired which was a very tedious; time consuming, expensive and error prone task. All of these hundred and thousands of relay needed power which was also an expensive energy burden. Difficult and time consuming rewiring and frequent malfunctions of relay system were one of the prime factors which affected the industry of that time especially automotive industry.

Before 1960, combination of thousands of relays, different closed loop controllers, drum sequences and timers were used in automobile industry for manufacture of cars. Modification in production system required rewiring hard wires which makes modifications difficult to execute and expensive. So, finally in 1960, programmable logic controllers were developed for American automotive industry to replace these relays based logic controllers with software based changes to update production modifications. In 1968, GM hydromantic requested proposals to replace their relay circuits with something more efficient. Bedford Associated won the contract and produced first ever PLC's with the name Modular Digital Controller (MODICON)[74]. Richard E Morley of Bedford Associates is considered to be the founder/inventor of programmable logic controllers. So, GM is considered to be the first company and automobile the first industry to use PLC's in their production plants. Introduction of PLC's meant that now there was no need of rewiring hard wires, replacing relays and change of control panels. Production modifications can be easily done using the ladder logic of PLC's. This revolutionized the manufacturing industry as now industries had more liberty of customization, quality control, reduced downtimes, and less money for change or upgrade of their industry. In 1970's, Modbus was introduced which was the first communication network to pass signals between different nodes. In 1980's PLC's software were developed which could run on personal computers[75]. This meant that there is no need for handheld programming devices or dedicated programming terminals. The development of PLC's technology around this era was enormous and this PLC technology evolved further to include Distributed control systems (DCS), motion control, process control and other complex networks.

The advantages of PLC's were very dominant and within no time, it changed the face and orientation of manufacturing industry. Different industry aggressively deployed PLC's based control units to replace relays and automobile was still the largest industry to use PLC's. The prime advantages of PLC's were that they were adaptable, meaning that they can be programmed for different applications very quickly. They were able to handle complex control systems and were very cost effective. It was easier for engineers to trouble shot and PLC's proved to be more reliable. They are good for years before they should be replaced. So, invention and use of PLC's in manufacturing will always be considered as one of the most important milestone and achievement which radically changed the manufacturing industry of that era.

There was always a unique, hidden, ambitious idea in the deepest layers of human brain that prime purpose of science and technology is to develop and invent machines that can assist and take over some of work of human beings. May be, there should be an invention through all the practical utilization of technology advancements where machines should do on behalf of humans or for humans. With the invention of numerically controlled machines, in other words digital machines and acceptable benefits of computers in 1950's along with concepts of automation and increasing using of intelligent sensor in manufacturing industry, the desire to develop an industrial robot was becoming overwhelming. But it is important to mention here that idea of a tool or machine capable of performing human labor came from Aristotle in 320 B.C. when he said “If every tool when ordered, or even of its own accord, could do the work that befits it… then there would be no need either of apprentices for the master workers or of slaves for the lords” [1]. So it is safe to say that ultimate goal of technologies employed in manufacturing is to produce a machine which could do work for human beings.

The first industrial machine aka robot that can be used in the industry was developed by George Devol and Joe Engelberger. George Devol is considered as the father of industrial robots and he is also credited for introducing the term Universal automation. He founded a company named Unimation to build robots and find their applications in industry. The very first robot developed by George Devol was capable of moving an object over a distance of twelve feet. In 1960, American machine and Foundry, marketed a robot named Versatran which was developed by Harry Johnson and Veljko Milenkovic. Unimate was the first industrial robot developed by Unimation to be used by major manufacturer. General Motors installed it at its New Jersey plant in 1962 for spot welding and extracted die casting. An interesting fact about Unimate was that it costed $65000 to build it but was sold for $18000 to GM motors. With its immediate benefits, GM ordered 66 more of these robots and in an effort to keep pace with GM motors, Ford also showed interest in their purchase. All this was a very clear indication that future and market of industrial robot is very bright and promising.

Different industrial robots with multidimensional qualities continue to evolve during the 1960’s and 1970’s. A lot of different industrial robots were developed during this era with wide range of application and capabilities. This ensured a lot of competition among companies to produce better and more capable robots and this drew a lot of funds for research and technological development of industrial robots. Especially after the development of integrated circuits and micro-controllers, there was a brisk increase in the development of industrial robots which were apart from powerful, were also cost effective and can handle complex tasks.

In 1963, Rancho Arm, a six-joint robot was developed to assist handicapped. Same company also developed Tenctacle arm in 1968 which can lift a person and had 12 joints. As need for industrial robots were increasing but the problem was that different industries required different types of robots. So, in 1967, company named ABB developed its own robot for its own specific needs. It was the first instance when a manufacturing company produced its own robots for its company specific needs. They developed a robot which was capable of painting different types of objects in their assembly line. In 1973, a company named KUKA developed a robot called Famulus which had six electromagnetically driven axes[76]. This concept is still very famous in today's world of robotic assisted manufacturing. In 1974, a robot which makes use of pressure and touch sensors to provide feedback for assembly of small parts was developed by Professor Scheinman. They named it Silver arm and it was the first robot which used minicomputer as its central processing unit[77].

Another important milestone in twentieth century was discovery of nuclear power which resulted due to ever increasing demand of power or energy resources from industry. All the other form of energy resources was polluting the environment at the rapid scale and there was loud noises coming from civic society about means to control this environmental pollution. Nuclear power solved problem on many folds as it didn't pollute the environment and it means that industries can use it without worrying much about environmental laws. Second, it was very efficient which meant that industries can make use of it to become more profitable and reliable. Third, it was practically unlimited and it was an important industrial parameter as it changed the way industries used to look at energy resources and were dependent on geographical, environmental and social economic factors. Previously, location of industries was highly dependent on the location of energy resources near them to assure the fast and interrupted supply to power up the industry. Nuclear power meant that now industries can be set up at any location without worrying about the environmental pollution, energy source location and distance from the cities. However, twentieth century also witnessed one of the most destructive uses of this energy as well in the form of Atomic bomb. When USA dropped an atomic bomb in Japan, there was a strong resistance about use of this energy source as if not used wisely; it could be the source of human destruction worldwide. This slowed the progress and research in the field of nuclear energy as there were sanctions on its research and open sale of its equipment. But if used in controlled and safe environment, it helped industries to be more efficient and paid way for products which required large energy sources for a longer period of time. Nuclear power is being increasingly used to produce electricity and if handled carefully, it can be enough to power whole city.

The technological development of second halve of twentieth century was laid down by an important innovation “Transistors”. Transistors are known as the stepping stone of digital world[78]. In 1947, a replacement for bulky, large vacuum tubes was found in the name of transistors which laid foundation for today’s semi-conductors and silicon chips embedded on a single board providing processing power and speed which was not reliable in the first half of twentieth century. Bell telephone laboratories of USA in 1947 invented transistors with helps of John Bardeen, Walter H. Brattain and Willian B.Shockley[79]. It was only due to transistors that human race saw the development of fax machine, personal computers, memory storage devices and thousand and millions of different control units employed in industries to control process at higher reliability and speed. This radically changed the efficiency out of the industries and helped industries to produce at much larger scale. In 1958, the first integrated circuit which was a collection of transistors to implement logic on a single silicon chip was developed and it barked loudly about the modern era of digital computing. Another key milestone which was made possible due to transistors was that now complicated electrical circuits can now be made on very small pieces of silicon or other semi-conducting materials reduced the size of the components and machines to a miniaturization to microminiaturization.

An American physicist Theodore H. Maiman in 1960 invented Light Amplification by stimulated Emission of Radiation aka Laser[80]. Apart from its use in many applications, what it essentially brought was accuracy in many industrial application and process. Still laser based bar code readers are used to read about product with much greater accuracy and at much larger speeds. It also revolutionized the medical industry as it is replacing some surgical process and is successful as there is not physical interaction with the human body. Lasers are actively used in the military world as well in the form of laser guided missiles which means more accurate target identification. It is also widely used in the aerospace world especially to localize and map the rocket when it enters back into the earth dimensions from a dimensionless world. In production industry, it is widely used for accurate cutting and signaling. It also helps to improve the speed of the process and hence the efficiency of the industry.

What locomotive did to the world in the nineteenth century, airplanes took the game one step ahead and transformed this world into a true global village. Airplane is probably one of the key developments in history of manufacturing and industrial world as apart from the technology itself, it helped in expanding the manufacturing human resource movability. In 1903, Wright brothers invented the first gas fueled airplance[81]. It truly helped in shrinking the world and people can fly any part of the world in matter of hours. It helped industries to move abroad and have better control over their corporate and international operations. They also become the important part of military combat and superior air force meant superior military dominancy. This led to a lot of investment in the field and this eventually paved way for space rockets and human beings were finally able to set foot on moon. Although Chinese used rockets three thousand years ago and there are instances in history which points to Greeks and Romans for their rocket usage, but all of these were just for mere amusement and were uncontrolled. After rapid development in aerospace technology, in twentieth century, researchers were able to control rockets and also were able to develop rockets with long distances. As rockets became more and more powerful, their usage in military increased and it also pointed towards the possibility of outer space travel. Rockets started to place satellites in the space which opened doors for today's modern communication. So, in reality, it was the invention of this important technology which opened galaxy of today's social media world.  Without this invention, world would have been so different without GPS, TV based communication, weather prediction and geological marking of the world.

Until twentieth century, the health of industrial worker was a major issue and industries were always on a hunt for more and more labor as any little germ that someone cached was potentially fatal. The average life expectancy of industrial workers was decreasing and there was a lot of labor that caught different diseases due to nature of their work and is rendered useless as there was no cure for simplest of bacterial infection. Many times, such affected laborers were left to live a life of misery until their death as industrial groups cannot afford to look after labors with disease for a longer time. In 1928, Alexander Fleming, invented first anti-biotic with name penicillin and within few years, a lot of different anti-biotic emerged in the market. This effectively meant that now affected labors can be treated quickly and they can get back to work in almost no time. This helped in better human resource management and larger pool of experienced human resource. Many scourges like gonorrhea, pox, and typhoid became treatable and due to better medicines against bacterial infection, it increased the life span and reduced the mortality rate.

Although there was a lot of research about alternative sources of energy and experiments were done with different types of materials which brought a lot of advancements in industrial process management, but still the biggest milestone in industrial process and manufacturing is credited to control engineering and automation. Transistors were a big breakthrough but really revolutionized the industrial and manufacturing process was the invention of computers and especially personal computers changed the face and inners of industrial world. Although, idea of computers were conceived by Charles Babbage in 1830s, but invention of digital computers brought a lot of advancements in industrial world. From management of human resource to management of inventory, from calculations of energy utilization to calculation of production forecast, from management of control rooms to the actual control of machines, from internal industrial communication to communication between different departments located miles away from each other, it is this very invention, Computers, which changed industries in the way that was not reliable even by the start of twentieth industries of earlier.

The machines that can operate at very high speed, became easy to control as even most complicated calculations and decision can be done at a brisk speed by virtue of electrical signals coded in a binary language and stored via punched cards or magnetic tapes were all the realities brought by computers. Initially, in 1944, Mark I, the first digital computer was working at Harvard University but it was only after the Second World War that exploitation of computers in industrial, manufacturing and scientific application was realized. That time, computers were large and bulky and were not capable of processing until the invention of transistor which revolutionized the computer technology. It was between 1950s and 1970's that computers became an integral part of most industrial process and machines though computers for home became widespread in 1980's. In Japan, fully automated and computerized factories became popular by mid-1970. The advantages of continuous production over batch production was truly realized only after computers became powerful enough to control the whole plant from a single processer and provide real time feedback to adjust machines parameters for continuous and uninterrupted production cycles.

Twentieth century saw greatest number of inventions discoveries and technological advancements than any other century. Twentieth century started with dazzles of automobiles, airplanes, antibiotic and radio and it ended with technologically advanced computers, spacecraft, cell phones and brisk fast internet. The development of twentieth century started with Charles Seeberger inventing a modern escalator[82]. The first radio receiver was also invented which was able to successfully receive a radio transmission. Willis Carrier invented the first air conditioner in 1902[83]. For agriculture, tractor was built by Benamin Holt in 1904. The most important industrial material which is now part of our every day's life, synthetic plastic was developed by Leo Baekeland by name Bakelite in 1907. This was one of the major milestones in the history of manufacturing. First electrical automobile ignition was invented in 1911 by Charles Franklin Kettering[84]. In 1912, first military tank was patented by Australian inventor De La Mole. Stainless steel which is one of the most important building blocks of today's industrial world was invented in 1916 by Henry Brearly. A flip flop circuit, which lies at the heart of today's embedded world, was first realized in 1919. One of the widely used sources of entertainment and communication world, TV or cathode ray tube was invented by Vladimir Kosma Zworykin in 1923. Differential analyzer, one of the very first forms of analogue computers was invented by Vannevar Bush at MIT. Electron microscope was invented in 1931 by max Knott and Ernst Ruska[85]. The bar code, still one of the most widely used mechanisms to keep track of inventory was invented in 1952 by Joseph Woodland and Bernard Silver. Hydrogen bomb was also built in 1952. The solar cell, still one of important source of alternative energy source was invented in 1954 by Chaplin, Fuller and Pearson. In 1958, integrated circuit was invented by Jack Kilby and Robert

Noyce and in 1959 microchip was invented[86]. Both of these factors reduced the size of industrial equipment's and helped to increase the speed of most of the industrial processes. In 1971, microprocessor was invented by Faggin, Hoff and Mazor[87]. In 1979, cell phones were invented but they were not sold commercially until 1983. The 1980's era is seen as the era where a lot of multinational cooperation's expanded exponentially and this decade saw the highest growth rate of whole century. Last but not the least, the most important development of twentieth century was world wide web or Internet protocol that was created by Tim berners-Lee in 1990 as it opened doors for Internet of things (IoT) which meant that now communications can be more fast and robust and industrial process can be easily controlled remotely[88].

### 2.1.6 Twenty First Century

The twentieth century is often termed as the century of innovations and twenty first century is known for the advancements in the innovations. The evolution of technology and development of economic growth is usually a time circle. It is only until twenty first century that true benefits of innovations in twentieth century have really started to make a difference the in the socio-economic factors of human race. There are not so many innovations to be credited in the twenty first century but advancements in the twentieth century innovations have radically changed the world and it has transformed the concepts about how the future world will be or direction of technological forecast. The twenty first century has taken an altogether different route in terms of market capitalization and manufacturing world.

The very first trend seen in the early part of twenty first century was manufacturing hubs shifted from technology development countries and moved to places with cheap labor and better weather. Now the war is not only about how advance a product is, it is also about how market competitive and price savvy it is to be able to survive in extremely competitive market value of twenty first century. A lot of companies shifted their manufacturing units to Asia especially to China and its neighboring regions in pursuit of cheap labor and better energy prices. This has brought some benefits as now technological products are almost radially available in all parts of the world. This has also encouraged local manufacturer of remote areas in Asia to join hands with leading manufacturers of the world and contribute in the industrial world. This has also made possible the availability of skilled labor in almost every part of the world. Now products are manufactured in one part of the world and assembled in other part of the world in an effort to be more price competitive.

Another important trend of twenty first century is increased used of robots and automated system in manufacturing. This has helped industries to operate at much faster rate and produce products of much better quality. This is all possible due to computers becoming more and more powerful with even greater reliability. This has started to cut down non-skilled labor jobs as robots have proved themselves to be much more efficient and less expensive than the non-skilled labor.

The third trend seen in the twenty first century is the war of survival of fittest. There are a lot more companies who have gone bank corrupt than in the whole twentieth century. There are even more mergers and take overs happened in the last decade as industries who fails to keep pace with the modern trends dipped into loses and were taken over by more tech savvy companies.

The fourth largest trend is seen in the retail market. The online stores have become more and more dominant and people's confidence in online shopping have increased over a period of time. The giants like Amazon have changed the outlook of the sales market and introduced new concepts which were not seen before in the retail market. People have stepped out of brick and motor shops and prefer to shop online which gives them much more information about the product and easy price comparison.

Another important advancement in manufacturing is the further development of Nano-technology research and this has helped to further reduce the size of the engineering products. The size of every product is shrinking which means fewer raw materials and space along with much more capabilities built in much compact space. There are now robots which can penetrate in human body and can perform biopsy without even cut on outside human body. Cell phones have shrunken to a much smaller size and electrical gadgets are continuously decreasing in size with the addition of much more capabilities[89]. Will Nano technology will be the future trend of twenty first century industrial needs?

A lot of investment and effort is done in finding alternative sources of energy. There were few wars in twenty first century where historians point to possibilities of effort to take control of more energy resources. There is a lot of work done to find alternative energy resources in the form of windmills, solar cells and bio gas[90]. This has led to introduce the concept of electrical cars and still there are few groups working on hydrogen fuels to power up the car. The leads to the question that will renewable energy source will be the future of industrial revolution?

Supersonic and hypersonic jets have been developed but their prime usage is in military[91]. As people want to travel more and there is a need for faster ways of transportation, there is strong possibility that there will be commercial hypersonic planes which will reduce the travelling time. By the end of nineteenth century, the fastest mode of regular transportation was around 60mph by train and by the end of twentieth century it was around 600mph which is almost ten folds greater than what was in nineteenth century. So if the trend grows at same rate, there is possibility that by the end of twenty first century, people will be able to travel at Mac 10. Are these advances in transportation will be the driving factor of twenty first century industrial revolution?

One can easily bet that internet of things is the main industrial revolution of twenty first century which has revolutionized the manufacturing process. Now processes are controlled over internet and whole communication in an industrial plant is by virtue of internet. Sensors like cameras, gauges and thermal detectors all communicate and talk via internet and adjust their reporting with an automated system transported via internet. There are more and more products coming up which are IoT compliant and there is even more emphasizes on the standardization of this IoT protocol. The question is will these advancements and continued interest of manufacturing world in internet of things will be a breakthrough of twenty first century manufacturing world?

There are loud talks about difference between an automated machines and intelligent machines in twenty first century and these discussions are becoming more and more intense as now there is a lot expected out of machines. A machine who can do some repetitive task are now considered dumb and machine who can adjust itself for some scenarios are considered automated machines. But concept of intelligent machine is different where machines are expected to be capable of learning, planning, deciding and thinking. They should be able to analyze the situations and find the best possible way to do a certain task and should also be self-repairing and self-maintaining. One of the examples are mobile robots which connects to charging docks automatically when they are low in power. There are robots that can now perform surgical operations without any human interaction. They are able to learn and adapt to every different patient by virtue of their learning capabilities. Will artificial intelligence and machine learning will be the next big thing in the world of industrial manufacturing.

# Chapter 3: Innovation Management

In today's competitive and global oriented market, understanding the concept of innovation, its effect on economic and social factors and its importance in the progress of the company is a tangible phenomenon with multi-directional folds. Innovation is believed to be an entity which brings economic uplift and positive social change but the term 'innovation management' was only first used in 1950's [92]. Over the years, different researchers have defined this term heterogeneously and concept of innovation management is poorly understood [93]. This is mainly due to the fact that different models for innovation management were developed over a period of time and researchers tried to comprehend the innovation concept in light of those evolving models. Also, the process of innovation takes different shapes in different industries and varied social orientations. Exponential increase in the published literature in the recent years and growing investment by companies in innovation stems the importance of innovation management in today's economically competitive global industry. This exponential increase in the number of published innovation related papers is shown in Figure 5. Innovation management has been identified as a major economic growth factor and constructive social change by several countries and world organizations [94].

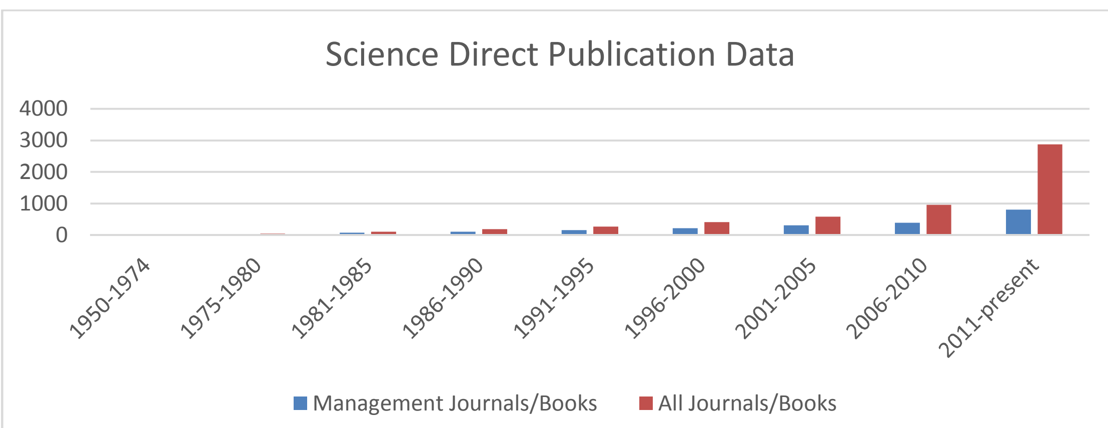


**Figure 5: Innovation management publications in science direct journals and books**

With rapid technological developments, sterns competition, global economy and resource insufficiency, organization must innovate to grow, to be efficient and survive [95]. To understand the term innovation more vividly often requires interaction and integration of different levels of analysis and distant fields of study. The term ‘innovation’ is often confused with ‘invention’, with factor of commercialization is a major difference between them. An invention can lack factor of financial benefit and can directly affect company success and failure. Contrary to invention, innovation is a calculated process which considers financial and commercialization factors ensuring the success and economic growth of the company [95]. With pressing issues like short products life cycles and resource insufficiency, still the process of successful innovation is still very nebulous which is also indicated by Rothwell [96]. Creativity is a fundamental agent of new ideas whereas innovation is its application. Innovation exploits the new ideas and transforms it into a social or economic change.

The term ‘innovation’ has been widely used in literature and researchers have defined it in terms of economic, social, technological or management advancements. Porter [97] in 1990 described it as a process that involves new knowledge and development of new products or significant improvement in the current product. He termed it as new way of doing the required or projected task that can be commercialized. Joseph Schumpeter explained innovation in economic terms in “Theorie der Wirtschaftlichen Entwicklung" (1912) as introduction of new product or outline of new or improved technique of production, or identification of a new market area, or takeover of new source of raw materials, or the carrying out the better functioning of any industry. Freeman and Soete [98] defined it as a process starting from the first commercial transaction of a new product, system or device, till it has been matured or accepted as an industry standard. He mentions that more invention can take place during this process and infect further innovation may be made as part of it. So, he described invention and innovation as a diffusion process. Hence, fruitful amalgamation of new product and inventive process can be termed as innovation.  UK DTI [99] has linked success with the implementation of ideas. He states that implementation has to be successful in order to be classified as successful. Some other authors have made innovation success independent and has just discussed it in terms of execution of new ideas. Albury in 2005 [100],[101] has described innovation as a successful creation and implementation of new ideas and these ideas could be for process, product or services. He also states that innovation could also be in form of method of delivery which can bring noteworthy improvements in results, quality, effectiveness and efficiency. He attached quality and efficiency metrics to innovation. Hartley in 2006 [102] termed innovation as "the successful development, implementation and use of new or structurally improved products, processes, services or organizational forms". He attributed that implementation as well as development and even use of new technology as innovation and again mentioned that it can be for products, processes or services. Jacobs and Snijders in 2008 [96] mentioned that only something new which has some value addition can fall into the category of innovation. Cooper in 2005 [103] on importance of innovation termed it as a "war: innovate or die". For him, for any company who want to compete for profit or grasp of market share has to innovate or else it will find themselves out of business in short time. Hartley 2005 and Albury 2003 mentioned that innovation cold also be in terms of services specially for public sector organizations [96].

From the above definitions, it can be seen that earlier, researchers have described innovations more in terms of radical change or something entirely new. They considered product innovation and concentrated more on generation of new ideas. As time passed by, it became imperative that innovation could also be in process or product or even services. Also, it was realized that innovation, instead of radical new idea, could also be in shape of small continuous improvements over the time and could be a controlled calculated process.

As latterly, some of the researchers have linked success as a major attribute of innovation, it can have deduced that innovation is not always easy. There are examples of many companies like mayor technologies who were once the market giants failed to remain competitive as they were not able to adapt themselves with changing environment, consumer needs and market trends. Chris indicated that it is mainly because of the fact that organizations are so much entangled in their core competency that they actually get trapped in it. Sometime, the lucrative of being the dominant in industry for a specific competency could stray company from focusing on future market trends. So, it's not always that companies don’t want to innovate, it is sometimes due to the fact that they are trapped in their core competency that they forget to pay attention to innovation. He mentioned that agile approach is somewhat should be a compulsory part of companies’ strategy.

In late 80’s and start 90’s, most researchers have tried to define innovation in terms of economic growth but Becheich et al [104] and other have pointed out that there exists a great deal of heterogeneity in understanding the concept of innovation and sometimes, it largely depends on the nature of the industry or social orientation. Utterback [105] explained four different types of innovation process based on the type of the product or service. He also draws a line between the impact of a new product and the improvement of the existing product on the market. This led to the new dimension of explaining innovation as incremental innovation or radical innovation. Incremental innovation is described as an improvement in the core component and use of word renovation better describes this type of innovation. Radical innovation involves the introduction of new product or more probably a new paradigm. Researched then tried to introduce different comparative ways of defining innovation process like Baldwin and Clark introduced the concept of Modular Innovation and Clark explained the term Architectural innovation. Modular innovation is small improvement or mini invention in the core components while effectively maintaining the old linkages between the core components. Architectural innovation improves or changes the linkage between the core components but core design concepts remain enforced. A new comparative distinction also emerged in late 1990’s which categorizes innovation as competence enhancing innovation or competence destroying innovations. This category of innovation categorization became famous after rapid developments in war animations and computer technologies. With the fast development of Information Technology sector, a new terminology has been increasingly being introduced these days as disruptive innovation. These forms of innovation are categorized based on innovations that are productive or useful for human race and others who have impacted negatively to current technological advancements.

Researchers have tried to define innovation based on their own background and field of study. Yet, there are few things which are common in almost all definitions and can definitely help to understand innovation at upper level. Luca, Paolo and Marco have mentioned that almost all definition have two common characteristics: the ‘novelty’ and possibility to ‘organize it’. Novelty refers to the property of being new and organization means that innovation can be managed. They gave their insight about innovation by describing it as an effort to bridge gap between industry need and technology that generates value for both manufacturer and customer. They termed innovation as the most important growth entity for an organization.

It is important to identify the key activities involved in the innovation process. Palmberg [106] in 2006 defined the innovation process as a combination of various stages. Available literature points that any innovation process consist of ‘generation of ideas’ [107] which possibly be converted into new products, with the help of ‘acquisition of new and complete knowledge’ [108] and finally ‘successful implementation and market monitoring’ [109]. These fundamental activities of innovation process stem the fact that innovation is not entirely an entity of creativity; rather it is a rigorous and carefully executed process which helps organization in keeps innovating and growth in the market. It indicates that apart from highly skilled people, innovation is also about culture and effort of innovating and development.

### 3.1 Innovation Management Models

The road of development of innovation process management can be broadly classified into different models based on the characteristic and evolution of innovation in different eras and market trends. Perunovic and Christiansen [109] classified models into five distinct groups. The main feature of classification among these models is the nature of interaction between organizations and market behavior. The five models are

**3.1.1 Technology Push Model** This model is based on the company ability to be innovative based on the internal research and development which is independent of demand needs from the market. It was popular in 1950’s when concept of innovation was first introduced in the literature and companies were heavily relying on push methods of producing products. Companies were able to identify the possible technological opportunity and tried to produce new products based on existing knowledge. It was a sequential model.

**3.1.2 Market Pull Model** In this model, the requirement and scope of innovation comes from customers/markets or the competitor industry or organization. Customer needs and market requirements were main driving forces in this type of innovation. This type of model was famous in 1960's and 1070's. Market pull model like technology push model was also sequential model.

**3.1.3 Coupling Model** This model is a combination of push and pull models and is also a sequential model. The difference is that this model has a feedback loop which was missing in first two models. It was developed identifying the shortcomings of above two models and was an effort to formulate a well-established connection between company's ability for new technology and corresponding demand in the market or customer needs. This model emerged in late 1970's and it was around that time when concept of internal networking and communication started between different teams involved in product development. Companies devoted dedicated teams as part of new product development project and new product results as coordinated efforts from different departments of the organization.

**3.1.4 Integrated Model** This model emerged in 1080's and model introduced the concept of vertical integration among teams within an organization and horizontal collaboration with leading partners to develop new products or improve the existing knowledge. Around this time, organization started to realize the importance of innovation with networking and collaboration being considered as major component of innovation process.

**3.1.5 Functional Integration Innovation model** In late 1990's, a lot of companies faced pressing issues like quick development of new products, decrease time to introduce new advance models, cost reduction and efficient way of operation in order to compete with competitors and global oriented markets. This model helped companies to innovate at faster pace with efficient cost management by using sophisticated computer algorithms and information technology. Computers have brought radical change in the innovation process development and are now at fore front of innovation management strategies.

### 3.2 Innovation Process Models

Chris in 2008 [110] reviewed many different innovation process models and deduced that many authors have described many different types of processes based on specific industry, type of business, large or small organization, public or private, and type of innovation itself (product, process or service). He states that innovation can have five different dimensions. The type of innovation and degree of novelty involved in innovation, the type of organization in which innovation is supposed to happen and size of the organization itself also have different implication and consequences on innovation. The fifth-dimension is environment/sector in which innovation has to happen.

The first innovation dimension is about the innovation type. Luecke and Kat in 2003 categorized innovation types as product, process and service innovation. These different types of innovations require very different types of innovation processes and feedback cycles. The second innovation dimension is about the degree of novelty in innovation, whether it is radical, incremental and systemic innovation. Albury and Mulgan in 2003 distinguished between these three type of innovation with different degree of novelty [96]. Jacobs and Snijders in 2008 proposed a fuzzy approach to novelty in which he assigned innovations along an axis from radical to incremental [113]. But he still weighted radical innovations more compared to incremental ones on his fuzzy innovation dimension. The third dimension is the type of the organization in which innovation has occurred. Organizations could be private or public with very different styles of management. Chirs mentioned that in literature, researchers have not paid much attention to this factor while it could have a huge impact on innovation process and innovation model used [98]. Hartley 2006 has discussed this issue and particularly discussed about innovation process in public organization which has more strong bureaucracy mindset [114]. The fourth dimension is about the size of the organization in which innovation is expected to occur. The organization could be very small to very huge and this indeed has significant impact on innovation process. Larger organizations have certainly very different style of management techniques and working protocol, which can affect the speed and length of feed backs involved in innovation process. Lastly, fifth dimension considers the type of environment and industry considered for innovation. Environment could be highly stable which gives room and time for incremental innovations compared to unstable environment which demands more rapid radical innovations. Type of industry also has notable impact on the innovation process like automobile industry gives more time leverage and incremental innovative process compared to software industry which is more rapid and demand very brisk radical innovations in order to remain competitive in the market.

### 3.3 Innovation Processes and Routines

Many scholars and researches have investigated about the procedure and protocols adopted to manage and execute an innovation process. Jacob and Snijders in 2008 have defined innovation as an active process, which involves generation and selection of new ideas for innovation and then transforming these ideas into innovation [96]. As mentioned, selection of ideas also hold key importance in innovation process, it dictates its uncertainty and risk nature. Andrew and Sirkin 2007  argued that innovation process can be managed like any other project with extra degree of uncertainty and risk [115]. Van der Ven 1990 have termed innovation process as an innovation journey [116]. The very first step in managing innovation is to lay down the roadmap highlighting set of routines/procedures or rules which will be followed during whole cycle of innovation. This roadmap or innovation model is important in evaluating the progress, quality and efficiency of innovation process. This model, if reconfigured through careful thought process during the innovation process, can help to reduce the time and chances of failure. Though these models can be industry specific and vary hugely depending upon the type of innovation, so, it is important to figure out a comprehensively basic model which can be altered based upon nature and type of innovation. Many models involve constant back and forth motion between theory and practice.

These innovation models vary a lot depending upon type or degree of innovation, radical or incremental, product, process or service, private or public though less attention is paid to innovation process in public sector. All innovation models involve certain phases, components, activities and stages. Usually, most of these phases are linear and orderly. Some authors claim that in order to start the next step, the previous step should be completely executed and evaluated before the next step could be started but some authors think otherwise. Tidd and Bessant in 2006 [117], Mulgan and Albury in 2003  pointed out that most of these phases have usually many different feedback loops and cycles associated with each stage [118]. They also claimed that phases are more non-linear in the initial phases, while later phases and steps are more rigid and linear.

Many researchers and scholars have also tried to attribute different management tools/skills and activities associated with different phases of innovation process. Many different phases and steps are discussed in literature but following five are basic phases which is covered by almost all researchers in their models.

**3.3.1 Idea Generation and Searching** Almost models starts with the phase of idea generation or search for new ideas/concept. This is one of the difficult phases in the whole model and is supported by activities such as market surveys, exploration of current technological literature, encourage people within the organization to come up with new ideas by sharing them freely, inviting people from outside the organization like customers, consultants, creative human resource and creating cross-functional teams to generate interdisciplinary ideas.

**3.3.2 Idea Selection** The next step as evaluated by many researchers is to narrow down the list of new ideas and make a decision about ideas to be proceeded which can have certain financial gains or are implementable or realizable. It must be noted that while selecting the ideas, they must comply with organization strategic strategy and must be aligned with existing projects. At this stage, potential of financial gain or worth of value addition is calculated and evaluated. The routines to consider at this stage are thorough evaluation of market potential and feasibility. Some customer reviews and feedbacks are taken into account to proceed with this selection of ideas.

**3.3.3 Development and Testing** This is one of the key steps in any innovation process i-e to be able to transform the idea into tangible finished product, process or service. This is sometimes one of the most time consuming and uncertain step in innovation process. It is the stage when present theory, resources and idea are mixed in an effort to generate something new. This is practically one of the difficult which serve as a make or break situation for whole process. Some authors considers development and testing phases separately Chris in 2010 and Van der Ven [116] considered them as a single phase with many feedback loops among them. Van der Ven termed it as a convergent behavior phase. This is the phase where most of the resources are allocated to the project and it is eventually decided how much resources are feasible so that it will still be a profitable venture. The major managerial activities associated with this phase are procurement of skilled and best human resource, providing appropriate development place, financial resources, support from cross-functional teams and management support. The testing phase usually involves application of certain quality and safety protocols, extensive testing of device before launch, early user involvement to get feedback, non-technical aspects are evaluated and testing under strenuous environment or conditions.

**3.3.4 Launch Phase** In this phase, product is presented in the market and in case of process or service; it is implemented in real environment. This phase involves the marketing and sales activities and initial feedback from customers is gauged to measure the success of the product, process or service. According to Chris [119] , most authors stop here but post launch and explicit learning phases should also be incorporated in the innovation processes. He also claims that activities in these phases are not explicitly related to innovation process. The main managerial activities in this phase are production start-up, marketing and sales, pre-launch market surveys and identification of targeted customers. Logistic activities and calculation of profit margins are prime goals of this phase.

**3.3.5 Post Launch Activities** Few scholars like Jacob and Snijder 2008 [113] , Tidd and Bessant in 2005 [117], also mentioned about this phase which involves sustaining and supporting the innovation after its launch. This may include technical support or post sales services. Sometimes, innovations are scaled up during this process and different versions or models of the products are introduced in the market. Managerial activities involve re-development, analyzing feedback and support of appropriate infrastructure.

**3.3.6 Explicit Learning** This process involves learning about the lessons learnt during the innovation process and innovation itself. This helps in learning about the mistakes committed and generation of recommended activities for future. This phase is often neglected and is sometimes difficult to carry out in a structured way. The managerial activities involve generation of data, numbers and other real time evaluations.

A little uniform trend is observed in all of these models and associated managerial skills. Almost or most of the models considers only product or process innovation and less attention is paid to service innovations. This is probably because product or process innovations are more exciting and researchers finds them more attractive compared to service innovations. Also, most of the models consider large and private organizations. The steps and skills explained by researchers concentrates more on working procedures and environment of large organization and private firms. Not much is written about small organizations with much less bureaucracy and about public organizations with huge management cycle and administrative protocols. Most of the researchers have tried to talk more about radical innovation with extensions about process innovations. Radical innovation was a hot topic which led to slow developments about incremental innovation though now, a lot is done in incremental process innovation. Although, most of the models base their grounds on economic fragility and high uncertainty of today’s market, yet most models have considered stable environment. A very little research is carried out about unstable environment, small organization, public firms and service innovation.

Some authors have also tried to find a relation between different routines among these models. Few claims that short coming in one routine can be compensated by routine above it but some authors think otherwise [120]. Prud’homme van Reine and Dankaar in 2009 made an interesting statement that all routines are not directly proportional or linearly related to innovation success [121]. They claim that this relation is hyperbolic and there is always a need to find a dynamic equilibrium. There are also some activities mentioned by authors like Mulgan and Albury in 2003 that does not fall under any activity in their models or routine [122]. They claimed that breaking rules is a prime activity to generate possibilities but it doesn’t mean that all rules should be broken. Jacobs and Snijder says that open culture is vital for any innovation process [113]. It is also observed that models are becoming more elaborative and comple over time. There is a greater emphasis on the post launch activities and incremental innovations are gaining their true value. But at the same time, it must be said that current literature is vogue is terms of identifying which management routines of tools could be used in what situation and what model fits best in certain condition and environment. Yet, there are no proper guidelines which can help to simulate innovation before it can be implemented.

### 3.4 Factors Effecting Innovation Management

The study of innovation processes and management cannot be complete without considering the factors which effects it. There is not much literature available about factors and protocols about initiating and maintaining an innovative momentum in organizations and to keep organization and its people to keep innovating and increase competitiveness. Again, these factors vary from organizations to organizations like public or private organization and the relative size of the organization. The factors which directly affect the innovation management and innovation process can be divided into following categories.

#### 3.4.1 Environment and Organizational Factors

There are number of environmental and organizational factors which effect the innovation or the way innovation is carried out. Some of these factors are:

**3.4.2 Country Environment** Whitley in 2000 mentioned that national characteristics coincides with innovation types [123]. He said that economic organization, industry co-ordination, compartmentalized, manufacturing fragmentation and highly coordinated market are some national level attributes which dictates innovation strategy, novelty and technical excellence.

**3.4.3 External Factors** Eternal factors are the prime source which dictates innovation. If the external environment is unstable, it means organizations have to innovate more briskly in order to remain competitive. This puts extra pressure on decision makers to create innovative culture within the organizations. Innovation is less noticeable in stable environment where customers prefer quality and price over novelty. Heterogeneity of external factors creates an ambiguous situation where some companies tries to innovate quickly to remain the market leaders [124], whereas for some companies, it can hinder their innovation process as they will prefer to sit back and let the market settle down. Same is the case for increased dynamism for external environment. Some companies try to innovate while other shows a static behavior. Technological advancements in the external environment also prove to be a vital factor in attracting companies to innovate. Georage Chryssochoidsis in 2003 [125] mentioned that companies are inclined to innovate if the external technological advancements are heartening. This specially becomes important for medium sized companies to take advantage of these technological opportunities and grow. Competitive competitors and hostile market drives innovation process and decides the pace of innovation for an organization. Shankar in (1999) claimed that hostile competitive environment adds pressure to initiate innovation and drives them to take better advantage of their resources [126]. Gopalakrishnan et al in 1999 that type of industry also plays an important role as realization of innovation might not be same for different types of industries [127].

**3.4.4 Organizational Demography** Size and Age of the organization are a critical measure of the eagerness of an organization innovation momentum. Gopalakrishnan et al in 1999 mentioned that as organization grow is size, they get scrummed to larger administrative cycles and eventually lose their aptitude to innovate [127]. Bureaucracy becomes more and more stubborn and innovation processes are slowed down. But on the other hand, larger firms are also in a position to allocate more resources and funds for innovation projects. Age of company also plays a pivotal role in its innovation momentum. Dougherty and Heller in 1994 said that mature organizations face difficulties due to gloomy motivation, political and administrative deadlocks, distorted perceptions and divided perceptions [128]. On the other hand, very young and small organizations don't enjoy the liberty of sufficient resources to invest in radical innovations. Organization type and innovation thrust is also a contributing factor in type and process of innovation management. Organization's market orientation describes the philosophy of innovation development for new or incremental products. Atuahene-Gima in 1996 claimed that market orientation is inversely related to novelty for customers [129]. Sometimes, it is because the aggressive nature of the market and organizations tend to stick to incremental innovation to mitigate the risk prevailing in the market. Zahra et al in 2000 claimed that as number of outsiders in organization administration or top management increases like stake holders, outside directors appointed by board of Governors, CEO operative from parent company or outsourcing, these all are positively associated with innovation [130].

**3.4.5 Organizational Structure** In some very formally structured organizations, where there is a highly centralized, rigid bureaucratic mechanism, politically empowered and unspecialized administration, it's become very hard to successfully implement radical innovative projects. Gersick said that deep structures hinder innovation process [131]. Researchers claimed that low centralization and flexible formalization are key ingredients to facilitate innovation process specially at the initial phases of innovation. But during implementation, scope of centralization and formalization can be increased to avoid ambiguity and role conflict. John claimed that managers and top management in high tech firms usually delegate power for strategy initiation and workout strong control during implementation [132]. On the other hand, organizations with less formal structure, easy consultation across departments and frequent face to face meetings helps easy flow of information and resolve conflicts more easily and briskly. According to George Chryssochoidis, the presence of informal organizational 'layer' is important for easy information sharing which is critical for innovation management [133].

**3.4.6 Facilitate Resources** Decision making and leadership style are very important for any innovation management project. Hardy and Dougherty in 1997 said that if decision and resources comes from a centralized system, biased individual influences, budget preferences are time based rather opportunity, unclear criteria, fixed job description and assigning technology people to management task can hamper the pace and methodology of innovation [134]. On the other hand, if resources are available as the opportunity comes, information is shared frequently, decision making by mutual consultation, rewards for innovation, more collaborative structure instead of centralized structure and management support for all groups speeds up the innovation process and generates innovative momentum.

**3.4.7 Team Composition** Researchers have found an interesting trend for team composition and structure. According to researchers [135], team composition varies depending upon whether innovation is radical or incremental. In case of incremental innovation which is usually fast to realize, team members should be educated and well acquainted with industry for some time as they understand the different aspects of business better than new comers. There should be participative culture among teams and collaborative culture. On the other hand, radical innovations are usually directed by a single project leader with better understanding of the idea and have relatively new team members so that they can think out of box for the project. Researchers also tried to identify team member's individual characteristics. They claimed that individual member cannot perform all task in a project, so team should be well diversified. Long term planners have greater role and responsibility in the initial phases of the innovation process while technical and specialist team members have more roles in development phase. Commitment, trust and co-operation are some major individual deeds present in any innovation team members.

**3.4.8 Communication Patterns** There should be a clear and non-formal communication mechanism for inter and intra team members, stakeholders outside and inside the company and administration should be very clear about its motives.

**3.4.9 Finding Alternative solutions** There should always be a strong desire to find alternative methods and solutions which can improve or supplement the innovation process. Solutions like communication in the style of storytelling, flexible work hours, communication over networking and finding suitable softwares like Inspiration, NamePro, Group System, Brain storming, Mindlink and BunDopt to better organize innovation process and align it with human nature demands.

**3.5 Characteristics of CEO or Top Management** One of the key attribute of successful innovative CEO is its ability to perceive external environment and able to find a positive association with its company's strategic strength to generate something new. Thoughtful scanning and sophisticated planning while able to efficiently gather eternal information can aid CEO with its policies and decisions [136]. Innovative culture, strong belief in his and team ability and specialization are some features of an CEO or top management who help them in developing feasible plan of action for innovation process. But at the same time, the nature of the environment in which organization operates and external market also hampers or constrains the range of CEO or top management [136] as it confines the managerial discretions. Environment uncertainty and degree of variation, level of power vested in the CEO to take decisions under hard times, range of decisions and number of possible planning possibilities by CEO to cope with uncertain and risky severe market can be directly related to the managerial powers delegated down in the hierarchy. Input of

CEO or top management act as a mediator between policy making and external environment in an innovation quest.

**3.5.1 Personal Traits of CEO or Top Management** About the personnel traits of CEO or attributes of top management, researches have come up with number of different characteristics. Too long or extended tenure for top management or CEO negatively effects the rate and effectiveness of innovation as it further deteriorates when faced with extended crisis [137]. Appropriate CEO or Top management turnover can bring notable changes and save company from going into a bureaucratic stubbornness as new management usually invest less in previous strategy psychologically. But on the other hand, too frequent top management turnover will impede the innovation process especially for radical changes as there will be not enough time to implement and execute change.

Ginsberg and Abrahamson in 1991 described the key personnel traits of the CEO or person's in top management[138]. They explicitly related CEO's personality and his demographics to rate of innovation and its success. They pronounced number of explicit qualities or traits for CEO's like cognitive complexity, time organization, locus of control, open mindedness, risk proclivity, knowledge, education, mental orientation for success, personal ethics, age, ability to absorb ambiguity and his past experience. Boone et al in 2000 termed CEO's with external locus of control as passive agent as they usually believe that what is happening is due to external forces which are beyond their control and they get stuck in a halt mode[139]. On the other hand, CEOs with internal locus of control are active agents as the believe that they are master of their internal capabilities and can mold external forces to their benefit. In the same way, CEOs with greater cognitive complexity can better envision transformation of ideas into radical innovation compared to other CEOs. CEO's aptitude or desire for achievement rationalizes the strategic innovation policies, swift decision making and better delegation of power within teams. Zyglidopoulos in 1999 explained the desire of CEOs or top management ability to shape problems, direct information findings and selective decision making are key ingredients to support radical innovation process[140]. CEO's ability to learn from past experience and organization's history could be beneficial for innovation process. Church and Waclawski claimed that ‘inventor’ and ‘motivator’ personality traits are more innovative and leadership oriented while ‘managerial’ and ‘implementor’ personality traits are more suitable for routine tasks[141]. Daellenbach et al in 1999 explained that having CEO or top management with technical background can further catalyst and increases the organization’s commitment to radical innovation via greater investment in research and development[142].

### 3.6 Future of Manufacturing: Computer based Innovative Manufacturing

The concept of innovation and innovation processes have been revolutionized and taken an altogether new shape. Now, computers lay at the heart of any process and manufacturing has taken all new shape and standardization. Innovation in manufacturing is now directly proportional to advancement and innovation in computer based technology which is currently being employed in almost all manufacturing processes and industries. Now, organizations have to employ agile strategies and agile manufacturing processes in order to gain advantage over their competitors. From 1990’s, companies are better able to compete in the global competitive market by introducing innovative features and agile manufacturing, of which, major contribution lies in the steep advancements in the field of computer based manufacturing[143]. Though, robots were introduced in the manufacturing in late 1960’s but robots have become more powerful in manufacturing, thanks to powerful computers which run them. Now, companies have entire manufacturing facility that involves only robots and no human interference is involved in whole process. Computers have also made it possible to create things virtually and run simulation tests on the object before it is actually manufactured. Amazon has warehouse where movement of objects is entirely carried out by robots thanks to power computer algorithms which control them. There are now self-correcting and self-calibrating machines which have reduced the downtime to a considerable degree. The quality and speed of manufacturing have increased dramatically as computers are getting more and more powerful. The paradigm of computer manufacturing has brought changes and advancements which were literally not possible or at least not thinkable in nineteenth or major part of twentieth century. Now, it is virtually impossible to think about competing globally without the help of computer based manufacturing. So, it is safe to claim that innovation in manufacturing is linked very tightly to advancements in computer technology. Advanced control systems, programmable logic controllers, simulations software, cloud based manufacturing; machine learning and artificial intelligence are new forefronts of manufacturing industries. In order to predict the future dimensions on manufacturing, a lot depends on what developments will be observed in computer industry and how rapidly company can innovate.

### 3.6.1 Future of Innovation: Role of Computers

The role of computers in innovations is non-questionable. The innovation field has taken many roads, leaps and bounds in its journey since its inception in 1960's. In 1960's, the innovation management was about development of new technologies. In 1970's, innovation management started to find its application in project management. Quality management became famous in 1980's and 1990's was era of efficient supply chain management. So, there lies a question, what happened in first decade of twenty first century and in last six years? The first decade of twenty first century saw the evolution of Data. The rise of internet and rapid sharing of data was made possible. The most notable innovation of last decade are Facebook, Google, twitter and Microsoft stems the fact that now innovation is largely co-related with computers. With more and more data coming up, companies are actively engaging themselves in the rapid sharing of data with customers and suppliers, digging hard in available data to identify patterns and predict future trends, means to generate huge and reliable data, closely monitor data to formulate the future strategy and planning, simulation software to analyze their performance and innovate based on the strengths of what modern computers have brought to this world.

Nambisan in 2003 pointed in his article that information technology and systems will be reference points for future product development[144, 145]. There was a rapid fusion of information system and technology in the new product development which posed challenges to managers which again could only be tackled with the power of computers and data mining. Another important phenomenon was extensive overlapping of different technological fields which were resulting in new innovations, was again handled largely depending upon strengths of information technology. From start of twenty first century, the innovation has radically changed its form as it has become more collaborative, global and involve many different distributed network innovation paradigms. Also, due to intense market and short life cycles of products, companies are forced to develop and follow standard innovation protocols, processes, tools and software which can help them to reduce cost and time with minimum amount of uncertainty[144, 145]. Embedding digital technologies into very range of products from house hold to construction, agriculture to industrial tools and research have increased to a considerable degree. So, there is a greater need of involving information technology and systems in study of any process of innovation and new product development cycle.

Studies in 1990’s were mainly focused on managerial and organizational issues involved in innovation process management. But with the evaluation of big data, it is not possible to tackle these challenges without exploiting the strengths of information technology and computers[146]. This is clearly be deduced from the fact that number of articles relating IT and product innovation gets doubled every year from 2004 to 2014 [147]. It is interesting to investigate that computers or digital tools act an enabler for innovation or they act as triggers. It is commonly believed that role of IT and computers is more of an enable to innovation process compared to triggering or initiating but the boundary between these two gets overwhelmingly diminished as modern innovations are more collaborative and open. This will also help to evaluate the impact of Information technology on the task and activities involved in product development and functionalities involved in innovation process itself.

Different studies show that role of information technology and computers are well investigated by researchers as an enabler or supporter for innovation. Durmusoglu and Barczak in 2011 and Kleis, Chwelos, Ramirez and Cockburn in 2012 discussed the impact of computers on design and product development and explicit advantages that are derived from using information technology in such activities[148, 149]. Chen in 2007, and Li and Qiu in 2006 investigated about usefulness of computers and IT in aiding innovation process and management. Some researchers have talked about the usefulness of specific IT tools and algorithms that have developed specifically for product innovation in the last decade[150, 151]. Nambisan in 2007 claimed that studies have empirically shown that efficiency and effectiveness of innovation process can certainly be enhanced by the use of IT application and appropriate set of algorithmic tools[152, 153]. He also claims that use of digital technologies lies at the core of the reason why some companies are able to outsmart others in today's competitive world. A new and more recent studies have shown that increased collaboration between companies for innovation, overlapping boundaries between different fields for invention and handling of data for incremental improvement is all possible due to support of information technology and computers.

Recent but increasing number of studies has claimed that the role of computers or IT is now quickly transforming into a triggering or initiative for innovation management. Dougherty and Dunne in 2012 and Faraj, Jarvenpaa and Majchrzak in 2011 investigated about the IT tools and embedded digital application can lead to innovation or help in innovation process[154-156]. A good example could be 3D visualization tools which have spur series of innovations in different fields like medical, construction, automobile and fashion industry. The emergence of machine learning and artificial intelligence is radically assisting in innovative ideas and often form the basis of modern day innovation. The good example of this could be Facebook, what Sapp, Google and Twitter. Data mining and information sharing have ablility to magnify the technological gaps and provided the basis for many technological innovations.

# Chapter 4: Deep Learning Based Learning

Human-Machine interaction is breaking strings of relying on rigid commands and has started to explore more intelligent means of communication like action recognition, gesture understanding and verbal commands. Efforts are directed in better understanding of human intentions by the machine and act accordingly before they are explicitly directed for the specific task. Human facial expression forms an important part of humans mode, preferences and desires. Expression is a form of non-verbal, no-contact communication and has specially fascinated researchers in the last decade. Understanding facial expressions can help machines to operate in intelligent ways and respond promptly according to human intentions. Due to non-uniform facial expression geometry among different ethnicities and person dependent expressions, automatic facial expression is a challenging task.

Most of the work in facial expression recognition is in classifying six universal expressions namely anger, disgust, fear, happy, sadness and surprise. Ekman et al. [157] claims that these six expression remain universal among different ethnicities. Most of the past research is focused on 2D facial expression recognition but with the availability of 3D expression datasets and having an advantage of pose and illumination invariance [158], 3D facial expression recognition has gained interest of researchers [158]. Most of the research in 3D facial expression recognition has employed two types of techniques [159]: feature based approach or model based approach. Feature based approaches [160], [161], [162], [163] places heuristically selected fiducially points on 3D face and explore their inter-relation with neighboring points. Soyel et al. [160] generated 11 landmarks and used 6 characteristic distances between them as features to be trained by a neural network. Berretti et al. [162] calculated SIFT features on certain landmarks and areas in the neighborhood of those landmarks. Wang et al. [161] suggested surface descriptors at manually located fiducially points using estimation of primitive surface distribution. Maalej et al. [163] make use of concentric geodesic path between selected 3D surface patches around specific landmarks.

Model Based approaches[164], [165], [166] normally fits a template 3D face model and observe transformation from neutral face to a specific expression face. Mpiperis et al. [166] proposed a bilinear model representing a whole face trying to establish relation between Face recognition and face expression recognition. They tried to encode expression and identity at the same time. Fang et al. [165] registers the face to a specific model and face is represented as a set of Point Distribution models using various surface descriptors.

Both of these approaches have certain shortcomings. In feature based approach, the location and number of fiducially points are purely heuristic. Many of the techniques using feature based approach adopts manually labelling of such points. It will be rather easier to manually label the expression which is the required task than to manually label the points. Though, techniques are available for automatic labelling of points [167], [159] but not many feature based approaches have used them. Also, as these approaches extracts features around the selected fiducially points, this results in a sparse representation of facial surface deformations which can sometimes be incomplete and imprecise as exact location and number of fiducially points is still an unsolved problem. Also, features extracted are hand crafted which lacks in explicit semantic meaning and it is a possibility that particular features extracted on one dataset might not work as good on other dataset. Model based approaches on other hand uses complex fitting models which sometimes can be adversely affected by topology changes [159].

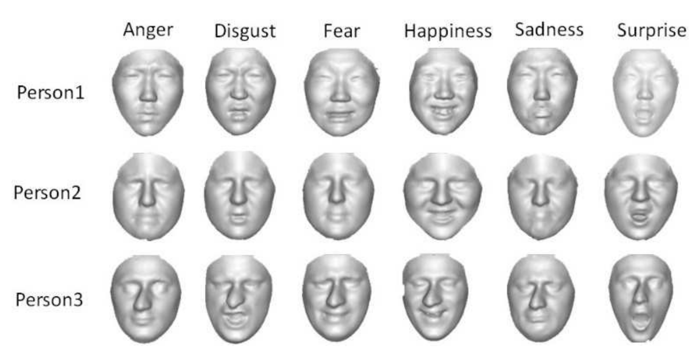


**Figure 6. Bu3DFE Facial Expressions**

Neural Networks are biologically inspired by the visual cortex mechanism of humans and animals. Convolutional neural networks (CNN) were first introduced by the Kunihiko Fukushima in 1080's. Le Cunn et al. [168] in 1995 developed Convolutional Networks for images, speech and time series based application. In 1998, Le Cunn further improved it by employing gradient based learning and it was generalized specifically for images by Sven Behnke [169] in 2003. Dan Ciresan et al. [170] in 2012 implemented them on GPU for fast computation and showed impressive results on MNIST and CIFAR10 datasets. Convolutional neural network have become extremely popular in the classification community as they have shown best reported accuracy on many publicly available datasets. When used for facial recognition, Taigman et al [171] recently showed very impressive results of more than 97% accuracy on LFW dataset and more than 90% on YTF datasets surpassing state of the art in both datasets. Hence, Convolutional neural network have shown very promising results for document, language and facial datasets compared to other computer vision techniques. Furthermore, CNN's have proven their dominance by winning several international recognition competitions [172].

In the recent past, CNN's are primarily been applied to 2D images. This stems from the fact that input to CNN's are raw images and then the network learns the hierarchy of features by building high level features from low-level representations. But with the recent development in 3D sensing technologies, color and 3D datasets have become available. Many of the researchers have developed techniques for 3D object, face and action recognition using Convolutional Neural Network [173], [174], [175]. Instead of using 2D feature maps and 2D convolution, they employed 3D convolution to generate 3 feature maps from RGB images. Instead of convolving in only spatial domain, they also perform convolution in temporal domain to generate spatio-temporal feature space. 3D convolution is particularly important in the analysis of video data, in which, researchers are more interested in considering several frames instead of a single frame to track motion.

The proposed system differs from majority of the work in the field as it uses Deep Convolutional Neural Network for well-engineered features instead of human crafted features. Deep learning has already proven their dominance in speech, language and facial classification and outperformed many classical computer vision techniques. This prompted to exploit Deep convolutional network for facial expression classification task. Mengyi et al. [176] and Susskind et al. [177] have used deep learning for expression recognition but they have employed Deep Belief Network structure and also evaluated their network on 2D datasets. In the proposed work, the following contributions are made 1) use of range image representation of facial expression as opposed to 2D grey/color image representation used in other similar work [176], [177], 2) introduction of 3D rotations along pitch, roll and yaw angles in training images 3) advancement of the state of the art for BU3DFE dataset by 3.1 %.

### 4.1 Overview of Proposed Approach

Earlier, the research on facial expression recognition is mainly focused on 2D datasets or videos [178] but recently 3D facial expression recognition have gained popularity [158] as facial expressions are more a property of geometric deformations rather than face texture [167]. Investigating depth variations and deformations in different facial expressions can help in developing efficient expression recognition schemes. The idea of this work is to exploit Deep Convolutional Neural network architecture for recognition of 3D facial expressions. Static facial expressions are normally classified into 6 main categories namely Anger, Disgust, Fear, Happiness, sadness and surprise [157].

Facial Expression recognition mainly consist of 3 stages: Detection, Representation and classification. Representation stage plays a pivotal role in any classification task. Most of the techniques used in 3D facial expressions recognition use hand-crafted features and deploy heuristic based points on face and extract patches based on these points. Also, different features are combined to improve on accuracy and performance. In contrast, in this study, raw range images are presented to a network and a deep convolutional neural network is trained by standard back propagation algorithm[179].

In deep networks, majority of earlier works employed Deep belief networks [180], [176] and 2D facial images for expression recognition [180]. Hence, depth information is ignored and deep belief networks are trained to learn the texture of different expressions. In this study, instead of 2D grey scale images, raw depth range images are presented to the network and a complete standalone convolutional neural network is trained.

Alignment and pose variation of facial images play an important role in any classification algorithm. One of the techniques employed in deep networks to cater alignment and pose issues is to introduce geometric transformations in the training images. Images are rotated, translated, deformed and scaled [172] in 2D plane to overcome variations in the test and validation data. This also helps to increase the number of training images [172] which in return positively effects the performance of deep networks [181]. But these 2D planer variations are synthetic and never corresponds to deformations in real life. So, in order to model the variations as close as in reality, the 3D point clouds are rotated for facial expressions along yaw, pitch and roll angles. These rotations can model the real world variations and can produce better results. So, a bigger dataset is generated incorporating these rotations. The 3D point clouds are then converted to range depth images and fed to the network. The block diagram of the algorithm is shown in Figure 7.

## 4.2 Model Architecture

Visual cortex of human beings and animals is the most powerful and complete vision system. Visual cortex has a complex distribution of cells which are sensitive to small regions of what an eye sees as a whole. These small regions are called receptive fields and these receptive fields are arranged in such a way to cover the whole visual field. Two types of cells are found in visual cortex, one that are sensitive to edge-like patters and other that are invariant to position of the stimulus. Convolutional Neural Network are largely inspired by the setup of Visual Cortex.

Convolutional Neural Network is a trainable multi-layer architecture having several stages. CNN’s extract local features at higher resolution and then combine them in a well-engineered way to more compact feature representation at lower resolution. Each stage has two types of layers: convolutional layer and pooling layers much like the two different types of cell in visual cortex.

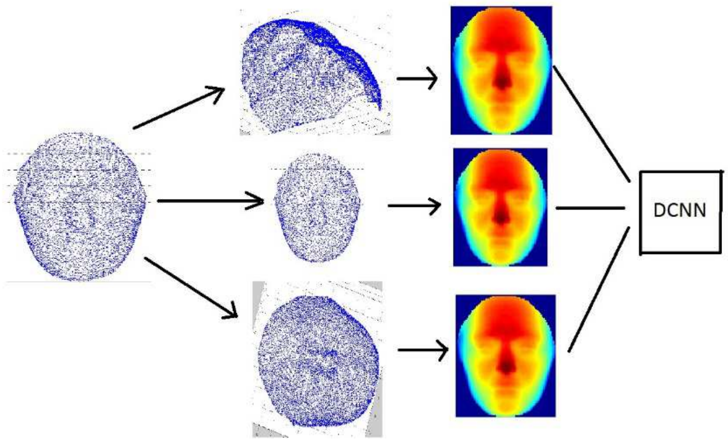


**Figure 7: Block Diagram of Algorithm**

Convolutional Layers are like cells that are sensitive to edge like patterns and pooling layers act like cells that are spatially invariant. The input and output of each stage is a set of arrays called feature map [181]. Feature maps are generated by applying a respective kernel at convolutional or pooling layer. Each feature map defines a particular feature extracted over the entire image. Typically, CNN's have 2 or 3 such layers followed by the layers of MLP's which are then connected to the output neurons.

Convolutional Layer: This layer performs a discrete convolution of the image with a filter kernel and then applies a bias term to it. The values of filter kernel are randomly initialized and are then learned using feed forward and back propagation. The number of kernels used decides the number of feature maps to be extracted and hence the number of different type of features extracted at all locations from the whole image. A non-linear activation function is applied following a convolution operation. Different types of activation functions are used like tangent hyperbolic sigmoid function or rectified sigmoid function with a gain parameter attached to it [181].

Pooling Layer This layer reduces the resolution of the feature maps to achieve slight spatial invariance of features extracted in the previous layer. This layer computes the average of the values in a neighborhood defined by the size of the pooling window. Pooling window is applied to each feature map separately. The loss of spatial information due to reduction in resolution is compensated by the greater number of feature maps in higher layers. Normally, two type of pooling operation are performed: 1) subsampling pooling layer which takes the average over inputs and 2) max pooling layer which calculates the maximum in the neighborhood defined by the pooling window. Max pooling introduces scarcity in the output maps.

### 4.3 Deep Expression Convolutional Networks

Deep Convolutional Neural Network is used as base classifier. The input to the network is a 64 x 64 range image. The network has three stages. In the first stage, convolutional layer has 7 feature maps and 9 x 9 filters, average pooling layer over non-overlapping regions of size 4 x 4. Second stage convolutional layer has 30 feature maps with 6 x 6 filter followed by an average pooling layers of size of 3 x 3. A fully connected MLP layer of 315 neurons is connected to the output of sampling layer which is then followed by the output layer. The output layer has one neuron per class. BU3Def data set has 6 expressions, so, the number of neurons in the output layer is 6. The network is shown in Figure 8.

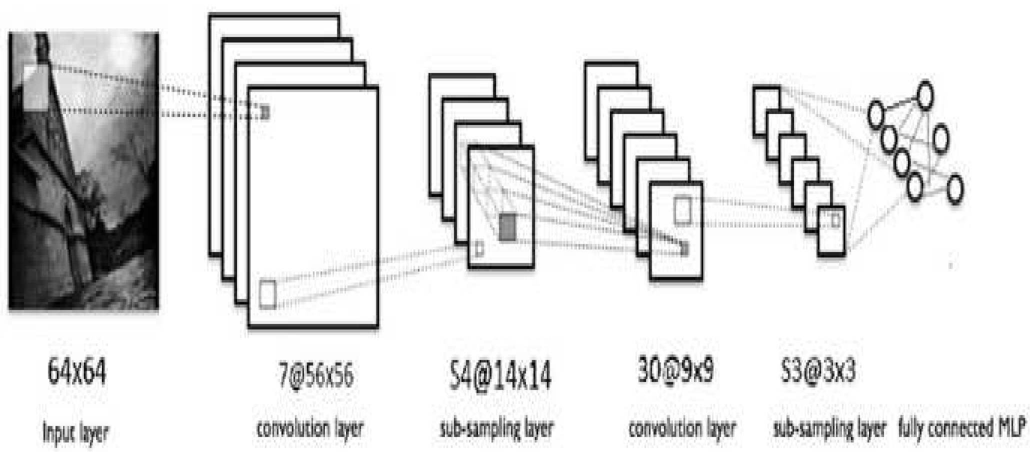


**Figure 8: Deep Convolutional Neural Network Architecture**

Sigma activation function is used for convolutional and fully connected layers, linear function for averaging sample layers and sigma activation function for the output layer. The initial weights are randomly initialized. Learning rate is set initially at 0.5 and is decreased by a factor of 0.995 per epoch until it reaches a minimum of 0.0003. The selection of learning rate is critical, should be large enough for fast learning but not at the cost of its effectiveness. Training ends once the learning rate reaches the pre-determined minimum value. The batch size is set to be at 6.

One of the limitations of using 3D data for training of convolutional networks is the small size of available 3D facial datasets and hence fewer number of training images. Deep convolutional neural network are reported to have achieved better results if the training datasets are comprehensively large [171], [182]. The size of dataset is directly related to the capacity of the network. The capacity of the network is directionally proportional to the number of feature maps and number of stages in the network. Insufficiently deep and wider capacity networks compared to the size of the available data can be exponentially ineffective [181]. Wider capacity network will result in over fitting and the generalization of classifier will become difficult.

One of the few available 3D datasets for facial expression recognition is a BU-3DFE dataset [183]. Most of the recent works have experimented on this dataset, so it is a good test benchmark for evaluation of the algorithm presented in this project. BU-3DFE dataset has 2500 facial scans of 100 identities. Among them, 56 are female and 44 are male. Also, there are vivid variations in ethnic ancestries and age group. Each identity has 25 facial scans with one scan of neutral face and 24 scans of 6 expressions namely Anger, Disgust, Fear, Happiness, Sadness and Surprise varying in intensities from level 1 to 4. The scans are taken under constraint environment and conditions (only frontal pose, no clothes, no hairs).

Most of the research work have only used extreme levels (3 and 4) of expressions [159], [161, 167],[163] [184], [185],[186], [187]. So, we have also used only extreme (level 3 and 4) expressions. Their experimental setup takes only 60 identities out of 100 and left out 40 identities [163],[184],[185]. It is worthwhile to mention here that it is not clear which 60 identities are selected and which are left out, so this appears to be an inadequate setup which is also pointed out and heavily criticized by [159], [167] and has used all 100 identities in their experimental setup, as selecting 60 ‘easy’ identities can give high accuracy as pointed out by [167]. Also, human expert results [183] are on complete 100 identities, so it makes appropriate sense to use all 100 identities in experiments. So, complying with the experimental setup of [159],[183], all 100 identities are used in the experiments. Out of 100 identities, 82 random identities are used for training, 9 random identities (5 female and 4 male) are used for validation and 9 identities are used as test data.

First, 3D point clouds of all images are converted to depth range images using 2mm distance. As convolutional neural network require all images to be of same size, so, all range images are resized to 64x64 and then all images are normalized. The order of images is randomized every epoch so that the network may not learn the pattern in which images are presented for learning.

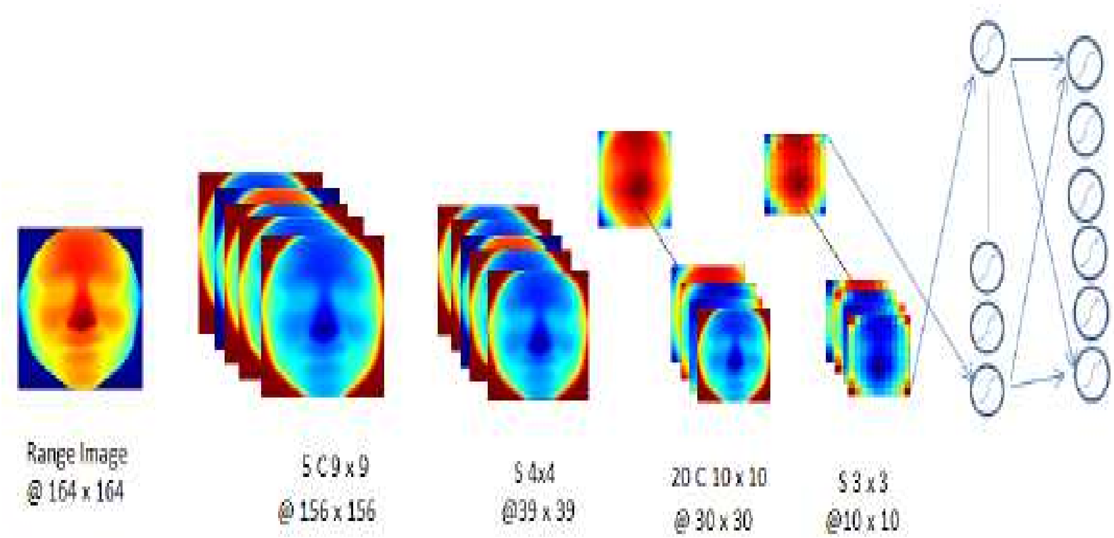


**Figure 9*: A complete structure of network with learnt features***

A series of experiments were carried out. First, random 82 (984 images) identities were selected for training, and 9 identities for validation. This setup is presented to the network and classifier reaches a mean accuracy of 79%. Next, planner rotations at angle of +5 and -5 were introduced in the training images which increased the size of the training dataset. The classifier then reported a mean accuracy of 86.10%. This increase in accuracy by introducing rotation images motivated this study to explore the effect of 3D rotations at pitch, roll and yaw angles. Each image is rotated in 3D at along x, y and z-axis at angles of $+5^o$, $+10^o$, $-5^o$ and $-10^o$ separately. The idea is to investigate, along which axis, rotations plays a critical role in improving accuracy. The results of these rotations is shown in table 1

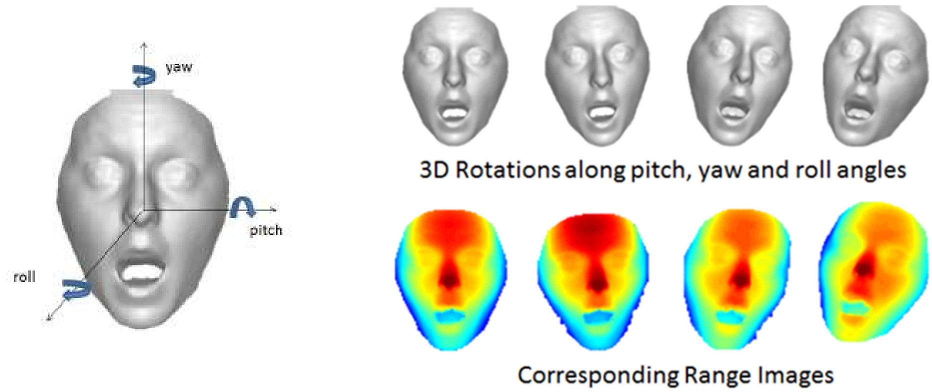


**Figure 10: Rotation of images along pitch, yaw and roll.**

Next, 1mm distance between pixels was used to generate range images to improve the resolution and better representation of expressions. The images are resized to comparatively bigger size of 164x164 and experiments were repeated. This time, results were much better and surpassed the state of the art. Table 2 shows the comparison of this work with existing manual and automatic 3D facial expression recognition schemes.

**Table 1: 3D Rotation Accuracy**

| **Rotation** | **Accuracy** |
|---|---|
| Rotation along pitch | 81.48% |
| Rotation along yaw | 82.41% |
| Rotation along roll | 84.12% |

**Table 2: Comparison of CNN based technique with existing work**

| **Method** | **Type** | **Average** |
|---|---|---|
| L. Yin [YWS+ 06] | Human Expert | 96.8% (100 Identities) |
| A. Maalej [MAD+ 11] | Manual | 98.8% |
| U. Tekguc [TSD09] | Manual | 88.2% |
| H. Tang [TH08] | Manual | 87.1% |
| J. Wang [WYWS06] | Manual | 83.6% |
| T. Sha [SS+11] | Manual | 83.5% |
| **This work** | **Automatic** | **86.10% (100 Identities)** |

| | | |
|---|---|---|
| M. Xue [XMLL14] | Automatic | 83.0% |
| P. Lemaire [LACD13] | Automatic | 78.1% (100 Identities) |
| P. Lemaire [LBAA+11] | Automatic | 75.8% |

The confusion matrix of recognition is shown in table 3

**Table 3: Confusion Matrix of Recognition on BU-3DEFE dataset**

| | | | | | | |
|---|---|---|---|---|---|---|
| **AN** | 16 | 0 | 1 | 0 | 1 | 0 |
| **DI** | 2 | 16 | 0 | 0 | 0 | 0 |
| **FE** | 0 | 0 | 15 | 1 | 2 | 0 |
| **HA** | 0 | 0 | 0 | 18 | 0 | 0 |
| **SA** | 5 | 0 | 0 | 0 | 13 | 0 |
| **SU** | 0 | 2 | 0 | 1 | 0 | 15 |

### 4.4 Supervised Regression

One of the most important features of any machine learning tasks is the analysis of available dataset, then finding the best possible pre-processing steps and finally, deciding about the most suited machine learning algorithms. Often features in the dataset are highly co-related, scaled and there exist missing values, varying standard deviation among features and outliers. Size of the available dataset and number of features also play an important role in the selection of appropriate machine learning algorithm. It is also important to mention here that it is almost impossible to say with confidence that any particular algorithm will produce the best result for the given task. Often, machine learning tasks involve evaluation of dataset with different algorithms and application of different pre-processing steps (often based on type of data features and requirements of a respective algorithm). Hence, machine learning task usually involves three tedious tasks in their development cycle: 1) Evaluating different pre-processing steps and respective parameter tuning, 2) Application of different machine learning algorithms and fine tuning their parameters, 3) Cross-validating and evaluating results based on different result parameters. The same approach was adopted in this project as follows: different pre-processing steps, and different machine learning algorithms in an effort to get better results.

The very first thing to analyze is the size of the data to avoid system to become over-fit or under-fit. This happens if the capacity of the proposed system is either too small or too big compared to available dataset. This available dataset contains only 1006 instances of training data which is a bit small compared to other usually available for machine learning tasks. The small size of dataset effectively omitted the benefit of deep learning tools. Deep learning algorithms like CNN and RNN have shown great promise in the recent years and would definitely have been an interesting choice but small size of dataset means that it will be hard for deep learning algorithms like CNN to converge. After analysis of the given dataset, SVM (SVR), Decision Tree Regressor and MLP were first choices. The main pre-processing task involved normalization and scaling of the data to bring mean to zero and bring all features on the same scale. As numbers of features were already very less, so it is believed that any dimensionality reduction technique like PCA or LDA will not produce considerable improvement in the regression results. But, it is important to mention here that choice of pre-processing is also highly dependent on algorithms as normalization is not a good choice for NN or SGD algorithms. It is often a good idea to randomize the available dataset so that classifier is not able to learn any particular patterns based on the order of the data. So, data is also randomized. The ground truth for the test dataset was not given, so the training dataset is divided into validation data and training data. The 90% of the training data is used for training and remaining 10% is used for validation. The task given is a regression task with supervised learning. Number of different algorithms were tested and their results are shown later in the report.

The evaluation metrics used for regression tasks are variance score, mean absolute error, mean squared error, median absolute error and R2 score. Variance score and R2 scores close to 1 are good and lower score means poor performance of classifier or training. For other error measurement metrics, lower values are better.

The pros and cons of different algorithms vary and are also associated with the pre-processing steps. Like SVR-rbf requires data to have zero mean and variance of 1. NN and SGD algorithms don't perform well if the data is normalized. Advantages of SVM is that it is usually effective in high dimensional spaces and are particularly effective if the number of features are less than number of samples. Also, it uses only a subset of training points in decision functions, which are called support vectors, which makes it memory efficient. SVM is also combined with different kernel functions which can help to better separate the boundary between features. SVM doesn't work good if the numbers of features are greater than number of samples in the data. Usually, for most machine learning tasks, SVM is a first try choice owning to its enormous success on many dataset and researchers were obsessed with it in the era 2008-2012.

Decision trees are also a very powerful algorithm employed in the situation like provided in the task. The biggest advantage of decision tree algorithm is that it can be molded to handle both numerical and categorical data. Also, they are effective in dealing with missing values in the dataset. Also, it requires minimal pre-processing steps and learns by simple comparison rules within the data. The disadvantages of decision tree are that they are somewhat unstable in some cases. Meaning they can create too complex model, which result in under fit of the data, can be biased towards a specific class and are sensitive to small variation in the data.

**Results:**

**Table 4: Results with different variant of support vector machines**

| **Techniques** | **SVR-RBF, γ=0.1, with preprocessing** | **SVR-RBF, γ=0.1, no preprocessing** | **SVR-RBF, γ=0.01** | **SVR-linear, C=1e3** | **SVR-Poly, C=1e3, degree=2** |
|---|---|---|---|---|---|
| **Variance Score** | 0.980 | 0.222 | 0.99 | 0.999 | 0.709 |
| **Mean absolute error** | 0.077 | 7.30 | 0.07 | 0.03 | 3.54 |
| **Mean Squared Error** | 0.016 | 103.96 | 0.01 | 0.002 | 39.74 |
| **Median absolute error** | 0.054 | 6.07 | 0.04 | 0.033 | 1.03 |
| **R-2 score** | 0.9805 | 0.221 | 0.999 | 0.999 | 0.702 |

**Table 5: Comparison of SVM with Decision Tree Algorithm**

| Techniques | SVR-RBF, γ=0.001, with preprocessing | Decision Tree Regressor, norm =l1 | DTR,norm=2 | SVR-Poly, C=1e3, degree=1 |
|---|---|---|---|---|
| **Variance Score** | 0.999 | 0.99584 | 0.994 | 0.999 |
| **Mean absolute error** | 0.06 | 0.000219 | 0.0002 | 0.04 |
| **Mean Squared Error** | 0.005 | 1.88117 | 3.3367 | 0.002 |
| **Median absolute error** | 0.064 | 0.00015 | 0.000183 | 0.03 |
| **R-2 score** | 0.9999 | 0.99584 | 0.9942 | 0.999 |

**Table 6: Accuracy results by MLP, Nearest Centroid, and Linear Bayesian**

| Techniques | MLP Regressor | Nearest Centroid | Linear Bayesian | Linear SGD |
|---|---|---|---|---|
| **Variance Score** | 0.9938 | 0.83 | 0.98 | 0.978 |
| **Mean absolute error** | 0.59 | 3.264 | 0.89 | 0.81 |
| **Mean Squared Error** | 0.82 | 24.03 | 1.36 | 0.45 |
| **Median absolute error** | 0.39 | 2.0 | 0.61 | 0.67 |
| **R-2 score** | 0.9938 | 0.81 | 0.989 | 0.988 |

# Chapter 5: Conclusion

Human race was, is and will be dependent on industrial advancements and progress of manufacturing processes. To understand what is the future of industrial manufacturing is a complex matrix with multi-dimensional factors affecting its future. Scientists and researchers have always come forward with different formulas, theories and models to predict future of technology. The value of this prediction is priceless as it can help industries to prepare well for the technologies which will shape the industrial world in future and give them ample time to adapt themselves to the needs of ever-changing scientific advancements. Hence, technology forecast holds a pivotal position in preparing industries to have a peak future and work as a guiding principle around which companies and industries can formulate their future policies.

Scientists and industrialists have taken different approaches in different era to predict about technology of future. In the past, it was linked with the geographical locations of industries meaning a certain industry prosper in one part of the world and different industry at different part of the world. Then, it was about the discovery of metals and materials. If a certain material is discovered in a specific era, then next few years will see the boom and industrial inclination of that particular material. Then, scientists formulated their models around military and war environment. Technology was purely advanced and researched just to prove dominance over enemies and take control of others resources and land. After that, it was an era of industrial revolution where repetitive part production technology was unearthed which really moved the manufacturing from small units to large industries. After that, it was all about energy and industries feared that energy resources will end one day and they have to look and find other sources of energy. Then came the digital and computer era which radically changed the face and outlook of technology and manufacturing.

All of these models to predict about future technology were either mathematical or logical. One model may behave or predict better for some instances and the other models outperform the best in some other aspects. The logical models were more time dependent and were biased towards the way different humans think and what has happened in the recent past. All of these mathematical models have certain assumptions and limitations. Such mathematical models were either based on probability or complex series based prediction rules which were true for some parts of technology forecasting while they behaved poorly on other aspects in predicting the trend of future. One of the reasons is that all of these models either relied on some mathematics which cannot cover all the boundary conditions or probabilistic theory which tries to add the certain amount of confidence in predictions. The truth is that as many mathematical rules were proven wrong by researchers and were corrected by late researchers, the quality and reliability of these models were as good as the knowledge available in that era or the caliber of the person who is developing such model. The reality is that all of these models and formulas were developed by human beings and as humans are prone to error or their ability to overlook a certain aspect is natural, these models are no different. Also, they are limited by human ability to vision a broader picture as some researchers looked in the recent past, some totally relied on available data, some based their prediction models on logical theories and some took the political and geographical environment into consideration in formulating their technological forecasting models.

The importance of human machine interaction processes will grow in future. There is a constant effort to find better means to improve the human machine interaction and define a protocol which gives appropriate powers to both human and machines in order to successfully execute a project or a certain application. There are efforts to better co-ordinate the multimodal human machine interfaces, clear understanding of machine networks, human centered learning mechanisms for machines, orient the future artificial intelligence algorithms along the defined rules respecting the human supremacy while giving due operation decision making power to machines. There are contact efforts in finding new methods and means for better understanding of human intensions by machines. This study also covers one of these aspects where future machines will also be able to respond human expressions and execute tasks which can be conveyed to machines just by the human expressions. There are already few human assistive robots which respond based on whether the person is happy, sad or angry. They can play different type of music or suggest a certain type of activity purely based on the human expressions. Recently, in manufacturing, smart systems are being deployed at factories where machines will continuously monitor human expressions to gauge their level of commitment and efficiency on a particular day or time. This helps them to allocate better time off slots for a certain group of employees rather a daily fixed time slot for breaks.

The conclusion is that in all of these technology forecasting mechanisms, the obvious decision making power was with human beings. If they make use of computers, it was solely for processing large chunk of data but still the procedure to process that data was laid down by humans. In this thesis, an interesting approach was taken by investigating manufacturing history right from the start and trying to find nodes which hold vital importance in manufacturing history and those nodes helped to understand key factors which changed the course of manufacturing in the past. Understanding these nodes helped us to identify the key knots which bounded the current technology of a specific era with the technology of the future. Once the nodes are identified, attempt is made to understand the proper path which connects these nodes by understanding the innovation and innovation management process. This helped to understand the process of future technology evolution process.

# Chapter 6: Future Recommendations

## 6.1 A Deep Learning Approach for Predictive Decision Making

Technology forecasting is now becoming a pivotal cog in the progress and growth of engineering industries. Typically, technology forecasting is either based on manual human methods (i.e. Delphi method) or on some rational and analytical data using either exploratory or normative methods. There is a growing need to develop artificially intelligent generic models which could help in predictive decision making and technology forecasting. The realization of such a model can be developed if machines start behaving much on the same principle used by human's cognitive system. The use of machine learning algorithms in the field of technology forecasting are still very much unexplored and it will be exciting to introduce artificially intelligent predictive systems. In the recent past, deep learning has revolutionized machine learning and has produced promising results compared to neural networks and other probabilistic machine learning algorithms. The exploration of deep learning algorithms for technology forecasting will be stimulating and will open new area of research.

### 6.1.1 Deep Learning

Deep learning is an emerging field of machine learning that models high level representation and abstractions present in the data using successive learning layers of non-linear transformations. Deep learning is an artificially intelligent algorithm that involves supervised or un-supervised learning for feature extraction that helps in learning different representations of data [6]. Previously, neural network were supposed to correctly model the working of human cognitive system but results were not promising when compared to human performance. The problem with neural networks was that if the data is high variance, they may not quickly converge or in some cases, they may never converge. This problem is also mentioned by Szejung Wu and Nagi Gebraeel [188], when they used neural network model to predict life expectancy of different parts used in rotary machines. Also, the quality of data fed to neural network is of major importance, as they process all input data identically and hence may become biased on factors which are not relevant or less important. The other machine learning algorithms used probabilistic models but sometimes they are application/data specific and may not perform equally well in all scenarios.

The most famous supervised deep learning algorithm is Deep Convolutional Neural Network (CNN). A Convolutional neural network approach involves convolutional and subsampling layers before data is fed to neural network for decision/prediction [172]. This has radically outclassed many complex probabilistic and machine learning algorithms due to its simplicity in implementation and amazing improvements in accuracies which were not achievable previously. The major advantage is that the features extracted are human independent and are free from biasness. Also, most of deep learning algorithms do converge and are able to handle "big data". Recently, big groups like Facebook revealed that they have achieved more than 97% face tagging accuracy for all faces present on their websites using deep learning [171]. Google reported to have used the same algorithm for their search architecture and recently Skype made use of same machine learning algorithm to translate voices in one language to another. Huge investments are made to further explore its usefulness in new fields like robotics, decision forecasting and video analysis to produce state of the art results.

The unsupervised and semi-supervised deep algorithms include Auto-encoders, stacked de-noising encoders, restricted Boltzmann Machine and Deep Belief Networks. The unsupervised algorithms are particularly important when validation data is not available.

### 6.1.2 Technology Forecasting

Technology forecasting (TF) is an activity that helps companies to identify technological opportunities, threats and to evaluate the on-going processes for future growth and better survival of their industry. It is necessary that after a technology is implemented, the firm monitors changes that may render the technology obsolete, dangerous, replaceable, or competitively weak. Technology forecasting is now widely considered an important strategic management factor of any industry, specifically for technology-focused firms. The basic process of TF involves gathering past or sensor data, interpret the information from the data and then introducing intelligence for forecasting as shown in Figure 11. Talking broadly, technology forecasting methods can be broadly classified in nine different categories namely expert opinion, trend analysis, monitoring and intelligence methods, statistical methods, modelling and simulation, scenarios, valuing/decision/economics methods, descriptive/matrices method and creativity method [189]. Basically, almost all TF techniques make use of extrapolation of past data, adapted by subjective evaluation regarding transformation of past trends into future demands [190]. Thus, TF process involves: Recognizing, shaping, extrapolating patterns of previous technical development and collecting/consolidating the experienced personnel advice [190]. The use of machine learning and deep learning algorithms for TF will be exciting as they promise to handle data more efficiently and smartly.

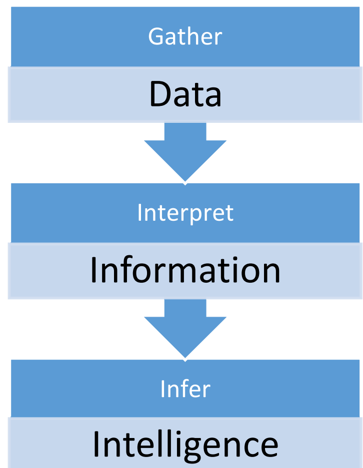


**Figure 11: Technology Forecasting Architecture**

### 6.1.3 Deep Learning Based Technology Forecasting

The boundary of TF field is yet undefined and it takes many shapes in the form of technology intelligence, forecasting, road-mapping, assessment, and foresight. TF is a multi-dimensional and multi-oriented field with varying applications in industries. The major shortcoming faced by TF methods is that they are either human biased, not able to handle big data and process data uniformly. Firat et al. [189] in his studies pointed out that though there are hundreds of different methods for Technology Forecasting and combining some methods may produce better results but there is a dire need of 'tech-minning' algorithms and introduction of semantic enabled features from the data may produce better result. Those semantic features must be able to mediate contextual in-capabilities and should be better able to capture hidden pattern available in the information and hence producing the improved representation of data.

Most of artificial intelligent systems involve two main steps, training/learning step and testing step. CNN's extract local features at higher resolution and then combine them in a well-engineered way to form more compact feature representation at lower resolution [191]. Each stage has two types of layers: convolutional layer and pooling layer much like the two di erent types of cell in visual cortex. Typically, CNN's have 2 or 3 such layers followed by the layers of MLP's (Multi-Layer Perceptron) which are then connected to the output neurons.

Machine learned features are expected to perform better as they are free from biasness and develop a unique low level representation of data which in turn helps in more accurate and reliable forecasting. Convolution layers will extract unique machine based features and will be updated by back propagation algorithm. The parameters selected by machine will be independent of human bias and will be free of particular inclination towards certain markers. Provided large number of training samples and parameters, machine learns the hidden abstract representation and will be able to select parameters which will be more helpful in accuracy. So, a larger set of parameters can be incorporated and their multiple variations can be considered without it being taxing in terms of processing and dimensionality/complexity provided huge network capacity of deep learning algorithms. The proposed approach is shown in Figure 12:

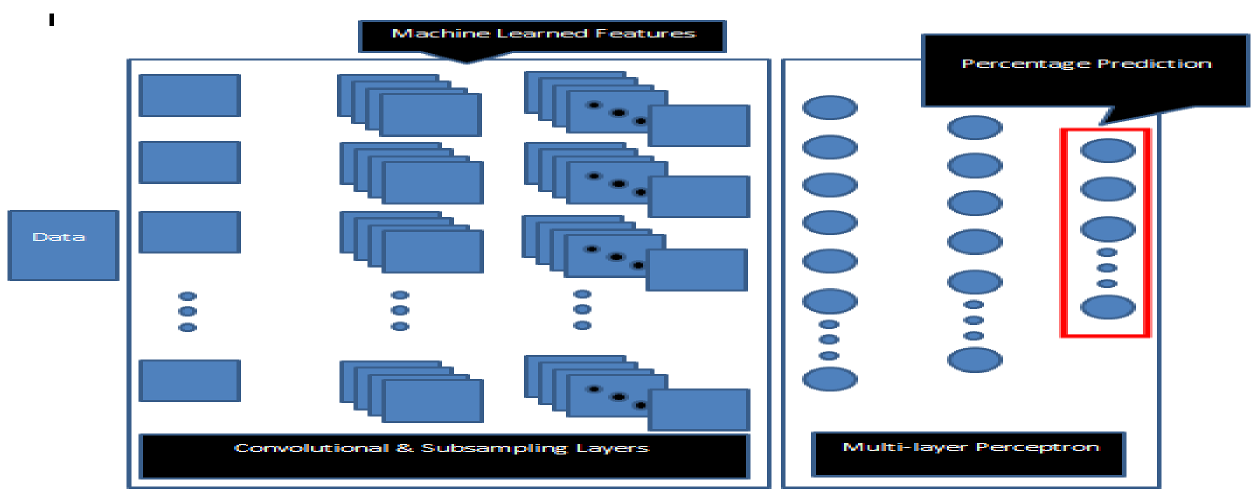


**Figure 12. Deep learning using CNN**

### 6.1.4 Case Scenario

Industries these days are aiming for more and more productivity and 'equipment reliability' is of major importance in achieving higher production. Equipment reliability is achieved via rigorous maintenance programs. This is done to eliminate unexpected breakdowns and reduce unscheduled downtimes. Normally, there are two types of maintenance schedules: Corrective maintenance and preventive maintenance. Corrective maintenance is done when a certain machine part has become faulty and repairing is required. This is also called run to failure maintenance. This results in considerable breakdown time and reduction in production. Preventive maintenance is done before part becomes faulty or run out of his life. Preventive maintenance is done at fixed regular intervals and it does not take into account the actual condition of equipment. It does not consider how much machine is used in that particular maintenance time and what is the actual condition of the machine? This results in high maintenance cost and unnecessary maintenance activities.

Eisenmann Sr. and Eisenmann [191] mentioned that predictive maintenance has huge advantages over preventive and corrective maintenance. The predictive maintenance overlaps the domain of preventive maintenance in the sense that instead of maintenance activities at fixed regular intervals, it is done based on the actual condition of machine and before it runs out of its actual life. This saves huge maintenance cost, maximum machine life and reduces unnecessary maintenance activities. The predictive maintenance is based on the collected data on machine condition. This data on machine condition is generated using sensory information placed on machine marking different operating and performance parameters.

All sensory information for machine condition may not be of same importance i-e some parameters are more important than others. Also, there might be a hidden pattern present inside sensor data which collectively or in some combination may result in fast decay of machine life. The model must be able to identify most significant parameters and should be able to find those hidden patterns or combination and hence must be able to predict the remaining life of the machine. Different statistical and probabilistic models are used to predict machine life based on sensor information. Sze-Jung Wu [188] in her paper used

Levenberg Marquardt based neural network for fast convergence and better results.


**Figure 13: Overview of Proposed Approach**

The application of deep learning model: a CNN based approach is proposed to predict life of a machine. A CNN model is expected to perform better as it has the capability to handle huge sensor data and will be able to uniquely identify the important parameters present in the data using convolution layers and down-sampling layer. Plus, CNN model usually always converges which is not always possible with neural networks. A CNN network generates a low level representation (artificially intelligent learned features) of machine sensor information. CNN model has training and testing phase. In training phase, a system learns the behavior of different machine performance parameters and then in the testing phase, it predicts the life expectance of test machine part. It is very similar to human experience based learning where a human takes decision based on its experience of past. CNN network can be trained in a very short time (hours or days) and can replace human experience gained over span of years. The block diagram of proposed model is shown in Figure 13. The prediction of CNN network can be coupled with other methods for improved results.

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