POLITECNICO DI MILANO

DEPARTMENT OF MANAGEMENT ENGINEERING

MASTER THESIS ON

IMPLEMENTATION OF IoT TECHNOLOGIES IN MANUFACTURING PROCESS

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Master Graduation thesis by

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ABSTRACT

The Internet of Things is emerging as the third wave in the development of the internet. Internet of things (IoT) is expected to have a massive impact on consumer products, business and wider culture, but these are still early days. Given its potential for very wide applicability to almost all verticals and aspects of business, industries, manufacturing, consumer goods, supply chains, etc.

This thesis is primarily focused on process optimization in manufacturing industry in business-to-business context. The study is an effort to point out the issues manufacturers face at their shop floor and it provides solutions for dealing with those issues. During the last decade the Internet of Things (IoT) has gained a lot of attention from both academia and practitioners. IoT emphasizes on the importance of physical objects transferring information by using software and the Internet. Based on the global trends, there is a need for companies to focus on how they can implement IoT to facilitate their businesses and create new business and market opportunities. IoT can connect various things and objects around us which are able to interact with each other. In other words, IoT technologies not only connect an industrial system or supply chain, but also connects stakeholders and end-customers.

The goal of the thesis is to discuss IoT technologies and elaborate how they are implemented in manufacturing processes. A qualitative document analysis will be conducted by comparing two case studies. Data will be collected from public, non-confidential information sources including press releases, newspapers, articles and journals. The research approach was primarily descriptive with the focus on differences between previous production optimization technologies and IoT applications in use today.

The results of this thesis demonstrate that IoT technologies bring transparency, traceability, adaptability, scalability and flexibility to the system. Therefore, the adoption of IoT has quite a few potential benefits, including improvement in cost and risk reduction, operational processes and value creation. This research also shows that using IoT technologies for their benefits is not an easy task for enterprises. Since IoT is a recent development, various aspects of the IoT such as economical, managerial and industrial aspects need to be studied and this makes companies hesitant to make decisions regarding the adoption if IoT.

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List of Abbreviations:

AGV- Automated Guided Vehicle

B2B- Business to Business

B2C- Business to Customers

BT- Bluetooth technology

ERP- Enterprise Resource Planning

EWA- Electronic Works Amberg

GPS- Global Positioning System

HMI- Human Machine Interfaces

IaaS- Infrastructure as a Service

IT- Information Technology

IOE- Information of Everything

MES- Manufacturing Execution Systems

MT- Manufacturing Technology

PaaS- Platform as a Service

PLC- Programmable Logic Controller

PLM- Product Lifecycle Management

RFID- Radio Frequency Identification

SaaS- Software as a Service

TIA- Totally Integrated Automation

UHF- Ultra High Frequency

UM- Ubiquitous Manufacturing

UT- Ubiquitous Technology

VPC- Virtual Private Cloud

WIP- Work in Progress

WSN- Wireless Sensor Networks

1. Introduction

1.1 Background

Manufacturing enters a new era, where higher levels of flexibility are required to address the challenges of shorter product lifecycles, increasing number of new products and variants, uncertainties and fluctuations in the market demands, especially for addressing the needs for mass customization and personalization. Nowadays production systems change from being located into a single area with centralized control into being distributed with decentralized control. This transformation of traditional factories into smart factories can be very disruptive for the daily operations of manufacturing.

Manufacturing has a big significance in the economic growth. In Europe alone, manufacturing accounts for more than 28% of the gross domestic product (GDP), even in today's economic recession. Moreover, the presence of Small and Medium Enterprises (SMEs) is very strong in the European industry. Specifically, European SMEs are the backbone of manufacturing industry in Europe with micro, small and medium enterprises to constitute around 45 % of the value added by manufacturing while they provide around 59 % of manufacturing employment. Therefore, the European SMEs need to be competitive to keep up with the fluctuating and the unexpected demands from the emerging market needs. Moreover, as companies make strides towards this new era, they will need to differentiate from the competition. To achieve this, manufacturing companies need to be innovative, create strong supply chain partnerships and being able to embrace modern technologies.

The pinnacle of computing technology in the 21st century, that has transformed the personal computers into smart devices, has been accompanied by a trend of providing information technology (IT) infrastructure and services. In conjunction with ever greater miniaturization and the unprecedented progress of the Internet, this trend is to move towards a world where ubiquitous computing is becoming a reality. Advances in the semiconductor industry with powerful and cost-efficient processors, storage devices that can contain many terabytes of information, along with autonomous embedded systems that are being wirelessly networked with each other enable the convergence of the physical and the cyber worlds. The contemporary factories need to take advantage of the latest innovations in IT solutions, as well as refined best practices for shop floor operations. This procedure of digitalization is not straight forward and depends highly on the nature of each manufacturing system. Nevertheless, the companies that are forward-thinking and confident into adopting innovative operational models will be able to endure the emerging market demands.

The advent of modern technologies such as Cyber-Physical Systems (CPS), Internet of Things (IoT), and big data analytics open new horizons towards the industrial digitalization by enabling automated procedures and communication by means that were not attainable in the past. Interconnected manufacturing systems and supply chains constitute and integrated whole that follows the System of Systems paradigm. In this context, the factory can be regarded as an ecosystem that is composed of interconnected entities that refer to the resources such as machine-tools and robots, the employees, the customers, the supply chain partners and other stakeholders of the value chain following the idea of Cyber-Physical Systems.

Moreover, the usage of processors with high processing capabilities to embed intelligence into manufacturing resources transforms passive systems into active entities with decision support capabilities. This transformation is described in the paradigm of IoT with the definition "In what's called the Internet of Things, the physical world is becoming a type of information system—through sensors and actuators embedded in physical objects and linked through wired and wireless networks via the Internet Protocol". The term IoT characterizes the radical evolution of the internet into a network of interconnected objects that create a smart environment. Despite the fact that various definitions for IoT have been proposed, a universal definition may not be the most important issue for the developers' society. The most prominent issue is to have agreed-upon standards for connectivity and security to ensure a future of IoT technologies that can communicate and collaborate instead of existing in their own standalone ecosystems. Nevertheless, another definition of IoT is "The Internet of Things allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service". This definition encapsulates the broader vision of IoT. In industry the term Industrial IoT (IIoT) is introduced and refers to the application of IoT in industry and implies the use of sensors and actuators, control systems, machine-to-machine, data analytics, and security mechanisms.

However, the application of IoT, especially in industry, results into the creation of vast amounts of information that needs special manipulation and analysis in order to perform meaningful reasoning and extract the actual value. To meet this challenge, the big data analytics is a facilitator to overcome the bottlenecks that are created by the data generated by IoT.

For years, sensors and data capture capabilities have been designed, built and embedded into production lines. Nevertheless, very little has been done so far with this capability, falling short of what could be done with it. Machines and automation on production lines have been equipped with sensors and intelligence since the mid-70's, but their embedded intelligence was scarcely exploited in terms of autonomous operation and decision making. Hence, data collection was rarely leveraged to make strategic decisions due to closed, hard-wired manufacturing environments.

The Internet of Things (IoT) is a new paradigm that combines aspects and technologies coming from different approaches. Ubiquitous computing, pervasive computing, Internet Protocol, sensing technologies, communication technologies, and embedded devices are merged together in order to form a system where the real and digital worlds meet and are continuously in symbiotic interaction. By definition, IoT refers to an emerging paradigm consisting of a continuum of uniquely addressable things communicating one another to form a worldwide dynamic network. A thing can be any real/physical object (e.g. RFID, sensor, actuator, smart item) but also a virtual/digital entity, which moves in time and space and can be uniquely identified by assigned identification numbers, names and/or location addresses. Therefore, the thing becomes a smart object that is easily readable, recognizable, locatable, addressable, and/or controllable via Internet. One of the greatest benefits of the IoT has been its ability to standardize and commoditize technologies. Recent IoT reference models can be used and can be enhanced, acting like live systems, where features are gradually developed and integrated in or on top of the IoT network infrastructure, slowly transforming it into an infrastructure for providing global services for interacting with the physical world.

In the field of manufacturing there are many opportunities from the industrial IoT. IoT will create 3.9-11.1 trillion $ of economic growth per year globally by 2025, from which approximately 1,2-3,7 trillion $ will be generated in production systems. IoT makes monitoring possible where it was not possible before. It makes things simpler, less expensive, and more accurate. The key is to know what are the problems that need to be solved. Knowledge of the application and the potential of IoT results into the definition of KPIs that could not be considered in the past. Sensor data can be used to predict when equipment is wearing down or needs repair can reduce maintenance costs by as much as 40 percent and cut unplanned downtime in half.

Inventory management could change radically (keeping stocks to minimum). Supply chain management and logistics can gain a real benefit from IoT. Harvesting data generated from the usage of products can support the companies to realize how do they get actually used. IoT can create new business models that would shift competitive dynamics within industries. One example is using IoT data and connectivity to transform the sale of industrial machinery and other goods into a service. The Industrial IoT increases the speed of manufacturing and reduces labor costs by giving the ability to monitor high-value and high-impact assets. Thus, the smart object should be the building block of the IoT vision. By putting intelligence into everyday objects, they are turned into smart objects, able not only to collect information from the environment and interact with the physical world, but also to be interconnected with each other through Internet and exchange data and information.

1.2 Objectives of the study

Since the concept of internet of things is relatively new, not many studies have been conducted about IoT and what it adds to manufacturing processes. The research work aims to focus on **"Implementation of IoT technologies (particularly RFID) in manufacturing process".** It takes into consideration the disruptions created by IoT in different businesses and the applications of IoT in various industries. Moreover, this study highlights the impact of IoT on enterprises and challenges and issues on the way of using it.

This thesis would provide answers to the following questions:

1. How can manufacturers use IoT technologies in optimizing their production process?
2. What are the benefits of IoT technologies on shop floors for factories?
3. What are the challenges and issues of implementing IoT in existing businesses?

This research has two goals. First, the purpose of theoretical part is to briefly discuss the history, definitions, challenges and distinctive characteristics of IoT. Also, it elaborates on smart factory, smart objects and most importantly the applications of IoT in manufacturing processes. Second, the purpose of case studies is to take a closer look at two of the most reliable and highly optimized factories in the world and analyze their production lines to realize how they use IoT in their facilities. The case analysis provides a deep understanding of the role of RFID in shop floors. Moreover, answering the above questions explain the challenges and benefits of implementing IoT technologies into production processes. The research offers practical recommendations for companies with plans to employ IoT technologies into their production processes. Finally, on the back of literature review and empirical case study, this paper suggests a framework for integrating RFID, Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP).

2. Theoretical Background

2.1 Internet of things

The IoT concept was coined by a member of the Radio Frequency Identification RFID) development community in 1999(Ashton, 2009), and it has recently become more relevant to the practical world largely because of the growth of mobile devices, embedded and ubiquitous communication, cloud computing and data analytics. Technology made its way in many sectors in the age of Industry 4.0 and the digital transformation of manufacturing is the market where Industrial Internet of Things(IIoT) need to be realized and where most IIoT investments are to be made.

2.1.1 Definition and features of IoT

During past 40 years, the Internet has been used mainly to connect people to each other through email, forums and most recently by social networking sites (SNS). However, in the future, the Internet will serve as a link between devices, machines and other things through wired and wireless networks using an open standard Internet protocol (IP). (Dutton, 2014) The next movement in the era of computing is estimated to be outside the world of desktop. A new paradigm called Internet of Things has grown fast during past years. (Botta et al., 2016) The term IoT was first pointed out by a British technology pioneer Kevin Ashton in 1999. (Ashton, 2009) As Andersson et al. (2015) explain, IoT is supposed to portray a major change in the history of Internet as connections move beyond computing devices and start to connect billions of everyday devices from parking meters to home thermostats. According to Bogue (2014), Cisco technology claims that the born of IoT was between 2008 and 2009 which the number of connected devices exceeded the world population.

According to Cisco, there were 8.7 billion connected objects worldwide in 2012 and this number exceeded 10 billion in 2013, showing a rapid growth. It is predicted that the number of connected objects reaches 25 billion by 2015 and 50 billion by 2020. (Bogue, 2014)

The goal of IoT is to extend the benefits of the regular internet to physical objects by offering features such as constant connectivity, remote control ability and data sharing. (Gao & Bai, 2014) It promises one of the most disruptive technologies, enabling ubiquitous and widespread computing cases. IoT is all about the pervasive presence around people of things with ability to measure, understand and modify the environment. (Botta et al., 2016)

After reading quite a few articles and papers about IoT, its definition, applications, implementation challenges and future, it has become apparent that there is no exact and agreeable definition for IoT till now. Fernandez (2015) in his paper explains that even when companies invest in possibilities created by IoT they are still facing challenges to define its parameters and the concept of IoT has not yet been set in stone. In this research various definitions of IoT have been studies and gathered which can be seen in Table 1 below.

Table 1. Definitions of IoT

Author	Definition
Rainie & Wellman (2012)	IoT describes human-computer interaction that goes beyond personal computing to an environment of objects processing information and networking with each other and humans. Objects would share and learn information and preferred methods of use by gathering data about people who are in the environment.
Valery (2012)	The IoT consists of the protocols and related technologies that enable these many different devices to communicate over electronic communication channels, wired or wireless – a network of things, including people that some have called the “thingternet”.
Gubbi et al. (2013)	Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with cloud computing as the unifying framework.
Vermesan et al. (2013)	IoT is a concept and a paradigm that considers pervasive presence in the environment of a variety of things/objects that through wireless and wired connections and unique addressing schemes are able to interact with each other and cooperate with other things/objects to create new applications/ services and reach common goals.
IoT European Research Cluster (IERC) (2014)	A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes, personalities and use intelligent interfaces and are seamlessly integrated into the information network.

As per the above Table 1, these definitions have many similarities and few differences which implies some define IoT as a narrower concept and some of them are broad. The definition chosen for this research study is based on Gubbi et al., 2013. Their definition is well rounded, acquainted and exactly points out at the topics covered in this paper. According to Dutton (2014) IoT is an umbrella term that includes various developments such as sensor networks and machine-to-machine (M2M) communications and some experts have argued to use more explicit terminology instead of IoT which has caused the main reason for differences between IoT definitions.

2.1.2 IoT technologies

IoT technologies have been receiving substantial amounts of attention and have a variety of applications in many fields. IoT represents objects that can communicate via the Internet. Therefore, historically IoT is associated with RFID tagged objects that used Internet to communicate. Nowadays IoT technology is used in different fields, for instance supply chain management, retail tracking and healthcare. (Gao & Bai, 2014) There is no doubt that IoT technology will increase efficiencies across many industries which brings great benefits to customers. (Uckelmann et al., 2011)

To better understand the role of IoT in its numerous applications, five different IoT technologies must be studied. They describe them as widely used IoT technologies for the deployment of successful IoT based products and services. They are as follows:

1. Radio Frequency Identification (RFID)
2. Wireless Sensor Networks (WSN)
3. Middleware
4. Cloud computing
5. IoT application software

In IoT scheme, RFID systems play a vital role. They are composed of one or more readers and several tags. These technologies support automatic identification of anything they are attached to, by readers generating an applicable signal which triggers the tag transmission. In this way they let objects assigned to unique digital identities and to be integrated into a network and associated with digital information and services. (Kosmatos et al., 2011) RFID allows automatic identification and data capture by using radio waves. Interestingly the tag can store more data than traditional barcodes. It contains data in the form of the Electronic Product Code (EPC) which is a global RFID-based item identification system. For this interaction three types of tags are used: passive RFID tags, active RFID tags and semi-passive RFID tags. Passive RFID tags are not battery-powered. They get their power from the radio frequency energy transferred from the reader to the tag and they are mostly used in supply chains, passports, electronic tolls and item-level tracking. However active RFID tags have their own battery supply and since they have external sensors they can monitor temperature, pressure, chemicals and many other elements. Active RFID tags are used in hospital laboratories, manufacturing and remote-sensing Information Technology (IT) asset management. Finally, the last type of tags are semi-passive RFID tags which communicate by drawing power from the reader and uses batteries to power the microchip. (Lee & Lee, 2015)

Wireless sensor networks are another essential technology in IoT environment. Sensor networks generally consists of a potentially high number of sensing nodes, communicating in a wireless multi-hop fashion. (Botta et al., 2016) These nodes typically have restrained resources, for example limited battery power, processing power and memory storage. WSN can cooperate with RFID systems to better monitor physical or environmental conditions. (Pesovic et al., 2010) Latest technological advances in wireless communications have made miniature devices available which are efficient, low-cost and low power and are ready to be used in WSN applications. (Gubbi et al., 2013) WSN have mostly been employed in cold chain logistics that use thermal and refrigerated packaging methods to transport temperature-sensitive products. Moreover, WSN are employed for maintenance and tracking systems. For instance, General Electric (GE) uses sensors in its jet engines, turbines and wind farms and GE saves valuable time and money through preventive maintenance by analyzing data in real time. (Lee & Lee, 2015)

Issarny et al. (2007) define Middleware as "a software layer that stands between the networked operating system and the application and provides well known reusable solutions to frequently encountered problems like heterogeneity, interoperability, security and dependability". Middleware is a software layer interposed between software applications. In other words, middleware is a mechanism which connects all the components together and makes communication smoother and input/output interactions easier for software developers. It is an interface which simplifies the interaction between the 'Internet' and the 'Things'. Middleware got popular in 1980s because of its considerable role in facilitating the integration of legacy technologies into new ones. Moreover, it simplified the development of new services in the distributed computing environment. (Lee & Lee, 2015) According to Kosmatos et al. (2011) the main job of middleware is the abstraction of the functionalities and communication capabilities of the devices. This task has its own challenges which are heterogeneity of the participating objects, their limited storage and processing abilities and vast variety of applications involved. Kosmatos et al. (2011) suggest a middleware as a software layer which is consists of three sub-layers: Objects Abstraction, Service Management and Service Composition as shown in Figure 1. These sub-layers mediate between the technological and the application levels according to interacting components/modules and abstracting resource and network functions.

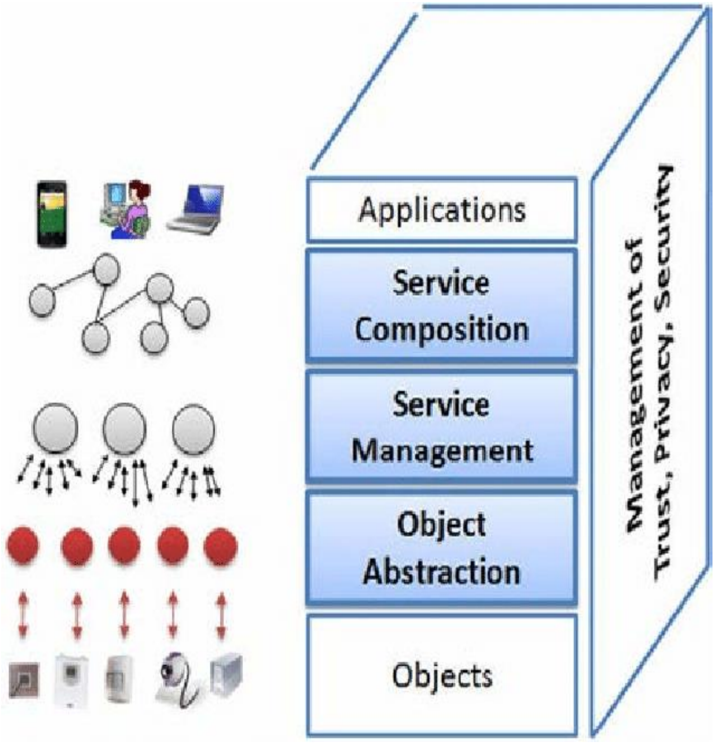

Figure 1. IoT middleware architecture

As we can observe from the above figure, the first layer is objects abstraction. This layer translates the services available to a set of device specific commands and vice versa by following a well-defined notification model. Due to the objects abstraction layer the real-world objects provide their abilities to the upper layers which results in enabling efficient service management and creation. Service management layer offers a basic yet extensible set of functions for the connected objects such as dynamic object discovery, status monitoring, service configuration and mapping of available services for objects. The third layer is service composition which offers the corresponding functionality needed for the composition of plain or more sophisticated services by joining and combining services exposed by the service management layer. Finally, even though Application layer on the top layer is not considered a part of middleware but it exploits all the functionalities provided by middleware architecture. (Kosmatos et al., 2011)

The term Cloud computing started to gain attention after the CEO of Google used it to describe the business model of providing services across the Internet in 2006, even though the term was not new. (Botta et al., 2016) Cloud computing has been defined by the National Institute of Standard and Technologies (NIST) as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction”. Cloud computing is a disruptive technology with profound implications for the delivery of Internet services in addition to entire IT sector. The acknowledgment of a new computing model got enabled by the availability of virtually unlimited storage and processing capabilities at low cost. In this case virtualized resources can be leased in an on-demand network access, being administered as general utilities. Giant companies such as Google, Microsoft and Amazon by adopting this paradigm for delivering services over the Internet have gained technical and economic benefits. (Botta et al., 2016)

To better understand cloud, various aspects of cloud, diverse types of cloud, layered architecture and service models are discussed in this research. There are many concerns for users to move an enterprise application to the cloud environment. These specific issues are mostly related to security (e.g. network security and integrity), privacy (e.g. data confidentiality) and in some scenarios service providers are particularly interested in lower operation cost or high reliability. Therefore, there are different types of clouds, each with its own advantages and disadvantages (Zhang et al., 2010) as described below:

Public clouds: A cloud that offers its resources as services to the general public. The benefits of public clouds for service providers are no initial capital investment on infrastructure and shifting the risks to infrastructure providers. On the other hand, public clouds pose lack of control over network, data and security setting which hinders their effectiveness in many businesses.

Private clouds: These clouds are provisioned for exclusive use by a single organization and they are generally owned, managed and operated by the same organization. Private clouds always offer maximum control over performance, reliability and security. On the down side, their disadvantages are their similarity to traditional proprietary server farms and not being able to provide benefits such as lack of up-front capital costs.

Hybrid clods: A hybrid cloud is composed of two or more cloud models (mostly public and private cloud models) which attempts to cover the limitations of each model. Hybrid cloud offers the versatility to run one part of the service infrastructure in private clouds and the other part in public clouds. They provide more flexibility than both public and private clouds in addition to higher control and security over application data compared to public clouds. However, for designing a hybrid cloud, public and private cloud components must be divided carefully.

Virtual Private Cloud (VPC): VPC is a platform running on top of public clouds and it is an alternative solution to address the constraints of private and public clouds. The biggest difference is that a VPC takes advantage of virtual private network (VPN) technology that enables service providers to setup their required topology and security settings (e.g. firewall rules). VPC virtualizes servers, applications and the underlying communication network. It is basically a more comprehensive design.

Typically, the architecture of a cloud computing environment consists of four layers: the hardware (datacenter) layer, the infrastructure layer, the platform layer and the application layer as it can be seen in the figure below. The architecture of cloud computing is more modular than traditional service hosting environments like server farms. Each layer connects loosely with its upper and lower layers, granting each layer to evolve separately. This architectural modularity allows cloud computing to support various application requirements while lowering management and maintenance overhead. (Zhang et al., 2010)

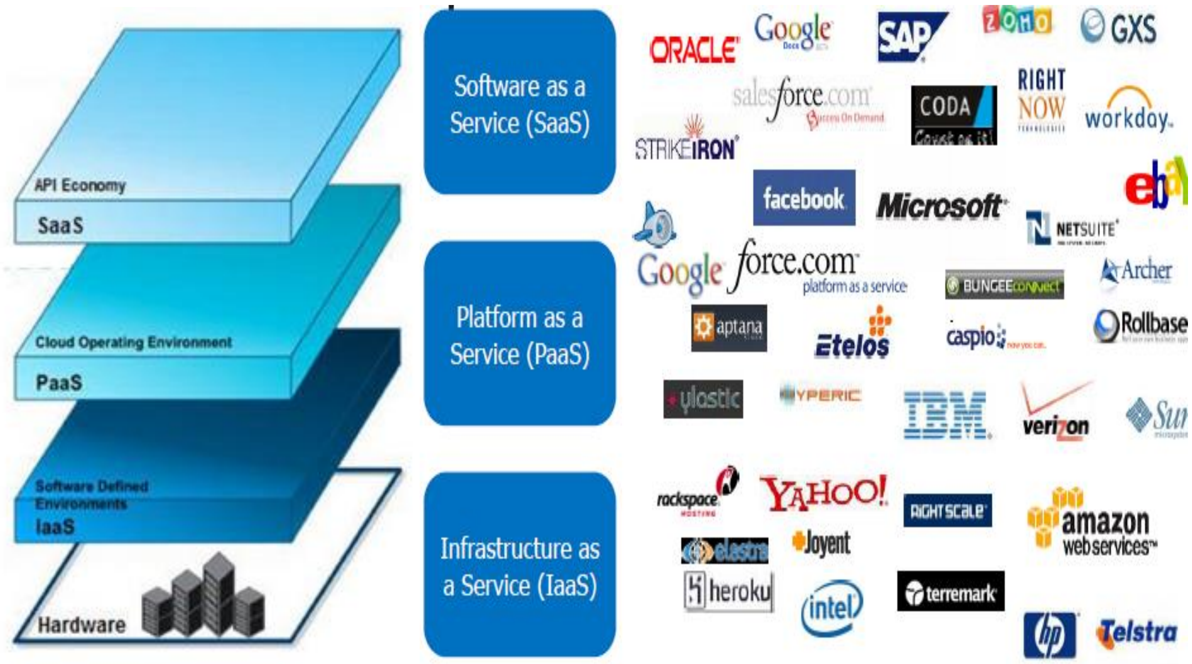

Figure 2. Cloud Computing Architecture (Adopted from Digital technology course slides)

The responsibility of *hardware layer* is managing the physical resources of the cloud, such as physical servers, cooling systems, routers, switches and power. A data center typically includes thousands of servers that are organized and interconnected by switches, routers and other fabrics and hardware layer is usually implemented in data centers. The most common issues at hardware layer are hardware configuration, power and cooling resource management, fault tolerance and traffic management.

Infrastructure layer (virtualization layer) is responsible for creating a pool of storage and computing resources by using virtualization technologies to partition the physical resources. The infrastructure layer has a significant role in the architecture of cloud computing, because several key features such as dynamic resource assignment, are accessible due to virtualization technologies.

Platform layer is the layer which contains operating systems and application frameworks. The platform layer is responsible for minimizing the concern of deploying applications directly to virtual machine containers.

And finally, the *application layer* which is built on top of the platform layer contains the actual cloud applications. The difference between cloud applications and traditional applications is that cloud applications benefit from the automatic-scaling feature to gain better performance, lower operating cost and availability.

Cloud computing utilizes a service-driven business model as shown in the Figure 3, below. computing hardware and platform level resources can be reached as services on an on-demand basis.

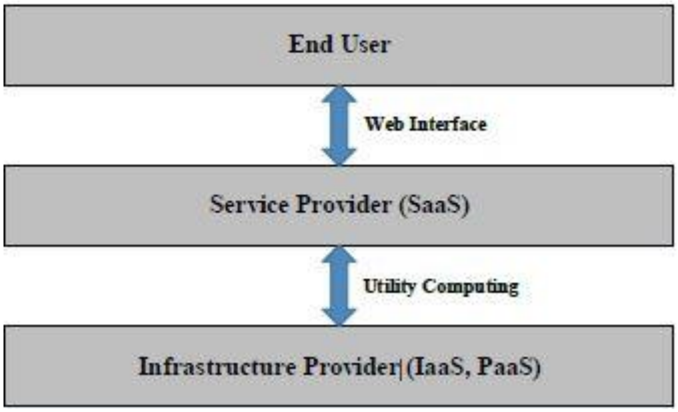

Figure 3. Cloud Computing Business Model

Theoretically, each layer explained above can be considered as a service to the layer above and as a customer of the layer below. However, in practice, clouds offer services which can be divided into three categories of *Infrastructure as a Service* (IaaS), *Platform as a Service* (PaaS) and *Software as a Service* (SaaS). According to NIST, IaaS provides processing, storage and network resources capabilities and allows consumers to control the operating system, storage and applications. For instance, GoGrid, Amazon EC2 and Flexiscale are among IaaS providers. PaaS Refers to providing platform layer resources, including software development framework and operating system support. Examples of PaaS providers can be Force.com, Google App Engine and Microsoft Windows Azure. And finally, SaaS refers to provisioning of on-demand applications over the Internet. A few examples of SaaS providers are SAP Business ByDesign, Rackspace and Salesforce.com. (Zhang et al., 2010) All the cloud services, their examples and their placement in cloud architecture can be seen in Figure 1.

While devices and networks provision physical connectivity, IoT applications enable machine-to-machine and human-to-machine interactions in a reliable and sturdy manner. The responsibility of IoT applications on devices is to make sure that data or messages have been received, processed and acted upon accordingly and on time schedule. For instance, transportation and logistics applications continually monitor the status (e.g. temperature, shock, humidity) of transported goods such as meat, fruits and dairy products and necessary actions are taken automatically to prevent spoilage. A good example for this procedure is FedEx. FedEx acquired SenceAware to be able to check the location, temperature and other elements of a package both during delivery and after the package is opened. It is crucial for IoT applications to be intelligently built thus devices will be able to monitor the environment, identify problems, communicate among each other and solve problems without human interference. (Lee & Lee, 2015).

Understanding the customer value of IoT applications for organizations is the key to fruitful IoT adoption. Therefore, they classify three IoT categories for enterprise applications which are discussed below:

Monitoring and control: Monitoring and control systems generally gather data on energy usage, equipment performance and environmental conditions and enable managers and automated controllers to continuously track performance in real time anywhere, anytime. Utilizing advanced monitoring and control technologies (e.g. smart grid, smart metering) makes it easier to find out operational patterns, spot areas of potential improvement, foresee future fallouts and optimize operations which results in lower costs and higher productivity. (Lee & Lee, 2015) A good example for using monitoring and control technologies in business-to-business (B2B) world is in oil and gas industry. These technologies provide real time data from extraction and drilling equipment and related systems, transport systems and refineries to enterprise systems. Consequently, the added value of utilizing these technologies are improved productivity, lowed accident frequency and reduced field inventories. (Harbor Research, 2013) Benefiting from IoT to monitor and control various components in cars is an illustration of IoT applications in business-to consumer (B2C) context, developed to boost customer value. In 2014, Ford and Intel joined forces to personalize drivers' experience taking advantage of facial recognition software and a mobile phone app. The goal of the project is improving privacy controls and identifying different drivers and automatically adjust features according to an individual's preferences. Furthermore, the in-car experience is personalized by displaying information specific to each driver, for instance personal calendar, contacts or preferred music. (Lee & Lee, 2015)

Big data and business analytics: IoT devices with embedded sensors and actuators generate massive amounts of data and transmit it to business intelligence and analytics tools where decisions are made by humans. These data are utilized to solve business problems such as reducing product test times and market conditions. (Lee & Lee, 2015) According to Bughin et al. (2015) gathering data from multiple IoT systems will not be enough to create opportunities for companies. By using IoT for prediction and optimization, organizations face a new analytics challenge. The challenge is that companies have to develop or purchase, customize and deploy an analytical software that extracts valuable data from the stream of data generated by IoT. As an example, Intel does a meticulous quality check (involving a complex series of tests) over every chip they produce. Intel realized by using historical information gathered during manufacturing, the number of tests required can be diminished which resulted in lowered test time. This solution avoided test costs of $3 million in 2012 for one series of Intel Core processors. (Intel.com/IoT) Moreover IoT based big data are changing healthcare product industry. Proctor & Gamble has developed an interactive electric toothbrush called Oral-B Pro 5000 that provides users a smart and personalized oral care routine. The interactive electric toothbrush logs brushing habits with mobile technology while giving mouth-care tips and news headlines. (Lee & Lee,2015)

Information sharing and collaboration: Information sharing and collaboration in the IoT can happen between things, between people and things and between people as shown in figure 4, which increases situational awareness and avoids information delay and misrepresentation.

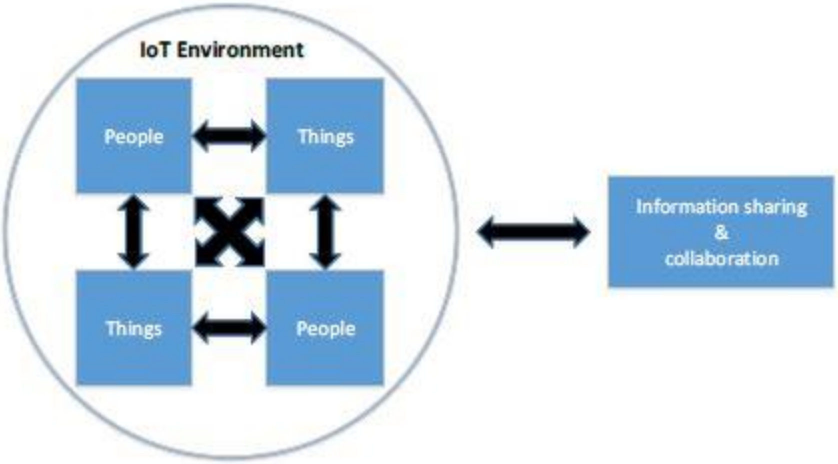

Figure 4. Network process for information sharing and collaboration

As an example, in supply chain field, if sensors are placed all around a retail store where refrigeration is essential, a malfunction in one of the refrigerators leads to an alert sent to the store manager’s mobile device. Then the manager checks employees’ availability by reviewing their employee status report and send task assignment to an available employee through his or her IoT-enabled mobile device. (Lee & Lee, 2015) A real case of sharing information among different kinds of devices, successfully implemented, is Fujitsu’s site ‘Shimane’. Shimane Fujitsu manufactures notebook computers and tables. They developed a manufacturing system software that displays the status of different vendor’s devices by developing four software.

Firstly, a connection software for each device followed by creating the second software which enables all devices on a network to share information among each other. Thirdly, a software which converts various types of data into a common format in order to acquire information from each device. And finally, a software was needed to show status information for each device. In this way, production is optimized and supported by data sharing and manufacturing is based on full interaction between humans and machinery enabled by using IoT technologies such as RFID tags. (Nishioka, 2015)

2.1.3 IoT application domains

According to Anderson et al. (2015), IoT technologies cover various application areas now such as security (e.g. access control, security care for elderly, time reporting for home care), payment (mobile payments), tracking and tracing (e.g. fleet management, logistics for goods transportation), health (e.g. e-home care), metering (e.g. smart power grids) and remote control and maintenance (e.g. smart homes, environmental monitoring). These areas can be divided into different application domains. Gubbi et al. (2013) categorize these applications into four application domains based on type of network availability, coverage, scale, heterogeneity, repeatability, user involvement and impact. They explain how each domain will be impacted by the emerging Internet of Things. The four domains are:

- Personal and home IoT at the scale of an individual or home
- Enterprise IoT at a community
- Utilities IoT at a scale of region or nation
- Mobile IoT which is typically spread across other domains because of the nature of connectivity and scale.

Personal and home: In this domain only, the network can use the collected sensor information. Typically, Wi-Fi is used as the primary element enabling higher bandwidth data (video) transfer as well as higher sampling rates (sound). During the past twenty years ubiquitous healthcare has been predicted. Today, IoT provides an impeccable platform to realize this vision by benefiting from body area sensors to upload the data to servers. As an example, a smartphone equipped with Bluetooth technology (BT) can be used for communication with interfacing sensors measuring physiological parameters. Currently, there are many applications available for Google Android, Apple iOS and Windows phone operating systems that measure different parameters. (Gubbi et al., 2013) Within a home, many appliances could be brought into IoT because of cost saving reasons. Home thermostats and hot water heaters are good examples, because they can be monitored and controlled remotely. Another example includes sensors attached to security systems, parking doors for more ease of mind and to relieve security concerns. The same logic can be implemented into third-party systems. This creates an interactive home which can give recommendations about its own upkeep and no direct input from the homeowner is needed to make decisions. (Fernandez, 2015)

Enterprise: An enterprise-based application is defined as ‘Network of Things’ within a work environment. Typically, the information collected from these networks can only be accessed by the owners and the data may be released selectively. Regarding factory maintenance, sensors have always been an integrated component of a factory setup involved in various areas such as security, climate control and automation. Eventually, this will be replaced by a wireless system which provides the flexibility to make changes to the factory maintenance. (Gubbi et al., 2013) Moreover, smart environment as another major IoT application is growing faster. Mark Weiser is a pioneer defined a smart environment as “the physical world that is richly and invisibly interwoven with sensors, actuators, displays and computational elements, embedded seamlessly in the everyday objects of our lives and connected through a continuous network”. (Weiser & Gold, 1999; cited in Gubbi et al., 2013) Smart environment as an IoT application consists of several sub systems as it can be seen in the below table 2.

The below table also represents distinctive characteristics of sub systems forming smart environment from technological point of view. Each of sub domains usually cover many focus groups and the data will be shared among them. (Gubbi, 2013)

Table 2. Smart environment application domains. (Adopted from Gubbi et al., 2013)

	Smart home	Smart retail	Smart city	Smart agriculture/forest	Smart water	Smart transportation
Network size	Small	Small	Medium	Medium/Large	Large	Large
Users	Very few (family members)	Few (community level)	Many (policy makers, public)	Few (land owners, policy makers)	Few (government)	Large (public)
Internet connectivity	Wi-fi, 3G, 4G LTE	Wi-fi, 3G, 4G LTE	Wi-fi, 3G, 4G LTE	Wi-fi, satellite communication	Wi-fi, satellite communication	Wi-fi, satellite communication
Data management	Local server	Local server	Shared server	Local server, Shared server	Shared server	Shared server
IoT devices	RFID, WSN	RFID, WSN	RFID, WSN	WSN	Single sensors	RFID, WSN, single sensors

Utilities: The main characteristic of Utilities domain which separates it from the previous tow is the fact that information from the networks in utilities domain is often used for service optimization instead of consumer consumption. Many utility companies use data (e.g. smart meter by electricity supply companies) for resource management and ultimately cost v/s profit optimization. Utility domain applications consists of broad networks laid out by large organizations to monitor critical utilities and efficient resource management. And usually the backbone network can be cellular, Wi-fi or satellite communication depending on the scale of network. Smart grid and smart metering both fall into utilities IoT domain. Efficient energy consumption is possible through continuous monitoring of electricity points and applying this information to make the necessary changes in the way electricity is consumed. An example could be water network monitoring and quality assurance of drinking water that uses IoT. Sensors are installed at crucial locations to measure critical water parameters and make sure of high supply quality. This evades incidental contamination among storm water drains, drinking water and sewage disposal (Gubbi et al., 2013).

Mobile: Smart logistics, urban traffic and smart transportation comes under IoT domain because of the nature of data sharing and backbone implementation. Traffic congestion causes tremendous costs on economic and social activities in many cities. Generally, supply chain efficiencies and productivity, such as Just-in-Time operations are extremely impacted by this traffic jam, resulting in delivery schedule failures and freight delays. Therefore, dynamic traffic information might be a solution. It helps with freight movement, enables better planning and improved scheduling. The transport IoT will overtake the traffic information provided by the existing sensor networks by allowing the use of large scale WSN's for online monitoring of travel times, original destination route choice behavior, queue lengths, air pollution and noise emissions. Another important application in mobile IoT domain is the emergence of Bluetooth technology devices which shows the current IoT penetration in a few digital products such as tablets, mobile phones and navigation systems. The signals sent by BT devices with a unique Media Access Identification (MAC-ID) number, can be read by BT sensors within the coverage area and readers which are places at various locations can be utilized to identify the movement of devices (Gubbi, 2013).

2.1.4 Future of IoT

Gartner (2014) predicts that IoT-enabled devices will reach 26 billion units by 2020 and it will impact investors and businesses of all types and consequently affects technologies that are being developed today. IoT will transform business processes from production line and warehousing to store shelving and retail delivery by offering more accurate information and real-time visibility into the flow of materials and products. By investing in IoT, companies will redesign the workflows of factories, optimize distribution costs and improve tracking of materials. For instance, companies such as John Deere and UPS are now using IoT enabled fleet tracking technologies to cut costs and improve supply efficiency. (Lee & Lee, 2015) Internet of Things has been recognized as one of the emerging technologies in IT according to Gartner's IT Hype Cycle. It has been predicted that the market adoption of IoT will take 5 to 10 years. The popularity of various paradigms differs with time.

Internet of Everything (IoE) is another term compared to Internet of Things. Bradly et al., (2013) define IoE as "bringing together people, process, data and things to make networked connections more relevant and valuable than ever before- turning information into actions that create new capabilities, richer experiences and unprecedented economic opportunity for businesses, individuals and countries." IoE has gained some attention since 2009 and it is still in infancy, but Cisco has forecasted that IoE will create $14.4 trillion in Value at Stake by increasing revenues and lowering costs among companies in different industries from 2013 to 2022.

Many firms including Microsoft, IBM, Intel and DHL are all investing in the IoT and predict against gigantic future growth for IoT. For instance, Business Insider is one of its recent reports forecasts that the IoT will be the largest device market in the world by 2019, overtaking mobile devices and desktop computers combined and create $1.7 trillion in new value. (Fernandez, 2015) Today, different kinds of IoT applications have emerged, and the number of enterprises that are willing to utilize them is quickly increasing. Figure 5 represents a road map of the technology drivers and key application outcomes expected in the next ten years.

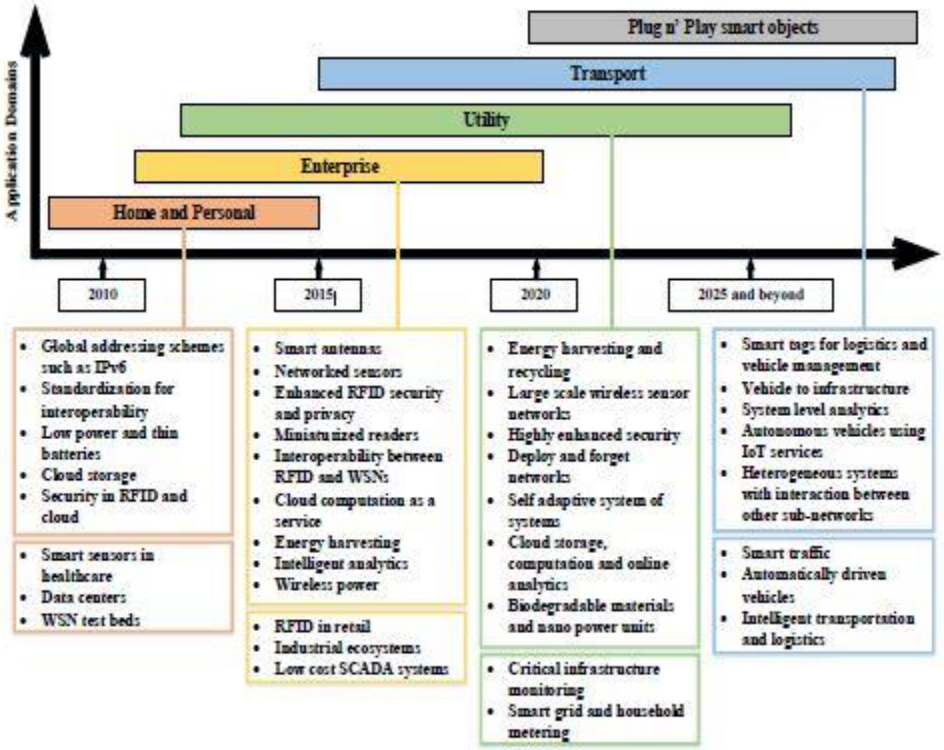

Figure 5. Roadmap of Key technological developments in the context of IoT application domains envisioned

As it can be seen in the above figure, the roadmap features the key developments in IoT research in the context of pervasive applications. It shows four IoT application domains and also domain called 'Plug n Play' smart objects yet to be added to the other domains in the future. McKinsey predicts that the potential economic impact of the Internet of Things will be in range of $2.7 to $6.2 trillion per year by 2025. (Manyika et al., 2013) From an industry's point of view, four industries compose more than half of the IoT in value. As Lee & Lee (2015) explain, these four dominant industries in terms of value at stake are manufacturing with 27%, retail trade with 11%, and information services and finance and insurance, both at 9%. In addition, other industries such as wholesale, healthcare and education all fall in the range of 1 to 7 percent, in terms of value generation. Manufacturers gain most of their value through higher agility and more flexibility in factories and from the ability to use workers skills to the most. Meanwhile, much of the value for retailers comes from connected marketing and advertising.

2.1.5 Opportunities and concerns

The opportunities behind the IoT as the near future technology and in business is very positive in various areas but not possible to implement in practice. In many cases, it is feasible both technically and functionally to use IoT technologies but there are some challenges on the way such as organizational, institutional and public policy constraints. It is promised that IoT will change the way we do things, but organizations are changing slowly due to complicated policy issues such as concerns towards data protection and privacy, ownership of data and standard setting between authorities. Therefore, till social and policy changes meet with technical opportunities, IoT developments will be slowed considerably. (Dutton, 2014)

IoT will create many opportunities for firms by enhancing data collection, enabling real time responses, increasing efficiency and productivity, improving access and control of devices, and connecting technologies. Through IoT, frequent data collection will be possible, thus today's big data will soon be tomorrow's little data. For instance, when a consumer wears a health-related IoT device, vital information (e.g. body temperature, pulse and distance travelled) can be collected continuously. Then, these data can be used to optimize outcomes for a person, such as weight loss and fitness. Another benefit of IoT is that, the data can be controlled instantly which makes the real-time decision making happen and necessary actions will be taken later. This would have a positive impact on supply chain management services. For instance, pay-as-go could be expanded beyond car rentals and mobile phone services to insurance or any other application. Additionally, fixed pricing in many contexts such as vending machines or parking meters, would become dynamic. The next benefit of IoT is in enhancing productivity at a larger scale where coordination of numerous pieces is crucial. As an example, different deices/appliances (e.g. locks, lighting, kitchen appliances and electric devices) in a house can be tied together and make a connected home. This would result in higher efficiency, effectiveness and satisfaction (Weinberg et al., 2015). As an added benefit, IoT can provide greater access and control over Internet-connected devices. For example, General Electrics (GE) smart jet engines now can transmit over one terabyte of sensor data during every flight. Therefore, by being able to access to this data, the airline already knows if any maintenance is required before plane lands. (Kavis 2014)

Porter & Heppelmann (2014) discuss that, completely new set of product functions and capabilities are enabled through intelligence and connectivity. They categorize the abilities enabled by IoT (or in general abilities of smart connected products) into four groups as it is shown in the below Figure 6. These groups are: 1. Monitoring, 2. Control, 3. Optimization and 4. Autonomy.

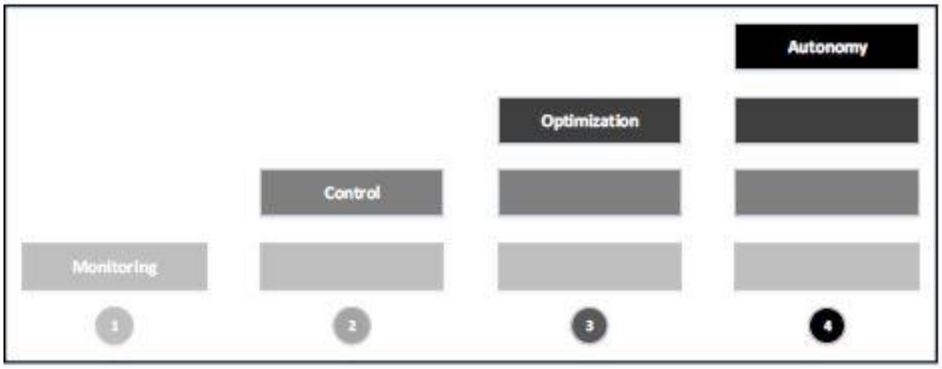

Figure 6. Capabilities of smart connected products. (Adopted from Porter & Heppelmann, 2014)

In monitoring, sensors and external data sources enable thorough monitoring of products operation and usage, products condition and external environment. It also enables alerts and notifications of changes. The second group controls which happens through the software embedded in the product or in the product cloud. The software allows control of product functions and personalization of the user experience. The next group is optimization. Its purpose is enhancing product performance and allowing predictive diagnostics, service and repair. To elaborate more, monitoring and control capabilities facilitate algorithms that optimize product operation and use. The last group is Autonomy which is a combination of the previous three groups. In other words, combination of monitoring, control and optimization allows autonomous product operation, self-coordination of operation with other products and systems, autonomous product enhancement and personalization, self-diagnosis and service. (porter & Heppelmann, 2014)

Using Internet of Things technologies results in generating more data. This data needs to be stored and processed. According to Adshead (2014), the amount of data on the planet will grow from 4.4 zettabytes 10^{21} to 44 zettabytes and 10% of this amount will be created by IoT. This huge amount of data raises concerns about privacy, data processing, data ownership, communication and standards. Manufacturers will be forced to define and implement new set of standards in order to coordinate and make the devices to work together. Therefore, deploying different approaches such as data structures and communications, considering IoT is needed. (Weinberg 2015)

Privacy issues regarding using IoT technologies are challenging to solve without facing other issues like trust. Guerra (2013) explain a concept called “trust tension” tied to privacy noting data collection can help trust by creating a legal bond between the parties involved. However, the collection and availability of data can create problems of trust in terms of privacy since individuals may be wary of data surveillance or of the secondary use of that information. Indeed, privacy is repeatedly identified as a concern that prevents consumers from using internet for transactions. In this way, there is a “trust tension” between privacy and identity. Absence of data impedes trust as accountability is limited, but data gathering creates trust problems regarding the use of data and intrusions on privacy. Therefore, in IoT, generating huge amount of data will create concerns over privacy, while the lack of data results in undermining trust. The big task for organizations using IoT is to come up with solutions to balance the obstacles. Another uncertainty is about the ownership of the collected data by IoT in different scenarios that involve multiple actors. Typically, copyright of the collected data by IoT in different scenarios that involve multiple actors. Typically, copyright agreements are signed to clarify the owner of the produced data by a machine. (Dutton, 2014) In case of an IoT object ownership, this object might be owned by a specific company, could be co-owned by several companies or it can be part of a public or private infrastructure. The concern then would be who has the authority to utilize the object and decide in how it is interacting with other IoT objects which requires modification in business model design. (Anderson, 2015) Cyber security is also a concern for the data or systems developed by IoT. IoT cloud create very sensitive data as well as supporting safety critical systems, such as managing transportation, powering or human health monitoring. It is necessary that these systems will be safe and secure from intrusion by an unauthorized user or any unintentional data breaches by authorized personnel to handle data. (Dutton, 2014)

To make the IoT more understandable, media normally focuses on consumer applications, however according to Bughin et al., (2015), 70 percent of the value created from IoT within next ten years is from B2B applications. The IoT uncovers opportunities for optimization, enhanced business processes, improved efficiency. It enables businesses to customize their product, to have access to real-time data and ultimately make wise decisions. Therefore, in next part of this chapter, smart factory, real-time data in ubiquitous manufacturing and challenges of applying RFID technologies in manufacturing are well discussed.

2.2 Optimizing manufacturing process

2.2.1 Smart Factory

According to Radziwon et al. (2014), the word ‘smart’ refers to an independent device, and the device normally includes a sensor, an actuator, a microcomputer and a transceiver. Moreover, ‘smart’ as an adjective is also used to explain an object that was improved by implementation of extra features, which enhance its computational and communication abilities. The term ‘smart factory’ has been used by both academics and industrial professionals but there is no exact definition. Usually scholars consider ‘smart factory’ as an approach, a technology or a paradigm and they use synonyms terms such as: U-Factory (ubiquitous factory), factory-of-things, intelligent factory of the future and real-time factory. According to Zuhlke (2010), embedded intelligence in all connected devices is a perquisite for ‘smart factory’ while some of the essential functionalities are provided by RFID technology. He explains that, not only 'smart factories' have modular structure but also they are internally connected by a wireless network which means every device should have its own IP address.

Smart factories are one of the components of Industry 4.0, as described by Hermann et al, which identifies it as a factory where CPS communicate over the IoT, assisting humans and machines in task execution. It enables the collection, distribution and access of manufacturing relevant information in real-time. Radziwon et al. gives a more comprehensive definition of the term saying, "*A smart Factory is manufacturing solution that provides such flexible and adaptive production processes that will solve problems arising on a production facility with dynamic and rapidly changing boundary conditions in a world of increasing complexity. This special solution could on the one hand be related to automation, understood as a combination of software, hardware and/or machines, which should lead to optimization of manufacturing resulting in reduction of unnecessary labor and waste of resources. On the other hand, it could be seen in a perspective of collaboration between different industrial and nonindustrial partners, where the smartness comes from forming a dynamic organization."* Wang et al., (2016) defines 'smart factory' as "*manufacturing cyber-physical system that integrates the physical objects such as machines, conveyers and products with the information systems such as MES and ERP to implement the flexible and agile production*." Wang believes that smart factory is an essential aspect of Industry 4.0 which offers networked manufacturing systems and the vertical integration for smart production. The combination of smart objects with the big data analytics is needed for implementation of smart factory. So that the smart object configurability leads to higher flexibility and feedback and coordination is offered by the big data analytics to accomplish better efficiency. In this way, the smart factory can manufacture customized and small-lot products efficiently and profitably. A framework of Industry 4.0 can be seen in Figure 7 below.

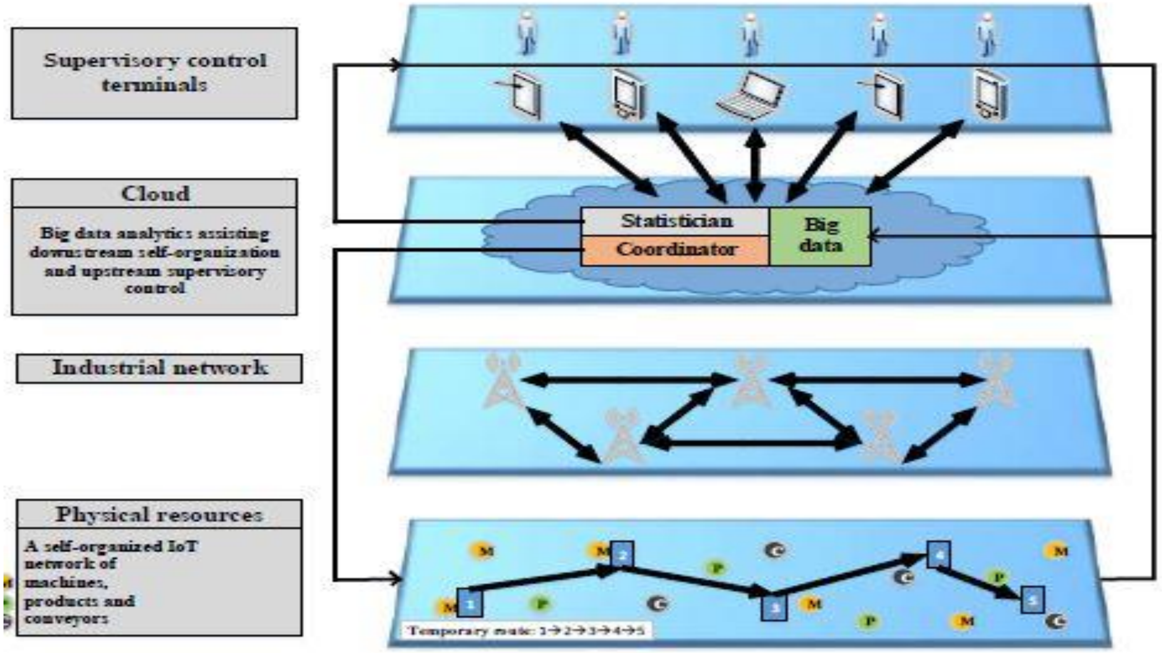

Figure 7. Framework of the smart factory industry 4.0 (Adopted from Wang e al., 2016)

As it is shown in the above Figure 7, smart factory framework is created by four layers called: physical resource layer, industrial network layer, cloud layer and supervisory control terminal layer. These layers work in a way that physical resources as smart objects communicate among each other, using the industrial network. Then cloud collects significant amount of data from the physical resource layer and collaborate with people through supervisory control terminals. (Wang et al., 2016)

2.2.2 Real-time data in ubiquitous manufacturing

At present, many manufacturing enterprises face familiar challenges which are timely, accurate and consistent inadequacies of manufacturing things during manufacturing execution. And therefore, having access to real-time information helps decision makers to make smarter shop-floor decisions. (Zhang et al., 2015) Real-time data is required in production shop floors of manufacturing firms. New advancement in wireless technologies and ubiquitous computing technologies have brought up the term “Ubiquitous Manufacturing” (UM) system. (Luo 2015) (Sun 2008), define UM system as a system established on wireless sensor network that assists the automatic collection and real-time processing of field data in manufacturing process. They categorize the characteristics of UM as presented below:

1. It integrates manufacturing technology (MT), information technology and ubiquitous technology (UT)

2. It covers manufacturing-related activities throughout the whole product lifecycle
3. It transparently collects and employs every product-related data at individual level
4. It facilitates real-time collaboration between stakeholders in a disturbed environment.

These characteristics create an opportunity to minimize the uncertainty and disturbance all through the production process and close the loop of production planning, scheduling and execution.

Regarding data collection, RFID technology offers a fast and accurate way to collect real-time data from shop floor. Therefore, employing RFID technology in the production planning and control has significant benefits. For maximum optimization, there should be a consistent dual-way connection between decision-making level and execution level. RFID tags can be attached to production resources, for instance product component, pallets, machines and operators. They are flexible and practical data carriers which are used to transfer information. The production data collected from shop floor can be written and rewritten without any manual interference. And, in a dynamic production environment is it highly important that production resources can carry their own status information and interact with each other. (Luo et al., 2015) The roadmap of RFID-enabled ubiquitous manufacturing infrastructure consists of three core components as presented in Figure 8 below.

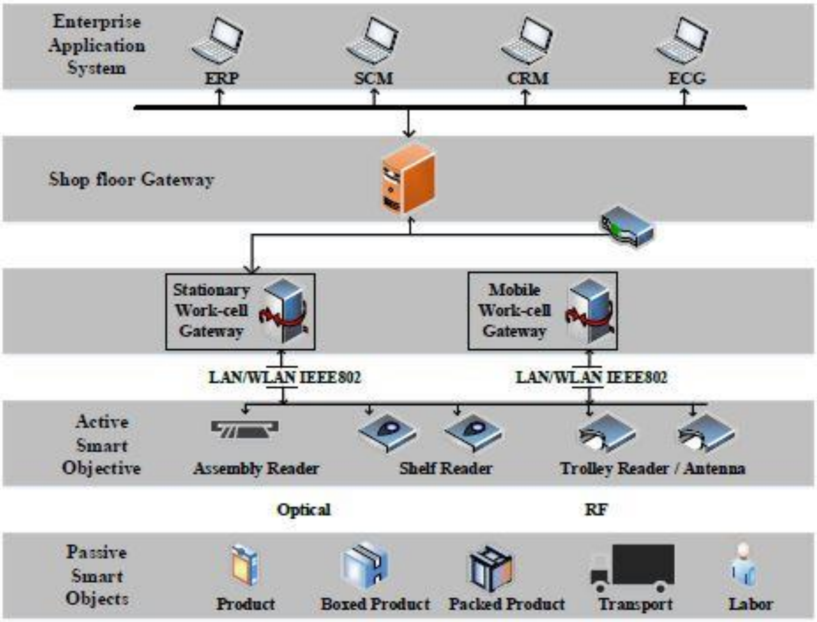

Figure 8. RFID-enabled ubiquitous manufacturing infrastructure (Adopted from Luo et al., 2015)

As it can be seen from the above figure 8, the first two layers of this platform are RFID-enabled smart objects. Those objects are called smart since they are equipped with RFID devices. Objects with RFID tags on them are considered passive and those with RFID readers are active smart objects. These objects can communicate with each other. Also, they are capable of sense, reason, act and react intelligently due to their specific operational logics, data memory and processing functions. Work-cell gateway (WC-Gateway) is another component of UM platform. It consists of a hardware hub and a suite of software systems. WC-Gateway operating system, smart objects are considered as software agents which are "universal plug and play (UPnP)" and interoperable. And finally, there is the Shop-floor Gateway (SF-Gateway) at the center of the overall platform. SF-Gateway provides the mechanism to define, configure and execute different working processes. In other words, SF-Gateway's job is to manage the workflow and assist in the configuration of smart objects in different manufacturing processes. (Luo et al., 2015) With these components working together, it can be said that UM platform succeeds at real-time and seamless dual-way connectivity and interoperability between application systems at factory, shop floor, work-cell and device levels.

2.2.3 Challenges of applying RFID technologies in manufacturing

Although promising, applying IoT technologies (RFID technologies in particular) in manufacturing is not without its technological and usage challenges. Yoon et al. (2012) explains in their paper about various problems factories face regarding implementing RFID technologies or in other words embracing UM. The major problems they identified are as follows:

- Tracking the process of products and materials in real-time is challenging. Therefore, sometimes factories must do manual tracking which delays the work process.
- Nonsynchronous communication between inventory control department and manufacturing schedules leads to no inventory for producing a backlog of orders which generates a time delay.
- Lack of proper real-time monitoring systems makes it difficult to collect information about conditions and failures in the system and figure out the reasons for them. Hence, repair time is delayed.
- Not being able to predict life spans, malfunctions and right maintenance schedule results in managing system through manual input.
- Lack of data compatibility and standardization creates errors when exchanging data between systems.
- Challenges of updating information to the system instantly makes the field situation analysis longer.

Despite all the advancement of implementing IoT technologies into manufacturing, Zhang et al. (2015) explain the remaining challenges in many manufacturing companies. The first challenge is how to build up a thorough information capturing and integration architecture and solution to collect, process and exchange the real-time manufacturing between enterprise layer, workshop floor layer and machine layer. The next challenge is how to effectively set up IoT technologies like RFID sensors to track and trace the manufacturing things during execution stages. The third challenge is how to process and integrate the real-time manufacturing data to achieve consistent dual-way connectivity and interoperability between enterprise layer, workshop floor layer and machine layer.

Even though employing RFID technologies brings some advantages but there are many challenges to overcome for that. Lieshout et al. (2007) elaborate on the challenges companies face for choosing the proper tag/reader technologies. Here is the list of potential problems when factories decide to implement an RFID solution:

- *Large amount of data*: Scanning each RFID tag several times per second by readers creates a large volume of raw data. Processing big data can be challenging.

- *Product information maintenance*: While numerous RFID tags are processed by the reader, the attributes of every tagged product should be continuously retrieved from central scale implementations.

- *Configuration and management of readers and devices:* Configuring and managing many deployed readers and hardware devices throughout multiple facilities is a big challenge.

- *Data integration across multiple facilities*: With various separated facilities in an enterprise, it is more difficult to manage data in real time and aggregate it inti the central IT facility at the same time.

- *Data security and privacy:* Depending on different business applications, security and privacy challenges can have an enormous impact on the architecture.

Luo et al. (2015) discusses specifically the challenges shop floor managers encounter while releasing the new orders to shop floor. The first challenge is lack of real-time data feedback channel. When shop floor manager dispatches the orders, the manager does not know what happens in the shop floor until the product reaches the last stage. The second challenge is the lack of information-sharing channel between stages. Sometimes one stage may process jobs faster than other stages and does not control the throughput. This results in unbalanced workloads for each stage. The third challenge is the order delay in peak season and order earliness in off season. This is due to lack of proper coordination mechanism from the upper level to control the order progress within the whole-time horizon.

2.3 Internet of things and process optimization synthesis

Higher efficiency and optimized production allows companies to outperform their competitors. Every manufacturing process faces a common set of business challenges including utilizing assets and resources efficiently, lowering costs, responding fast to changes in market demand and the need to be able to recognize potential issues in advance and address them for optimal results. (Prokos, 2015)

IoT technologies such as RFID, enables businesses to achieve this elevated level of optimization by connecting operations and allowing manufacturers to collect data from connected equipment, sensors and devices in real-time. Equipment across the shop floor generates huge amount of data which can be stored in the cloud and used for analysis.

Many academics have studied IoT and the technologies related to it. Also, some research has been done on role of IoT in manufacturing. In this regard, Table 3. demonstrates prominent previous studies which has been used in theoretical part of this research.

Table 3. Analysis of earlier similar studies with focus on IoT applications in process optimization

Author	Topics discussed	Findings
Schlick et al. (2013)	• Applications of IoT and their potential • Challenges faced by IoT industry applications • Smart factory • Smart product • Automation • Big data • Product tracking • Product lifecycle management	The research recognizes the value of IoT industrial applications in different domains such as: optimizing business process flows based on the big data analysis and optimizing processes based on smart tags and smart objects. Schlick et al. emphasizes that the success of IoT industrial applications depends on extracting relevant information and handling and managing the data along with other factory information and processes.

Author	Topics discussed	Findings
Gubbi et al. (2013)	• IoT definition • Cloud computing • RFID • Wireless sensor networks • Applications of IoT • Future of IoT	The study presents a framework enabled by a scalable cloud to provide the capacity to utilize the IoT. Also, a model of end-to-end interaction between various stakeholders in Cloud centric IoT framework is offered.
Dutton (2014)	• IoT definition • Features of IoT • Challenges of IoT	If core values such as privacy and trust are not designed into IoT architecture, IoT could undermine them.
Luo et al. (2014)	• Real-time data • RFID-enabled ubiquitous manufacturing infrastructure • Shop floor data capturing • Challenges of in implementing IoT in manufacturing process	Luo et al. introduces smart objects, work-cell gateway and shop floor gate as three cores of RFID-enabled shop floor. They proposed a multi-period hierarchical scheduling mechanism which is divide into two levels. The mechanism improves the coordination between decision makers in two levels and efficiently handles the rush orders in the production.

The above Table 3, presents the title of each paper and then authors, the topics covered and their findings. These research papers have some of the topics which can help me to answer the questions in this thesis study. These credible studies offer in-depth analysis of IoT technologies and applications of IoT. They also discuss the role of IoT in process optimization and how smart manufacturing is possible through implementing RFID technologies.

3. Case studies

3.1 Case Siemens

3.1.1 Facility

The Siemens facility in Germany, is a dream plant with a flawless, 10,033 square meters high-tech facility that shines with efficient digital wonder as its smart machines coordinate the production and global distribution of Siemen's simatic control devices. Amberg site can be seen in figure below. According to Siemens (2015) production at Amberg plant is a custom, built to order process, which involves more than 2 billion components for over 50,000 annual product variations. Siemens sources about 10,000 materials from 250 suppliers to make more than 1,000 various products at EWA.

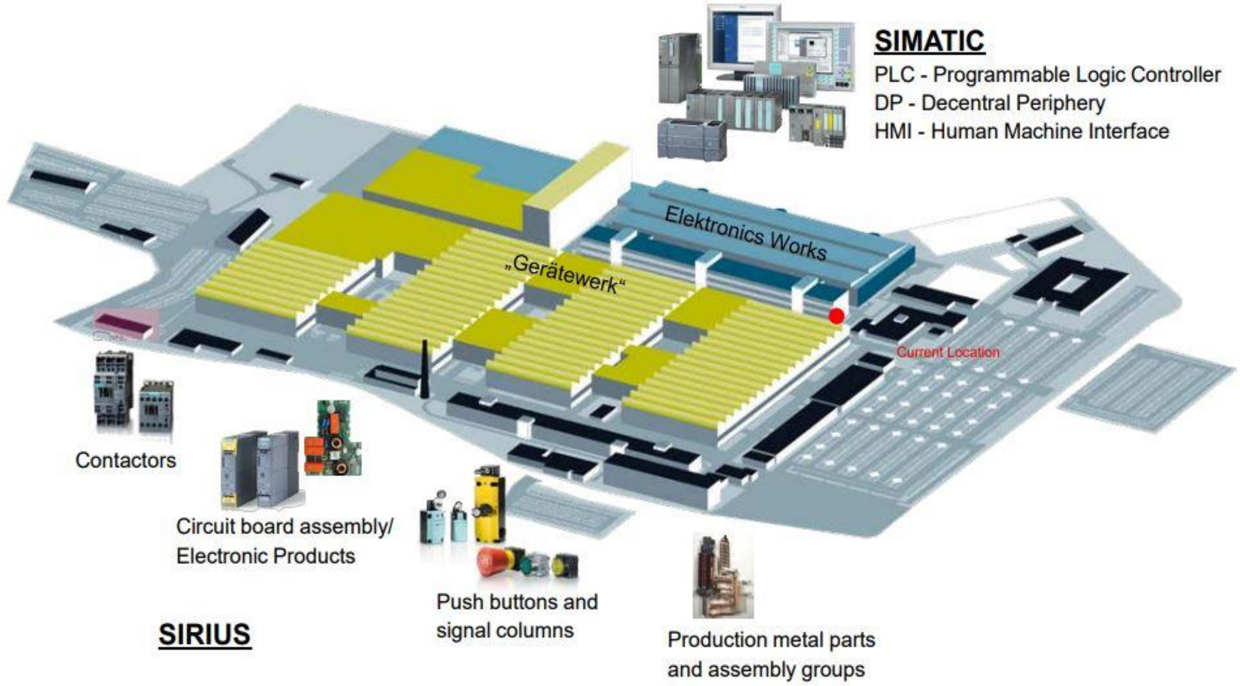

Figure 9. Amberg site, plants and products. (Adopted from Beitinger, 2015)

The above Figure 9. shows different products being produced at Amberg plant. The light-green parts of the site are equipment plants where production of various parts and assembly activities will take place. The blue part is the electronics section of the site where circuit boards transform into Simatic products.

According to Siemens, every year more than two billion subassemblies such as resistors, relays and condensers are soldered in this factory. The Siemens own Simatic IT makes sure that only components that the customer wants are attached to each circuit board. Meanwhile, for quality assurance, cameras and x-ray equipment are set up to inspect the quality of the connections. If any issue is being spotted, workers step in and check the controllers manually. After that, the product is automatically packaged at the end of 80-meter production line and forwarded to the shipping center in Nuremberg and from there, 1,000 different products are shipped to more than 60,000 customers around the world. (Siemens Industry Journal, 2014)

Hessman (2013) explains that the endless variables, extremely complex supply chain and production process at Amberg factory requires capabilities far beyond a traditional factory. He mentions, organizing the material flow and sequencing the processes is a challenging task. And moreover, intelligently managing and scheduling factory’s 1,200 employees to meet the requirements of an ever-changing job exceed far past any single technology or any single tool. Basically, machines are used for production, while employees are responsible for programming, control and monitoring those processes with the help of software solutions which represents Amberg’s motto “Simantic controls Simantic”. According to Hessman, the key factor in making EWA or any other future smart factories work, is creating a solid network of technologies that are integrated and cooperating into a smarter, more efficient system. The below Figure 10. shows the electronic work facility at Amberg.

Figure 10. Highly Automated electronics work facility at Siemens Amberg site. (From Siemens.com)

As it is shown in Figure 10. above, EWA's factory hall is as tall as a two-story building and the area it covers is the size of one and a half football fields. Second floor gives a view of the extremely clean production floor. Aisles are wide enough to easily fit three workers walking side by side, and with the majority of machines no higher than 1.4 meters, there is no problem making eye contact between workers.

According to Siemens' Journal Industry (2014), even though considerable part of the production at EWA is handled by machines and robots, the employees are responsible for smooth operation of the plant. Siemens foresees increase in automation in upcoming years, but they believe the highly automated production facility will never be able to run entirely without humans as Karl-Heinz Büttner, Plant Manager of the EWA and Vice President Manufacturing at Siemens explains "*people will still be irreplaceable for developing innovation products, planning production, and handling unexpected incidents during everyday operation.*" On the other hand, it is not just people who are essential. The quality and efficiency at Amberg are results of benefiting from high-tech machines. For every mechanical task done by a human, 5,000 mistakes will be made. Therefore, we are operating at a shy failure rate of 0.5 percent. Looking at defects per million opportunities (DPMO) rate of Amberg factory 25 years ago, it stood at 550 defects per million. But that number was too high for the managers of Amberg factory, especially because a broken controller as a product of the plant can shut down the production of a factory and costs its owners millions of dollars per day. (Jacobs, 2015) Based on a Gartner Industry Research study conducted on EWA plant in 2010, the reliability rate at Amberg factory is at astonishingly 99 percent and the plant enjoys a 100 percent traceability on its expensive lines. (Hessman, 2013). The significant improvement of DPMO rate at EWA can be seen in Figure 11. below.

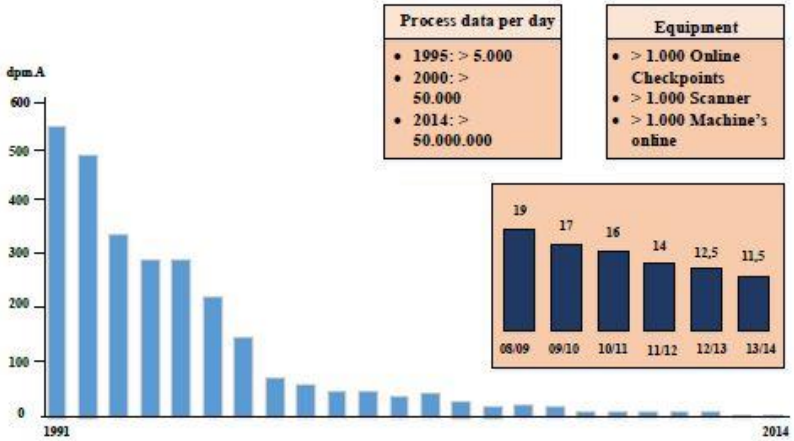

Figure 11. Perfect result of DMPO rate at Amberg site (Adopted from Bihler, 2015)

As it is shown in the above Figure 11, over the course of 25 years, Amberg plant has enhanced its reliability to almost perfection and this happened through automation. In 1990, only 25 percent of the shop floor was automated. Siemen's managers decided to move the factory towards a more automated future. Today, 75 percent of the shop floor at Amberg factory is automated. Therefore, the defect rate has dropped dramatically to 11.5 per million which means the reliability rate is at staggering 99.998 percent. Above all, the output of the factory has grown 8.5 times, while floor space and the number of employees has stayed steady. (Jacobs, 2015) According to Siemens' Industry Journal, EWA ships 12 million Simatic products every year. Considering the factory works 230 days a year, which means one equipment is completed every second. Amberg plant is a state-of-art showcase factory in its field and Büttner stated at Siemens 25th anniversary as, "*I do not know of any comparable factory in the entire world that achieves such a low failure rate*".

3.1.2 Smart integration

According to Helmuth Ludwig, CEO of Siemens Industry Sector North America (2013), the future of smart manufacturing is now. He believes, earlier distinct parts of the industrial value chain were implemented separately, including product design, production planning and engineering, production execution and services. But today, these worlds are brought together by innovative technologies. He explains the reason why Amberg plant is thriving in the integration of three specific crucial manufacturing technologies: product lifecycle management, industrial automation and manufacturing execution systems (MES). (Hessman, 2013) Each of these technologies and its application at Amberg are explained below:

Product Lifecycle Management (PLM): PLM is "managing all data relating to the design, production, support and ultimate disposal of manufactured goods." (Product-lifecycle-management.com, 2016) Siemens' definition of PLM is "an information management system that can integrate data processes, business systems and ultimately people in an extended enterprise." Siemens uses PLM software to efficiently manage the information during the entire lifecycle of a product, from ideation to design and manufacturing and finally service and disposal. Siemens believes PLM software allows companies to realize innovation and their PLM software products portfolio includes: Teamcenter, Active Integration, NX, Solid Edge, Fibersim, Syncrofit, Seat Design Environment (SDE), Femap, LMS, Quality Planning Environment (QPE), Tecnomatix[14] and PLM Components. At Amberg, before purchasing Tecnomatix PLM software, they were facing a few challenges including products in many quantities and customer-specific variations, increasing cost and time-to-market manufacturing lines, and worldwide manufacturing lines. Peter Engelhardt, a manufacturing planner at Amberg explains that as a leading factory, Amberg had problems with giving manufacturing planners a more systematic way of working. He mentions *"the minimal level of data integration on our old process caused us additional work, along with the labor required to trace out and provide proof of the outcomes for the planning works."* Amberg plant was aiming to considerably reduce the effort needed for manufacturing planning of product variants along with increasing workloads with higher efficiency. Moreover, they were eager to improve the quality of individual project reports to facilitate management decisions and simplify the understanding of production process changes. To achieve these goals, Siemens Industry Sector's IA CD unit purchased the Tecnomatix digital manufacturing solution from Siemens PLM Software which fulfilled these goals in a step by step approach by nearly 100 percent. Tecnomatix offered assembly planning and validation capabilities which made it possible to evaluate manufacturing methods, calculate production costs, schedule resources and examine resource utilization. (www.plm.automation.siemens.com) The impact of implementing PLM software is summarized in table below.

Table 4. Impact of implementing PLM software

Product	➢ Tecnomatix
Business initiatives	➢ Production efficiency
Business challenges	➢ Products in huge quantities and customer-specific variations ➢ Increasing cost and time to market pressures ➢ Worldwide manufacturing lines
Key to success	➢ Tecnomatix as a standard tool for manufacturing planning ➢ Simulation for assembly planning and material flow ➢ Interface between planning tools and SAP
Results	➢ Standardized planning processes across worldwide manufacturing locations ➢ Consistent data for decisions about manufacturing locations and production introductions ➢ Better control over manufacturing process changes

Industrial automation: According to Omer (2014), industrial automation is defined as "a set of technologies that results in operations of industrial machines and systems without significant human intervention and achieve performance superior to manual operation."

Derived from Siemens' website, at Siemens, industrial automation is called Totally Integrated Automation (TIA). It is a name given to efficient interaction among all the automation components. TIA is Siemens's answer to the demanded elevated level of efficiency at the engineering stage, as the first step approaching faster, production becomes more flexible and more intelligent. TIA is a portal that offers an integrated engineering framework and best possible support for optimizing all plant, machine and process sequences. TIA portal provides a standardized and dependable operating concept. It integrates controllers, distributed I/O, human-machine interfaces (HMI), power supply, drives, network components, motion control and motor management in a single engineering environment; therefore, it covers the whole production process. TIA is based on the constant presence of consistent data management, global standards and uniform hardware and software interfaces. These characteristics result into minimizing engineering time which leads to lower costs, reduced time to market and higher flexibility.

Manufacturing Execution Systems: Manufacturing Execution Systems (MES) is the link between the production and management levels which provides higher transparency throughout the plant. It is crucial in guaranteeing overall component integration, ensuring maximum quality and product optimization across global facilities. Siemens was one of the first to understand the challenges facing manufacturing industries, offering MES SIMATIC IT as a solution. The Manufacturing Execution System, SIMATIC IT, is a sophisticated, highly scalable MES that delivers multiple capabilities and allows you to combine production efficiency with quality and visibility, as well as production optimization, ultimately resulting in higher manufacturing responsiveness. The SIMATIC IT MES is part of the Siemens PLM software Manufacturing Operations Management (MOM) offer for the digital enterprise, the holistic solution that supports the entire value chain, from product development through production planning, production engineering and production execution to service. Within Siemens digital enterprise, MES/MOM is the Siemens product portfolio aimed to facilitate the realization phase by acting as the bridge between PLM and Automation, by executing production processes and managing production operations.

Together, PLM, TIA and MES create a powerful software suite for Amberg plant which connects all the levels from field, control and operator levels to management level and finally, enterprise level. The plant employs the latest tools, such as NX, Tecnomatix, Teamcenter and PLM programs for production development. Also, MES software, Simatic IT, many Simatic controllers and RFID systems are used for production processes. These products are linked through interfaces with enterprise resource planning (ERP) systems (Wegener, 2014). This helps the seamless integration of data from development, production and suppliers along the industrial value chain.

3.1.3 Internet of Things

Anders Gustafsson, CEO of Zebra Technologies, states the internet of things as “an exponential explosion of connected devices.” He says, IoT gives a digital voice or a virtual voice to all physical things. Then the digital voice enables them to communicate something about themselves, for instance what they are, their condition, where they are and more. As it is explained in the Gartner report, inside Amberg facility, there are touchscreen HMI’s that permit users to drill down from time-based performance trends to individual product lines and levels. This enables the process of tracking performance and in-depth root cause analysis of over 400 points of automated data collection. (Hessman, 2013)

Based on press releases of Siemens, due to manufacturing enormous number of different products at Amberg plant, the facility has to operate at maximum efficiency to remain competitive. Over the time, it has become harder to organize the production sequences in a way that an economical production is possible. Engineers at EWA has found the solution in a process flow that is fully adjusted with the product variation using IoT technologies. According to Bartneck et al. (2009), by adding a new production line to the facility in 2009, Siemens' goal was to maintain high production quality while manufacturing a considerable number of variants. They were aiming for more flexibility, lower cost and higher quality production.

At Amberg plant, each product is considered as a unique specimen and they are not treated as mass production goods. This approach has become possible by a flexible production, where each workstation and each machine is able to process a lot of different products. At EWA, this process starts with flexible mounting machines for manufacturing printed circuit boards and ending with packaging workstations where the assigned accessory items for every product are shown on the monitor, their removal from storage bins is checked. After analyzing production processes, managers at Amberg chose RFID and barcodes as potential technologies for their business. After comparing the two technologies, the results proved that RFID is a far better option for Amberg. The qualitative benefit of RFID in detail can be shown in table below:

Table 5. Qualitative benefits of RFID technology

Benefit	Description
Increased quality	➢ Manufacturing dates constantly updated on the RFID transponder ➢ RFID transponders are written with information from current QA results ➢ Faulty components are automatically sorted out and the errors are directly eliminated ➢ Components are returned to the assembly process following correction
Increased speed	➢ Increased throughput speed – "Data on tag" which results in fast data transfer ➢ Reduction of setup time – "Data on tag", the production control system is triggered directly
Reduction of use of IT	➢ Managing without implementing a database by using "Data on tag" ➢ Focusing the employees on high system availability, timely error correction and quality assurance

Siemens experts at EWA plant implemented a cost estimation to quantify the benefits of each technology. The costs for barcode technology were lower than for RFID technology. Even though the total cost for implementing RFID technology was higher than its rival, due to its increased system production capacity, it was feasible to overcompensate the higher investment in RFID.

In Siemens Amberg plant, engineers have utilized to IoT technologies to implement a self-organizing production which prioritizes and enters jobs into the production network. The production employs specific work-piece carriers which are well equipped with SIMATIC RF300 type RFID transponders. This system enables data to be retrieved remarkably fast, and therefore the work-piece does not have to stop at the reader. The transponders contain the building plan, which allows automatic testers to run an individual test program for every device. Then the results and other related data are stored on the RFID chip or transferred to the control systems by PROFINET network.

Figure 12. Range of Siemen's SIMATIC RF300. (From siemens.com)

Typically, as the number of variants increases in the production flow, the utilization of the machines decreases. Amberg factory has overcame this obstacle by replacing machines involved in decision making of production steps with trained, skillful workers equipped with RFID technology. Through RFID chip, workers receive precise instructions on the touchscreens regarding what to do with specific work-piece. (See Figure 13) The solution is that each work-piece carrier of the assemblies is equipped with data medium MDS D422 passive transponder made by Siemens. This transponder has the capacity of 8Kbyte and can be written and to read unlimitedly. After the selection of a pending production order, the corresponding data record is automatically written to the transponder. The data includes the production identification and also the exact product-specific timetable and work plan.

Figure 13. RFID supported production at the Siemens plant in Amberg. (From Bartnect et al., 2009)

3.2 Case Volvo

3.2.1 Facility

These days RFID as a popular identification technology in non-contact data transmission scene. However, RFID is already well established in automation and especially in automotive industry as a pioneer. For instance, RFID data carriers are built into or installed on vehicles for production control. (Logident Press Release, 2009)

According to Volvo, from 2000 to 2010, the company was owned and involved with Ford Motor company as a joint organization and later on in 2010 it was bought by Chinese firm Zhejiang Geely Holdings Group. One of the largest assembly plants in the portfolio of Volvo Cars Corporation is Ghent factory. It assembles more than 35,000 vehicles per year. Moreover, Ghent is the home to the VCC's world's largest spare parts distribution center for trucks, buses, construction equipment and marine and industrial engines. With typically have more than 200,000 spare parts in the warehouse, the facility handles over 6.8 million orders per year. (iMinds, 2014)

Alec Paepens, Network Manager at Volvo Ghent, in his interview with iMinds on October 2014, discussed about stable wireless communication and installation of IoT applications at Ghent factory. He mentioned that the factory uses technology for instant request of refilling parts on the line. Also, Ghent owns a large fleet of Automated Guided Vehicles (AGVs) driving around the facility with chassis which are equipped with wireless trackers and sensors and fully connected by antennae. (iMinds, 2014)

At Volvo factory in Ghent, after the discontinuation of the outdated identification system in the finishing industry, managers’ focus was on the entire production chain from the body plant phase to the final assembly stage. Ghent’s main goal was to introduce a universally applicable identification technology. From 2006 to 2008, decided to review its approach totally. Jacquet explains: “*to do so we had extensive previous experience and built up our knowledge from the beginning. It took 6 years till we managed to develop a complete solution. During these years we tested 80 prototypes and over 50,000 tags in the process. We developed the tag and the reader but still had to be adopted to overcome interferences and reflections caused by metal*.” (PR RFID im Blick, 2014)

Therefore, instead of 2D-barcodes, VCC decided to choose passive UHF-RFID technology. The modern technology had significant advantages due to its range and the flexibility to extend use to other applications. The UHF reader (Figure 14) enables the use of customer-specific applications and middle-ware functionalities precisely on site in the reader unit.

Figure 14. UHF reader at Ghent production line. (From Logident, 2009)

At Ghent, all three of the reader, PC and antenna are in a single housing. Because it makes the installation much easier and protects the antenna against severe operating conditions such as humidity, high temperatures and flying sparks. Till 2009, there were 85 readers installed in the body plant, generating around 85,000 read events per day with an impressive reliability of 99.99%. (Logident Press Release, 2009)

Today, Ghent factory uses only one passive UHF transponder tag from the first stage of the process line. This tag is a disposal tag which stays intact on the car from the welding and paint shop stages to the final assembly shop and it is still used when the car leaves the plant. By May of 2014, over 2 million cars were built on that concept in Ghent factory. (PR RFID im Blick, 2014)

3.2.2 Internet of Things

The controllability of a factory is greatly dependent on the interaction between enterprise resource planning system and shop floor, and the capability of any authorized user to review the status of sales orders on the shop floor. Business and plant systems should be combined to shorten decision making process, improve plant productivity as well as eradicating human intervention to increase accuracy and data availability speed. (Ghannam, 2014)

Today, a car manufacturer like Volvo must adopt itself to the diversified consumer requirements while at the same time increasing production volumes and lowering costs. The fact that many customers order assorted options while purchasing their cars, makes many cars unique in the production line. At Ghent, the production is even more complicated than other plants because several different models are assembled in the same production line. That is why Ghent factory relies on IoT applications to identify and reliably track every car during the whole production process to manage such a variety of products. In case of Ghent plant, Volvo uses RFID technology to raise its production. Confidex (the Finnish RFID tag manufacturer) developed a robust passive UHF RFID tag for Volvo to track its production assets during all stages of production. (Miettinen, 2014) By taking this approach, Ghent changed four essential functions in its production process. First, changing the functional models which developed to manage the static basic information. Second, the functions used to collect the data from shop floor and warehouse in real-time. Third, the functions developed for production planning and scheduling. And finally, the functions which are used to combine the real-time information with the decision-making models. (Pan, 2012)

Volvo has always had a clear RFID strategy to use one permanent tag throughout the entire production line. The Confidex Corona tag can be seen in figure 15 below. The tag is affixed to the shock absorber system (crash box) below the bumper which is located on the chassis above the front tyre and will stay there during the whole production process. (PR RFID im Blick, 2015)

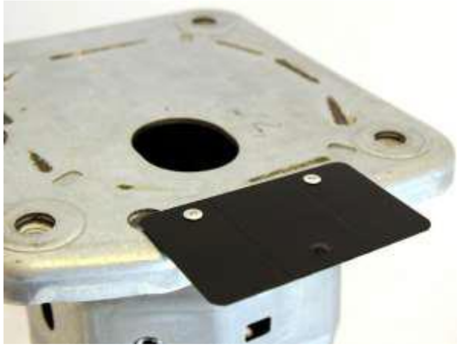

Figure 15. Corona tag affixed on a chassis. (From confidex.com, 2016)

IoT comes into play the moment chassis receives an RFID tag. At Ghent, a chassis passes an RFID reader in the production line, the tag ID number and the information saved in it is recorded and transferred to the backend system. The software which runs on any reader, interprets the read events, filters false data and transfers the relevant information to the middleware. Then, the middleware passes this data to the backend system. The chassis goes through a series of data points. In each data point, a record is generated which documents the stages that have been carried out. Meanwhile, the software manages and monitors the RFID hardware and software status simultaneously. A simplified product identification process is shown in figure. 16 below.

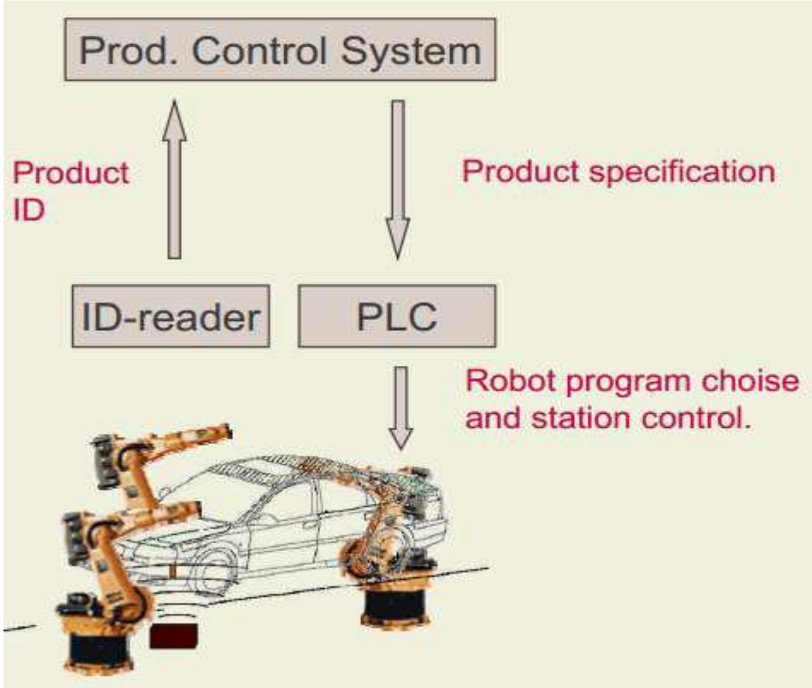

Figure 16. Product identification process at Ghent plant. (From Olsen, 2010)

The above figure is a response to mass customization of products at Ghent which forges a need for product identification and IoT solutions to be able to control the manufacturing process. After leaving the welding shop, car-bodies move to the paint line which is the harshest environment for the tags used. As the car-body with attached tag moves through the paint line, it passes a reader which verifies a unique ID for the body and the control system instructs the automatic spray booth what is the right color to paint the specific car (See Figure 17). (Nathan, 2015)

Figure 17. Paint line at Ghent plant. (Volvo car corporation, 2014)

On the paint line, the car goes through an electrolyte bath for corrosion prevention, several layers of paint and a series of elevated temperature drying ovens. It is crucial that the RFID tag remain readable and reliable in these severe conditions. (Miettinen, 2014) Jacquet explains that Volvo had developed a platform solution for all of its six car models. All the reading points of the RFID system on the assembly line are installed in a way that tags are read in the same position every time. During the finishing process, cars are driven to the parking lots and the RFID data capture continues there also. For vehicle identification, stationary readers are installed at the gates, passages and parking areas. During the parking process UHF tag and parking space are read by the driver with a handheld reader to collect the vehicle location. (PR RFID im Blick, 2015)

To sum up the smart implementation of IoT application at Ghent factory, the work-in process (WIP) is always monitored by a tag affixed on the chassis that moves through the production line as it is planned by ERP. By using this RFID solution, Ghent plant can track the progress in real-time on the floor shop with the help of the readers at each work station. This provides Ghent a full visibility of the WIP data across all processes and stations and makes the decision-making process smooth and ultimately an optimized production.

3.2.3 Challenges and benefits of IoT

Implementing new applications and making them work for the factory has its own challenges. Jarkko Miettinen, Vice President of sales at Confidex, says: “Automotive production is one of the most challenging applications for RFID not just because of its complexity, but also due to its uncompromising, high-reliability requirements.” Furthermore, Mark Higham, General Manager of Process Automation at Siemens, addresses general challenges of adopting RFID technologies as tag cost and customer nervousness in adopting this innovative technology. The reason is there might be concerns about reader consistency. It is managers’ job to analyze the situation and come up with the solutions to minimize the concerns and make those applications possible. (Nathan, 2015)

Alec Paepens and Kris Van Cauwenberge, Technical Support Manager at Volvo, count three challenges they face at Ghent factory regarding the implementation of RFID solutions. Cauwenberge believes the biggest challenge is the ever-changing geography of Ghent’s warehouses and production lines. At the warehouse, wooden containers full of metal parts are stacked up. Those act like walls which move and change frequently. That has a serious negative impact on wireless coverage. And also, the factory cannot afford to continually redeploy cables and move access points due to restricted time and advanced planning. Moreover, managers cannot use AGVs and wireless-enabled forklifts to maintain a connection because the speeds they move at. Paepens thinks that security is also a big challenge. He explains that a secure network is a necessity at Ghent due to large amount of automation and proprietary information flowing back and forth. But having a stronger security infrastructure means it is more complex and maintaining successful wireless connections become more challenging. He states: "*there is also the interaction between clients and access points, which are usually made by different companies. It should not be an issue, since providers are supposed to be consistent with IEEE standards. But unfortunately, in our experience, that is not always the case which can cause problems with devices, clients and access points establishing and maintaining robust connections."* (iMinds, 2014)

According to PR RFID-im-Blick Intl (2015), the project manager at Ghent discusses an ongoing challenge at the factory. He explains that there has been a change in assembly process of some models. The spot on the car body which had been used for the tags so far is not available anymore in the welding shop, because bumper beam will be placed in final assembly shop. As a result, factory has to relocate the tag during process. Also, the transponder is surrounded with integrated electronics such as sensors. It gets significantly harder to guarantee the UHF reading performances that leaves Volvo with the question of which transponder position is optimal for consistent identification.

NXP (2013) has made a comparison between RFID and older technologies such as barcode scans to point out the benefits of RFID. Four bold advantages of RFID over other technologies are:

1. RFID readers are much faster than barcode scans in identical setups. This is a significant benefit for production lines with many stations since saving time results in lowering labor costs.
2. RFID method is much more accurate which leads to less scrap
3. Customization of related products for different customers will be easier by using RFID technologies.
4. There is no need for line of sight to read RFID tags.

Implementing IoT applications at Ghent factory has had positive impacts on the plant also. Cauwenberge believes the rise of internet of things has changed production at Volvo. As one massive benefit of this phenomena, he mentions that equipping conveyers, automatic strapping machines and warehouse vehicle with intelligent sensors is a great boost to the production at Ghent. Cauwenbege adds: "*we have got over 300 forklifts that require manual maintenance. We are able to only service them and check for technical problems when they are not being used, which is not enough time.*" By benefiting from IoT-enabled technology, Ghent is able to employ a proactive approach to maintenance, collect performance data in real-time so that they can prevent problems before they shut down the vehicles or production installations.

Paepens describes another advantage that IoT brings in Ghent factory which is complementing forklifts with devices and sensors for tracking and picking purposes. Ghent plant needs intelligent machines and an intelligent network in order to embed intelligence into the system. He adds: "*We can do more work, higher quality work, and increase productivity to attract new models to the plant.*" (iMinds, 2014) Moreover, real-time information enables warehouse operators to minimize material delivery delays. Earlier, the shop floor operators were sometimes unaware of out of stock materials. But now the real-time information will automatically set off an alarm to inform the warehouse operator about the assigned delivery task. Having access to real-time information, enables managers to make better decisions and ultimately improve the responsiveness to everyday market and engineering changes, in addition to the shop floor productivity and quality. (Pan et al., 2012)

3.3 Cross Case Analysis

During the cross-case analysis, the major similarities and differences between two case studies are emphasized. The comparison is made according to the background of case studies and their level of involvement in previous chapters and author's perception of the cases. After studying Siemen's Amberg factory and Volvo's Ghent factory, it was apparent that they have some big differences and a few similarities in terms of using IoT technologies, IoT solutions and challenges of implementing IoT applications into the production process. Each of these differences and similarities are categorized and discussed below.

3.3.1 Level of IoT integration:

After an in-depth analysis of both the case studies, it was noticeable that there is a big gap between the level of IoT integration between Siemens and Volvo's factories. As it is explained above, Siemens' PLM portfolio in use at Amberg factory includes Teamcenter, Tecnomatix and the TIA Portal as a unified interface for MES and PLC's. Teamcenter is the most successful solution in the industrial market for product data management which offers more efficient manufacturing process to Siemens' factory. On the other hand, Volvo cars was integrated with Ford for ten years and it was involved in shared work processes in many areas including PLM portfolio. Today as an independent company, Volvo is reviewing its work process and is determined to choose the best software solutions to integrate IoT applications into its production. Volvo cars is planning to employ Tecnomatix and Teamcenter products into its facilities as it recognizes the benefits of using the manufacturing process management capability of Siemens PLM solution.

3.3.2 Software and Hardware challenges:

It is safe to say that substantial portion of challenges at Amberg site are related to software. However, at Ghent site, managers face challenges related to software and hardware. There are still some weak spots that need higher level of standardization in integration of PLM, MES and ERP solutions. That is one crucial reason for Siemens' aggressive acquisition approach. Whereas, at Ghent factory, managers face challenges related to both software and hardware. On top of Volvo's software challenges explained above, continuous evolvement of product design and factory layout are two hardware related challenges that managers come across in Ghent factory. Modifying the design of the product and phases of assembly plan has been a significant issue, since engineers have to figure out another suitable spot to attach the RFID tag to the chasis. Moreover, changes in the layout of the facility affects the quality of data transfer on the shop floor due to lack of wireless coverage.

3.3.3 Customization:

Customization is one of the mutual aspects of these two case studies. As mentioned earlier, IoT technologies enable businesses to customize their products effectively and profitably. This study shows that both Siemens' Amberg and Volvo's Ghent plants are involved with elevated level of customization. Production at Amberg is a custom, built-to-order process, which involves more than 2 billion components for over 50,000 annual product variations. Majority of the units can assemble components without further human aid. This is one of the types of plants which is capable of manufacturing fully customizable products while they are on the shop floor. Nowadays, car buyers order a few custom options for their cars while purchasing. Therefore, a car manufacturer like Volvo must identify and track each vehicle during the whole production process to make sure that all the order options are applied. At Ghent, the production is even more complicated than the other plants since several different models are assembled in the same production line. This is one of the reasons Ghent plant relies on IoT applications to identify and reliably track every car during the whole production process to manage such a variety of products.

3.3.4 Customers:

Volvo's Ghent plant covers both B2B and B2C contexts while Amberg plant is purely focused on B2B. Amberg plant produces Simatic programmable logic controls which are used to automate machines and equipment in order to improve product quality and the products are purchased by other manufacturing companies. On the other hand, Volvo’s strategy includes both B2B and B2C. As it is discussed above, Volvo sells cars through its networks of dealers or other middle companies but during past few years, Volvo’s goal has been strengthening its connection with the end-customer without interfering with the relationship that dealers have with their customers.

4. Discussion

In this chapter, the key findings of this study are elaborated. It demonstrates how thoroughly the objectives of the thesis are met. The answers to the main research questions of the thesis are explained in this chapter. Also, provides a detailed comparison between empirical findings of the study and literature review. The summary of the comparison is shown in three tables for easier comparison.

The three main questions of this research to answer are:

1. How can manufacturers use IoT technologies in optimizing their production process?
2. What are the benefits of using IoT technologies on shop floors for factories?
3. What are the challenges and issues of implementing IoT into existing businesses?

4.1 How can manufacturers use IoT technologies in optimizing their production process?

Based on the literature review of this study, IoT technologies are proved to be an influential help in production processes. They facilitate the process in many ways for manufacturers. As discussed in the above chapter 2, generally the abilities of IoT technologies to impact production processes are categorized into four groups namely monitoring, control, optimization and autonomy. Each group is briefly discussed below to make possible the comparison of literature and case studies:

In monitoring, sensors and external data sources enable the thorough monitoring of products operation and usage, products condition and external environment. It also enables alerts and notifications of changes. The second group is control which happens through the software embedded in the product or in the product cloud. The software allows control of product functions and personalization of the user experience. The next group is optimization in which its purpose is enhancing product performance and allowing predictive diagnostics, service and repair. To elaborate more, monitoring and control capabilities facilitate algorithms that optimize product operation and use. Autonomy is the last group which is the combination of three previous groups. In other words, combining monitoring, control, and optimization allows autonomous product operation, self-coordination of operation with other products and systems, autonomous product enhancement and personalization, self-diagnosis and service.

Products at Siemens' Amberg factory are made in many varieties based on the demands of the customers. And this needs a flexible production capable of many variants. Machines and pick-and-place equipment should be automated enough so that manufacturing various products is possible. RFID systems improve flexibility and as a result the productivity of the plant. They are considered as significant factors in production and logistics. Therefore, at Siemens' Amberg factory, customized products are manufactured flexibly and fast. What IoT technologies offers to the factory is a reliable identification system and a high-performance network. These key offerings enhance the simulation of production sequences, the engineering automation, the production planning and supply chain management systems.

At Volvo's Ghent plant, IoT technologies such as RFID solutions, wireless networks and cloud computing provide an overall more flexible production to respond to global consumer demand. RFID solutions make the production process faster and more reliable, so that the cars reach the market quicker. At Ghent, IoT technologies combine information, technology and human skills to deploy manufacturing intelligence into every aspect of production process. All of this leads to a more optimized and a more efficient plant which can react to changes in real-time by continuous monitoring and control of the production. Additionally, warehouse management and logistics at Ghent have improved considerably.

After discussing the above question, the answers provided in theoretical part and case study part are compared in the table below. "**Monitoring"** and "**Optimization"** are the shared answers that are discussed in both theoretical and empirical parts.

Table 6. Key findings for Research question 1

Theoretical studies	Case studies
Control	Monitoring
Monitoring	Flexibility
Optimization	Optimization
Autonomy	Efficiency

4.2 What are the benefits of using IoT technologies on shop floors for manufacturing plants?

IoT technologies brings many advantages to the shop floors and creates many opportunities for plants by enhancing data collection, enabling real-time responses, increasing efficiency and productivity, improving access and control of devices.

Through IoT, frequent data collection will be possible and then, these data can be sued to optimize outcomes. Another benefit of IoT includes, the data can be collected instantly which makes real-time decision making happen and necessary actions will be taken later. This would have a positive impact on Wait in Progress (WIP) at shop floors. By capturing real-time information, it is easier to make sure production line runs smoothly and efficiently and the lack of spare parts or raw materials will be minimal. Another benefit of IoT is in enhancing productivity at a larger scale where coordination of numerous pieces is crucial. This is due to IoT's ability to provide better access and control over Internet-connected devices.

At Siemen's Amberg site, IoT technologies offer a high quality and faster production and reduction of IT usage to Siemens. This increased quality is due to manufacturing dates being constantly updated on the RFID transponder. Faulty components are automatically sorted out and the errors are removed directly, then those components are returned to the assembly process following correction. The increased speed is because of faster data transfer and reduction of set-up time due to data on tag. And finally, reduction of IT usage eliminates the need of database for shop floor management and also lowers the error rate.

Implementing IoT applications at Volvo's Ghent factory has had positive impacts on the plant. An important benefit is equipping conveyers, automatic strapping machines and warehouse vehicle with intelligent sensors which is a great boost for production at Ghent plant. By benefiting from IoT-enabled technology, the plant can employ a proactive approach for maintenance, collect performance data in real-time so that they can prevent problems before they shut down the vehicles or production installations. Earlier, the shop floor operators were sometimes unware of out of stock materials. But now real-time information will automatically set off an alarm to inform the warehouse operator about the assigned delivery task. Having access to real-time information, enables managers to make better decisions and ultimately improve the responsiveness to everyday market and engineering changes, in addition to the shop floor productivity and quality.

After discussing the above question 2, the answers are provided in theoretical and case study part are compared in table below. **"Data collection"**, **"Availability of real-time data"** and **"Enhanced productivity"** are the shared answers that are discussed in both theoretical and case studies.

Table 7. Key findings for research question 2

Theoretical studies	Case studies
Data collection	Data collection
Availability of real-time data	Availability of real-time data
Enhanced productivity	Enhanced productivity
Better decision making	More reliability
	Advanced customization
	Better maintenance

4.3 What are the challenges and issues of implementing IoT in existing business?

Using Internet of Things technologies results in generating more data which is required to be stored and processed. This large amount of data raises concerns about privacy, data processing, data ownership, communication and standards. Manufacturers will be forced to define and implement new set of standards to coordinate and make the devices to work together.

Therefore, deploying different approaches such as data structures and communications, considering IoT is necessary for businesses.

One of the crucial challenges is about the ownership of the collected data by IoT in different scenarios that involve multiple parties. Typically, copyright agreements are signed to clarify the owner of the produced data by a machine. In case of an IoT object ownership, this object might be owned by a specific company, could be co-owned by several companies or it can be part of a public or private infrastructure. Then the concern would be who has the authority to utilize the object and decide on how it is interacting with other IoT objects which requires modification in business model design.

Cyber security is also a concern for the data or systems developed by IoT. The IoT cloud creates very sensitive data as well as supporting safety critical systems. It is vital that these systems be safe and secure from intrusion by an unauthorized user or any unintentional data breaches by authorized personnel to handle data.

Companies face many challenges while implementing RFID technologies into factories. The first challenge is tracking the process products and materials in real-time. Second challenge is nonsynchronous communication between inventory control department and manufacturing schedules which results in a backlog of orders and ultimately a time delay. Next one is not being able to forecast life spans, malfunctions which leads to managing systems manually and time delays. And finally, lack of appropriate real-time monitoring system and feedback channel are also big challenges for businesses and shop floor managers. Lack of monitoring system makes it hard to capture information about conditions and failures in the system. Therefore, repair time is delayed.

Siemens Industry’s Automation Division President Raj Batra, believes that the future of manufacturing is in finding the impeccable connection between PLM, MES and industrial automation and learn how to blend them together as a complete system. He states the real issue at Siemens Amberg plant was defining all the shared points among those three technologies in order to get the sum of the integrated whole. According to Batra, to have a complete system, manufacturers must pull together all of their high-tech tools which is another challenge in itself. (Hessman 2013) Other general challenges that many factories face in adopting RFID technologies are tag cost and customer nervousness in adopting this modern technology. Customers reason might be concerns about reader consistency.

At Volvo’s Ghent factory, implementation of IoT technologies is a daily struggle and managers face many challenges. One of the biggest challenges is the ever-changing geography of Ghent’s warehouses and production lines. At the warehouse, wooden containers full of metal parts are stacked up. Those act like walls which move and change frequently. That has a serious negative impact on wireless coverage. And, the plant cannot afford to continuously redeploy cables and move access points due to restricted time and advanced planning. Security is also a major challenge. A secure network at Ghent plant is necessary due to large amount of automation and proprietary information flowing back and forth. But having a stronger security infrastructure means it is more complex and maintaining successful wireless connections becomes more challenging. Additionally, an ongoing challenge at the plant has been the change in assembly process of some models. The spot on the car body which has been used for the tags so far is not available anymore in the welding shop, because bumper beam will be placed in final assembly shop. As a result, Ghent plant must relocate the tag during process. Also, the transponder is surrounded with integrated electronics such as sensors. It gets significantly harder to guarantee the UHF reading performances that leaves Volvo with the question of which transponder position is optimal for consistent identification.

After discussing the above research question 3, the answers are provided in theoretical and case study part are compared in table below. **"Data processing"**, **"communication"** and **"cyber security"** are the shared answers that are discussed in both theoretical and case study parts.

Table 8. Key findings for research question 3

Theoretical studies	Case studies
Privacy	Customer trust
Data processing	Matching existing technologies
Data ownership	Continuous changes in plant layout
Communication	Communication
Standardization	Cyber security
Cyber security	Continuous changes in product design
	Data Processing

4.4 Suggested Framework

This framework suggests a simplified enterprise architecture which can integrate sensor technologies (particularly RFID), a manufacturing execution system and an enterprise resource planning. The framework also provides practical recommendations on feasibility and cost efficiency of RFID solutions based on previous literature and empirical studies. The recommendations are an immense help to companies who are making decisions to implement IoT technologies into their facilities. It raises important questions about different integration issues which companies must address when determined to employ RFID technology into their architecture.

During the past two decades IT advancement has been significant and the progress of RFID technologies has been a part of it. This development has provided firms with dazzling productivity gains in different areas. Nowadays some enterprises are benefiting from automated data capturing in their production facilities and supply chains and many enterprises have decided to follow the same path. Even this causes substantial challenges such as privacy issues and the idea of an integrated enterprise architecture. However, it brings many advantages for companies that many of them are willing to take risk. For example, it enables factories to track their products or any object inside and outside the plant, starting from production, finishing stages, inventory, distribution, aftersales and even recycling. It is worth mentioning that, this study is mostly focused on production stage on shop floors of factories.

For companies to successfully integrate RFID technologies into their businesses, they should have an answer for a few important questions. The questions are listed below and the suggested framework in this paper gives answers to these questions.

1. What are the advantages of RFID technologies for the business?
2. Do those advantages outweigh the costs of integration?
3. Which RFID tag collected data should be sent to MES layer?
4. What RFID tag collected data should be sent to ERP layer?
5. Who have permission to reach sensitive information in the enterprise?

Data capturing on the shop floor of factories occurs by RFID readers through sensors. Those RFID readers and sensors are directly connected to computers called "edge servers" and they pass the data on to the computers. Data processing stage is done by edge servers. Companies must have a back-end system which collects information from shop floor and other systems inside the enterprise such as inventory, orders and supplies for processing. The back-end system consists of edge servers, MES and ERP systems. The suggested framework is shown in below figure 18. Generally, MES controls the production process by collaboration with RFID applications. In this suggested framework, MES handles four broad functions inside the plant. These four functions are operations scheduling production and control, labor management, maintenance management and quality management. Below the role of RFID in each function is explained. Overall, this framework demonstrates the integration of IoT technologies into MES and ERP system.

For operations scheduling and production control, materials or containers (objects) on the shop floor are equipped with a tag or in other words a unique ID. The production order data is stored in the RFID tag.

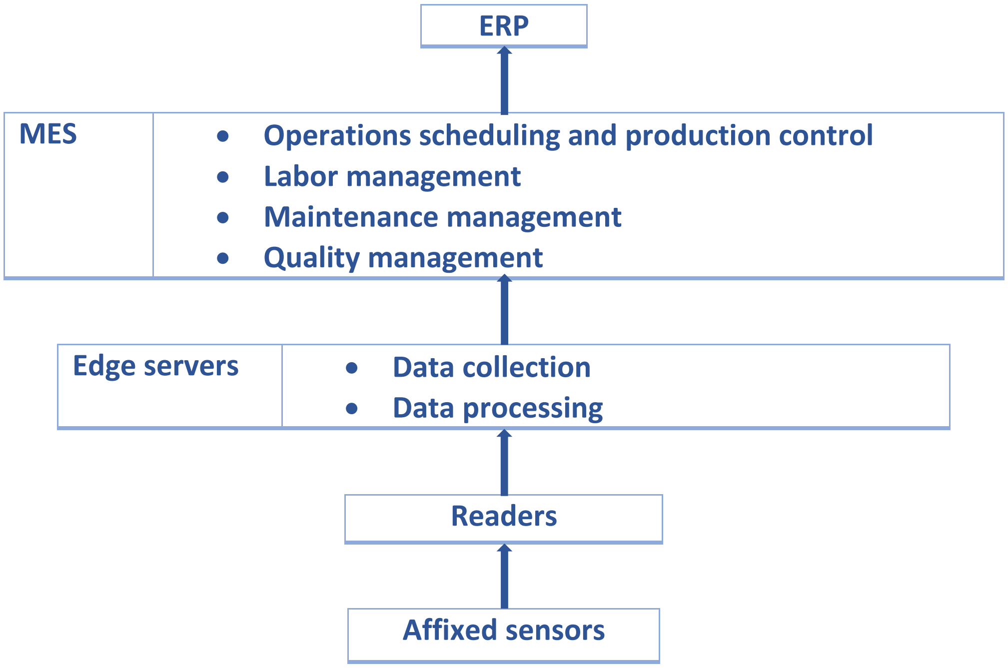

Figure 18. Suggested Framework

For labor management on the shop floor, workers and personnel can be registered by proper sensor technologies and managers are enabled to track them inside the plant. However, this many cause privacy issues and businesses should be extremely cautious about their decisions in this regard. Next function is maintenance management which can minimize quality issues and various sources of loss. It should be mentioned that in some architectures maintenance is considered as a business process and a part of the ERP system but in this research, it is considered as an operational process. Therefore, from functional point of view, maintenance is part of the MES. The locally stored records in RFID tags can be used to lower the needed paperwork for carrying out maintenance and updating records. And finally, for quality management, the locally stored data of material in tags are used to examine quality targets. The examination involves area functional checks, rework and re-tests, laboratory tests, checking real-time alerting, reporting and corrective actions.

When data passes on to the ERP layer, then ERP can continue with connecting to the suppliers, customers and other partners in the supply chain. Three important outcomes of this suggested framework can be summarized as:

- More optimized production process due to improved visibility of shop floor and production lines.
- Higher efficiency by having access to real-time data, updated orders and location of materials on the production line.
- Increased readiness to react towards unexpected changes of market and unplanned events.

5. Conclusion

The aim of this research is to study the implementation of IoT technologies in manufacturing process. The analysis is broad in coverage and shallow in detail because of the unavailability of data. The level of integration of IoT technologies in each case study is different, therefore cases couldn't be compared in every aspect. Also, the case study method can be very subjective which may lead to misunderstanding and errors due to researcher's interpretations. The topic of this research is very new and there are less published sources and materials available.

The automotive industry has been using RFID for many years and other manufacturing industries are now recognizing the fact that RFID can improve their operations as well. In many cases, RFID is the preferred method of product identification in a manufacturing environment as compared to the more traditional bar code. Advantages include the ability to withstand high temperatures and other harsh conditions. The fact that line-of-sight is not required is particularly useful on the factory floor as conditions can be dirty in some areas, making bar codes difficult to read. Since an RFID tag can store a lot of information and can be overwritten numerous times, this makes the technology ideal for including routing and processing information specifically for a particular part which is being produced. Benefits observed include improved accuracy of information, efficiency and productivity gains, improved quality control, reduction of labor requirements, a higher degree of material traceability, reduction of errors and rework, improved product tracking and bottleneck analysis, faster parts replenishment, reduction in WIP, increased flexibility and enabling of mass customization and even improved maintenance and process safety.

At Siemen's Amberg plant, engineers have utilized IoT technologies to implement a self-organizing production which prioritizes and enters jobs into production network. The production employs specific work-piece carriers which are well equipped with Siemens own RFID transponders. It enables data to be retrieved remarkably fast, and therefore the work-piece does not have to stop at the reader. Through RFID chip, workers receive precise instructions on the touch screens regarding what to do with specific work-piece. Whereas, Volvo's Ghent uses technology for instant request of refilling parts on the line. Also, Ghent owns a large fleet of Automated Guided Vehicles (AGV's) driving around the facility with chassis which are equipped with wireless trackers and sensors and fully connected by antennae. The controllability of a factory is greatly dependent on the interaction between enterprise resource planning system and shop floor, and the capability of any authorized user to review the status of sales orders on the shop floor. At Ghent, the production is even more complicated than the other plants because several different models are assembled in the same production line. It is one of the reasons, Volvo relies on IoT applications to identify and reliably track every car during the whole production process to manage such a variety of products.

It was apparent that Volvo's personnel had a hard time to adopt themselves to the new IoT approach. They have struggled even in the managerial level, since connecting with end-customer was not something that Volvo was used to before. Therefore, it is beneficiary to raise their skillset and understanding of IoT. As we also find from Volvo's Ghent plant, transformation of products makes it hard to affix the tag on the products and ultimately makes the tracking and collecting real-time data harder. Thus, frequent changes in the design of products might become a serious challenge for any company.

In terms of feasibility and cost efficiency of RFID solutions for businesses, it is recommended that companies notice the following issues:

- Firms must address the issue that combining RFID and location sensing technologies such as Global Positioning System (GPS) is not always enough to locate the materials on the production line. Thus, three-dimensional position tracking might be needed.
- Frequent changes in the design of products might become a serious challenge for any company as in the case of Volvo's Ghent plant.

Finally, every manufacturer's goal is to have more optimized production process. They can achieve it by IoT technologies. But to invest in IoT, the potential financial returns are the most key factors to be considered. Thus, firms constantly require new business models and ways to create value for IoT technologies. Also, firms need to concentrate on cost-benefit analysis of IoT technologies, since the adoption of IoT technologies is a fast pace, companies face many uncertainties regarding potential benefits and high investment costs. And also, when using IoT for problem solving, technology takes on a more noticeable presence. As companies more rely on machine-to-machine communication, interaction and decision making, there will be less human involvement in many IoT related actions. This results in a high security risks. Therefore, this paper strongly recommends companies which are planning to integrate IoT technologies in to their businesses to carefully take privacy and security issues into consideration.

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