CARVING FUTURE MANUFACTURING IN NORWAY

Future Manufacturing Systems in Norway – Strategy, Architecture and Framework

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ABSTRACT

This study investigates the suitability of Cyber Physical Systems (CPS) in Norwegian manufacturing industries and its implementation. This study explores the research and innovation needs in Norway which will be given as inputs to Strategic Research Agenda (SRA) 2030 of European Commission to share future manufacturing strategies in Norway. The objectives of the research are to identifying the opportunities and challenges of CPS, developing a feasible reference architecture of CPS which benefits Norwegian manufacturing industry, a framework to identify driving forces of CPS and necessary actions, and strategy development for future manufacturing systems in Norway to fulfil the needs of sustainability and societal challenges. Previous research offers a descriptive knowledge on future manufacturing systems and digital transformation to Industry 4.0 with associated challenges and opportunities. This study advances in to real time challenges and step by step implementation procedure for CPS in Norway. As a part of the research 3 in depth interviews with manufacturing and R&D organizations in Norway are carried with qualitative, observational research strategy. The key findings of the research are, companies in Norway interested in digital transformation to CPS but lack of skilled employees, analysis of big data, high investment cost, uncertainty on payback, and security of CPS are major barriers to it. Therefore, a suitable strategy for implementation of CPS, reference architecture for CPS, and framework for CPS are developed to support the key challenges. New concepts such as collaborative manufacturing, knowledge quadrangle, and security management of CPS are used to support the models developed. Impact of CPS on industrial services, recommendations to implement CPS and future research are discussed. Finally, inputs to SRA 2030 with objects, research, and innovation needs are presented and discussed.

Key words: Cyber Physical Systems, reindustrialization, industry 4.0, big data, smart products, ad hoc, smart factories, smart logistics, and teaching factories

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ACRONYMS

ADS – Attack Detection Systems

AI – Artificial Intelligence

CPS – Cyber Physical Systems

ERP –Enterprise Resource Planning

FMS – Future Manufacturing Systems

IT – Information Technology

ICPS - Industrial Cyber Physical Systems

ICS - Industrial Control Systems

ICT – Information and Communication Technology

JIT – Just in Time

KPI – Key Performance Indicators

MES – Manufacturing Execution System

MOQ – Minimum Order Quantity

NAV - Norwegian Labour and Welfare Administration

PLC - Programmable Logic Controller

PLCM – Product Life Cycle Management

RFID - Radio Frequency Identification

RQ – Research Question

SCADA - Supervisory Control and Data Acquisition Systems

SOA – Service Oriented Architecture

SRA – Strategic Research Agenda

SME – Small and Medium Sized Enterprises

TPS – Toyota Production System

WLAN - Wireless Local Area Networks

WSN – Wireless Sensor Networks

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Dedicated to my Parents, Sister, Teachers and Friends

1.0 INTRODUCTION

Norwegian manufacturing industry has undergone drastic changes during the last two decades. A report by Nordic Council of Ministers (2015) says that the percentage of jobs in manufacturing industry in Norway has decreased from 14% to 9% because of off shoring of production and outsourcing non-core activates etc. Manufacturing sector plays a major role in job creation and economic growth of the countries. It is important to reform the status of manufacturing sector in Norway. The need of adopting new trends in manufacturing will play a crucial role in increasing competitiveness, value addition to customers, quality, and sustainability. In this thesis report theoretical study on a new trend in manufacturing industry called as Cyber Physical Systems (CPS) is carried out. An effort also made to find the impact of CPS in increasing sustainability of manufacturing industries in Norway. CPS is in the initial stage of development (Lee et al., 2014) so it is important to define its structure, architecture and implementation strategy. CPS is also referred as Industry 4.0 in academia and research. Implementing Industry 4.0 in existing Norwegian manufacturing industry provides many new opportunities along with enormous amount of challenges which are presented in this report after in-depth interviews with manufacturing and research focus groups. At the end a strategy to implement CPS in Norwegian manufacture industry is proposed with a supporting framework.

The thesis work also aimed to give inputs to Strategic Research Agenda (SRA) for 2030 which is a part of European Commission's research framework. This can be done by mapping manufacturing, research needs during the years 2020-2030 in Norway. Norway has a long tradition of participating in EU research framework programs and is an active member of Horizon 2020 (European Commission, 2011). This framework is focussed on developing science and innovation activities in European manufacturing companies and help them to move towards smart, sustainable, inclusive growth and societal challenges. The present framework H2020 will end in the year 2020 and the next framework needs input from all participating countries. As a part of thesis extensive interviews are carried out among manufacturing and research focus groups to map the manufacturing and research needs in Norway during 2020-2030.

1.1 Problem Description

The Norwegian Labour and Welfare Administration (NAV, 2016) estimated 3.3% of unemployment in Norway with 2.6% of women are unemployed and 3.9% of men are jobless. Unemployment rate in European Union (EU-28) is 10.3% (Ec.europa.eu, 2016) which when compared to Norway is very high. It is important to deal with the unemployment situation in Norway which can be done by '*reindustrialization*' in manufacturing sector in Norway. Implementation of CPS needs more people with specific skills, so the Research Question 1 (RQ) is formulated with regards to the implementation of CPS in Norwegian Manufacturing Industry.

The question arises what happens to the existing lean manufacturing systems when CPS are implemented? Whether lean becomes obsolete or is it possible to integrate lean manufacturing with CPS? So RQ2 is formulated in order to find the possibilities of integrating lean with CPS. Theoretical and practical studies are conducted to understand the possibility of integrating lean manufacturing systems with CPS in manufacturing sectors.

These changes need strong manufacturing strategies to able to fulfil the demands like sustainability and to overcome to societal challenges like unemployment and inclusive growth. RQ 3 is formulated with regards to future manufacturing strategies in Norway.

1.2 Research Questions

The research is carried out to answer the following RQ's

RQ1: How to implement Cyber Physical Systems in Norwegian Manufacturing Industry?

RQ2: How to integrate Lean manufacturing systems with Cyber Physical Systems?

RQ3: How to formulate future manufacturing strategies in Norwegian Manufacturing Industry to produce sustainable products and overcome societal challenges?

The results from RQ 1 and RQ2 will be used as the basis to answer RQ 3. Norwegian governments' policy documents are used to improve the answers for research questions, to create an architecture and framework close to real time industry behaviour.

1.3 Objectives

The objectives of this research are,

- Identifying the opportunities and challenges of CPS
- Developing a feasible architecture of CPS which benefits Norwegian manufacturing industry
- Framework to identify driving forces of CPS and necessary actions
- Strategy development for future manufacturing systems in Norway to fulfil the needs of sustainability and societal challenges

1.4 Organization of the Report

Chapter 2 deals with the evaluation of Industry 4.0 and its potential to meet future manufacturing demands. This chapter also presents basic information about Industry 4.0 and Lean manufacturing systems

Chapter 3 presents the literature review on CPS

Chapter 4 discuss various opportunities, challenges and applications of CPS

Chapter 5 explains the methodology undertaken to carry out the research

Chapter 6 presents the results of the research as objective as possible. No interpretations are drawn in this chapter

Chapter 7 is the discussion part. Interpretations are drawn from the results and all the research questions are answered. A feasible architecture of CPS which suits Norwegian manufacturing industry is discussed with possible opportunities and challenges. Framework to integrate CPS with lean manufacturing systems is presented. Inputs for SRA 2030 are briefly presented.

Chapter 8 concludes the thesis report, states the limitations of work and possible future work

2.0 FUTURE MANUFACTURING SYSTEMS

Manufacturing industry has begun to integrate solutions provided by the developments in information technology (IT). For example, email is the basic communication channel among most of the industries. Advancements in IT provides new opportunities to create added value in the manufacturing sector. Adopting future manufacturing systems (FMS) obligate the industry to change the way it operates, its business model and concept. Present day enterprise resource planning (ERP) solutions needed manual operators to enter the data related to production and processes. FMS focussed on merging real and virtual worlds (Deloitte, 2014) then it is possible to integrate machine data directly to information cloud. In the following section, a brief historical review of manufacturing systems is presented followed by potential of Industry 4.0, CPS and lean manufacturing systems. In this report future manufacturing systems and Industry 4.0 are used interchangeably.

2.1 HISTORICAL REVIEW

Industrial technologies are spread all over world after industrialization. The consequences of industrialization are economical along with social and sustainable challenges. Industrial revolution refers to changes in technological, economic and social systems in the industry. These changes significantly affect the behaviour of work, life style and creates wealth for industry and its people (Dombrowski and Wagner, 2014). When Thomas Newcomen first invented (now called) steam engine in 1712 the agricultural society saw a tremendous change and the change started spreading in USA and other European countries. Iron and textile industries played central roles in 1st industrial revolution which in turn needed bigger factories to produce goods. The factories are established in cities and so people from smaller places started relocating to get employment. Initially, the wages were low and often resulted in degraded living conditions for poor and working class. The population in cities growing rapidly, along with food and health supplies, these situations triggered the necessary inventions such as railways, steamships etc. In order to produce greater volume and variety of products more man power was recruited along with children. Anyway, first industrial revolution raised the standard of living for middle and upper class families at the cost of un skilled labour, poor and child labour.

Tim McNeese (2000) in his book *History of civilization – The age of the progress* explains 2nd industrial revolution started with the invention of electric power and automatic operations. At this time the iron and steel industries developed world wide and transportation to remote locations was possible with newly built bridges and rail roads. The concept of division of labour allowed to decentralize engines in the production system (Huges, 1983). In 1885, Gottlieb Daimler and Karl Benz invented car, a new form of transportation, which is considered as a revolutionary invention of second industrial revolution. This period formed the bases for present day production lines, assembly lines, division of labour and mass production. As a result, productivity and wages were significantly increased with decreased price of finished products.

The invention of Programmable Logic Controller (PLC) in 1969 and microchip in 1971 are considered as the starting point of 3rd industrial revolution. The use of personal computers, communication devices profoundly increased during this period. The invention of new production processes such as lean manufacturing systems increased the productivity, reduced the waste and delivery time thus adding value to customer. Automation and robotics became common practice among the manufacturing giants. During this period efficiency and effectiveness in organization have equal importance. The concept of management, human perspective in industry, health and safety became important over technology. Quality movement, Sustainable manufacturing changed the way goods are produced with increased concentration on carbon emissions, wastes etc.

The impending revolution which is preliminarily known as Industry 4.0 started with a vision of converging virtual and real processes. The concept is characterized by complexity, as it demands intelligent communication among machines and IT tools/ software etc. Therefore, the concept of mass customization came into picture. The research is ongoing to find a way of customization in production. Internet of things and services is the basis for new industrial revolution. Smart objects called CPS are capable of establishing a global collaboration network of machines, production systems and warehousing (Kagermann et al., 2013). These networks are capable of transforming data independently to some storage systems and create a possibility of controlling each other independently. Figure 1 depicts the chronological view of industrial revolutions and their key technologies. Researchers believe that implementation of CPS improves production processes, life cycle management, material usage, and supply chain etc. the concept 4th industrial revolution or Industry 4.0 is not universally recognized but is undergoing huge research in European countries especially Germany. In the following section the key potentials of Industry 4.0 are presented.

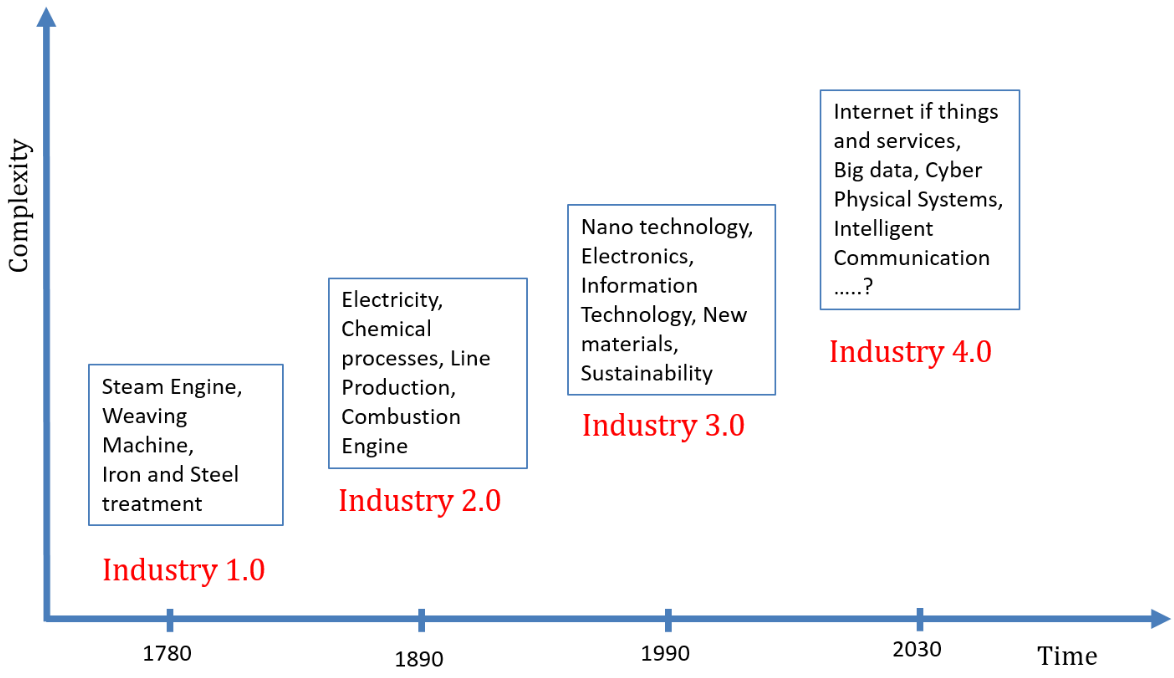

Figure 1: Evolution of Industry 4.0

2.2 The potential of Industry 4.0

The potential driver for Industry 4.0 are integration of horizontal and vertical value chains, digitalization & interconnection of products and services and digital business models to offer additional value to customers (Geissbaue et al., 2014). As mentioned above Industry 4.0 converges several technological developments with respect to products and processes (Lee, 2008). This is possible by so called Cyber Physical Systems where production steps go along with computer based processes (Schmidt et al., 2015). CPS is amalgamation of machines, things, electronics, storage and computation capabilities. This gives an opportunity to develop new products and services. Schmidt et al. (2015) defines Industry 4.0 as "Embedding of smart products into digital and physical processes". According to the definition Industry 4.0 aims at producing smart products which are capable of computations, storage and provide intelligent communication with its environment. Development of Smart products can be considered as significant potential of Industry 4.0.

2.2.1 Smart Products

Smart products are intelligent products which can identify themselves by Radio Frequency Identification (RFID) this enables them to interact with environment surrounded by them. The smart products can describe their properties, if it is on the production line the data related to finished steps are stored on to the storage network which is available to customer so that customer can monitor the product while it is on production line. Smart products can easily be modified, for example if the customer optimized the product while it's on the production line it can be coordinated with storage network and then production line can modify the process according to request. The security challenges are discussed further in this report. Smart products also allow manufacturers to capture various measurements like visual information on real time, videos etc. with the help of sensors (Beckert, 2014), previously these measurements are restricted to temperature and pressure etc. The data is collected continuously throughout the life cycle of the product and stored in big data systems for the future use.

According to Kagermann's (2013) report Smart Products and Smart factories will futher enhance the potential benefits of Industry 4.0 as follows,

Meeting Individual Customer requirement is one of the major opportunity with Industry 4.0. The design, configuration, production and all operational phases will become customer centric and enables one-off items in less volumes alongside making profits. The minimum order quantity (MRQ) requirements will reduce, as well as, minimizing unnecessary production. On the other side *Flexibility* can be achieved with CPS and *ad hoc* networks enabling dynamic manufacturing systems as the customer can demand last minute changes for production. With this manufacturing process becomes agile and configures quality, lead time and eco friendliness. *Optimized decision making* provides manufacturers to take right decisions in short notice of time, this is the key feature to succeed in the global market. According to the report, end – end transparency in real time is possible with the implementation of cyber networks and enabling all the production sites to be aware of optimized changes in the decisions in a short span of time. *New service* for example downstream services create new employment opportunities. The continues data also called big data collected from machines can be managed by smart algorithms therefore services can be made available locally. Small and Medium sized enterprises and start-ups can be utilized to deliver services. Other potential benefits from Industry 4.0 are resource productivity, efficiency, high wages, flexible to demographic changes in workplace as well as flexible organizational models meet better work – life balance.

2.2.2 Smart Factories

Advancements in IT and communication sectors enabled internet of things and services to be available everywhere. The world is becoming smart and networked and the emergence of smart grids, smart logistics, smart mobility and smart products are just a matter of time. Smart factories are future factories with the ability to manage complexity, make optimized decisions and offer end to end engineering solutions. The 3 major features of smart factories are horizontal integration of the services, vertical integration of manufacturing systems and digitalize end to end business value chains (Kagermann et al., 2013). Smart factories will be capable of delivering product robustness with highest quality standards in design, manufacturing and services. These systems are self-regulatory, networked, real time optimized and not prone to disruptions. Smart factories produce smart products which carries the information related to manufacturing process, delivery place and be able to connect with manufacturer with the assistance of big data. Figure 2 illustrates the connectivity among the value chain of smart factory.

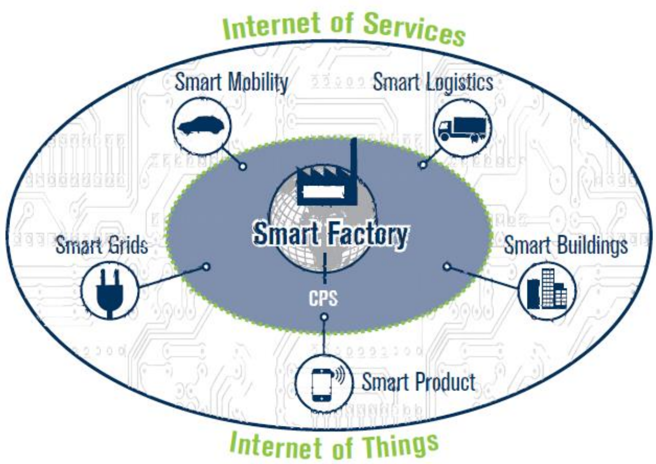

Figure 2: Smart factory as a part of Internet of things and services

2.3 Lean Manufacturing Systems

Lean manufacturing systems or simply lean is defined as "Systematic method of eliminating all nonvalue adding wastes (muda) from the manufacturing system (Wikipedia, 2016)". Lean also takes into account on reducing waste created through imbalances (mura) and overburden (muri). Lean became dominating in manufacturing industry after the introduction of "Toyota Production Systems (TPS)" at the manufacturing giant Toyota. The founder of TPS, Taiichi Ohno (1988) defines TPS as,

"... All we are doing is looking at the time line from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by removing the non-value added wastes ...(Ohno, 1988)"

As per the definition of TPS, the aim is to reduce every non-value adding wastes and increase efficiency and effectiveness of the manufacturing process. Figure 3 (Giæver, 2015) shows the 8 different wastes that has to be eliminated by lean manufacturers.

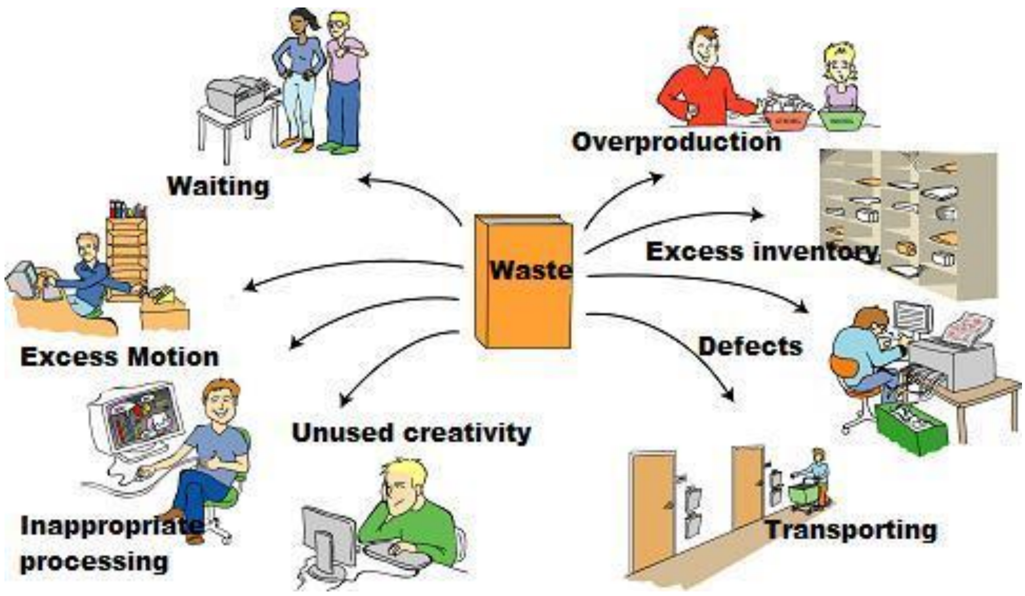

Figure 3: 8 Different wastes

Reducing *defects* means controlling the products and services that are out of specifications and reducing rework or scrap. Lean also focusses on pull strategy to reduce the *overproduction* of products before it is ready to be sold. In the manufacturing plants reduction of *waiting time* reduces imbalances in workload and one piece at a time (explained in next section) reduces the waiting time effectively. Non utilizing the talent of employees also considered as waste which in turn reduces the effectiveness of process.

Reducing unnecessary transportation, movement and inappropriate processing are important factors in lean manufacturing. Excess inventory needs place to store and excess economy is spent which in turn adds no value to the manufacturing systems, so it has to be reduced. In order to reduce different wastes lean tools are implemented and practiced for years with a proven record of effective reduction of waste. In the following section, lean tools are briefly discussed.

2.3.1 Lean Tools

In lean manufacturing systems the processes are designed to add value to customers by fulfilling their demands. The advantages are many but not limited to customer value, focus on value stream, desired product, short production time and appropriate price. Breyfogle (2007) explains lean tools that improve processes and can bring the above mentioned advantages.

Achieving *One-piece flow* means achieving just in time (JIT) manufacturing which reduces excess inventory and waiting time. Figure 4 depicts the one-piece flow functional layout for product A in lean environment. Implementing JIT ensures right product is made at right time and in the quantity they are required. As one-piece flow focusses on one product at a time it avoids waiting, storage so that it is conductive to pull system. The advantages are reduced product's lead time, flexibility in transactional demands, reduced operating costs, reduction of waiting time and storage. Batch production which is observed many manufacturing plants produces large number of transactions at one time so the above mentioned benefits are not observed.

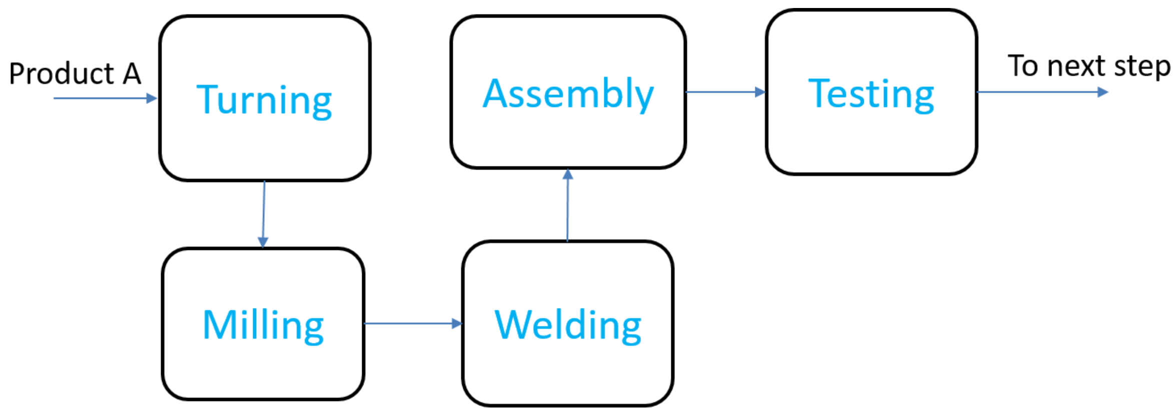

Figure 4: One-piece flow functional layout

Poka-Yoke in Japanese which means error proofing or error prevention by means of correcting, preventing or drawing attention of the operator. In the quality aspects of the product manufacturing it is important to eliminate the errors to prevent accidents or defective products. Poka-Yoke can be implemented anywhere in the manufacturing system for example, in order to avoid frequent discrepancies in the packing or connecting the male and female connectors of a battery.

Visual Management addresses the issues related to display of information and control wherever necessary. The information related to schedules, work, quality and production are displayed so that the plant manager or department can ensure whether the production is running according to the plan. The highlighted problems such as exposed waste, quality defects and safety are controlled by experts or higher authorities in the organization.

5S is introduced in TPS with the aim of standardizing the work processes. 5S offers basic discipline at the office and workshop. 5S stands for sort, shine, set, standardise and sustain. Sorting clearly specifies what tools are needed and make them available at the right time at right place. Each item is marked with their status either good or broken etc. and placed in particular places so that the operator need not search for them. Shine paradigm ensure the cleanliness of the workspace so that the workplace looks visually attractive and efficient. Set ensures space for every equipment with marking which allows easy access to equipment. Standardizing working methods, tools effectively identifies the source of waste and debris in the production. Right tools will be used for specific operation by preventing unnecessary defects in the production. 5S is regular part of daily work. Having 5S audit every month ensures sustaining the standardized processes.

Value Stream Mapping is defined as “A Lean management method for analysing the current state and designing a future state for series of events that take a product or service from its beginning through to the customer (Rother and Shook, 2003)”. Value stream mapping required planning and preparation, creating flow, defining problem, setting goals and objectives for production. Drawing a map while on shop floor shows the current status, delays and information flow and standard symbols represents production and design flow. The current map and waste produced will be used as the source of future maps.

Kaizen is a tool which uses group thinking to reflect on problems and brainstorming for improvements. If the analysis indicates a better way of doing things, then that Kaizen event must be undertaken. Kaizen means continuous improvement process that triggers peoples to use their creativity, experience to fix specific problems.

In push systems the product is created then it is sold and if there is no proper demand after the product is made then it creates lot of problem including economic breakdown. Whereas, pull systems or Kanban systems are customer driven, the manufacturing process starts once the customer demand is known or the order is placed. The intention of Kanban is to signal the preceding process that next process needs material or parts. In Kanban systems the parts are drawn only when needed, defective parts are removed from product line and will not be used for next steps. Kanban systems produce only number of products required and the buffers will be cleared off once the production target is reached. Kanban signals are shown with lights or computer networks and Kanban label includes number, bar code, shipping address, supplier name, part number, quantity in each pack, part description, part store address, line site address etc.

Other lean tools include *bottleneck analysis,* where the brain storming sessions are initiated to reduce the waste from specific process. *Key Performance Indicators* (KPI) are the measures that are designed to trace the current reality in the production system and identifying the parameters that are responsible for smooth flow of production and improving them. *Demand Management* and *Continuous flow* are also observed in lean manufacturing systems.

Lean promotes semi automation with manual touch with an argument of manual flexibility and cross functional ability. One of the objective of this research work is to integrate the lean manufacturing systems with future manufacturing systems, which are digitalized and networked. Some of the lean tools such as one-piece flow, Kanban and poka-yoke are already implemented in automation processes but no research has been found on the status of lean manufacturing after the implementation of CPS. The interview guide made for this research work focusses on integration of lean tools with CPS. The next chapter deals with basics of CPS and reviews the available literature on CPS.

3.0 CYBER PHYSICAL SYSTEMS (CPS)

3.1 DEFINITION

According to Krishna et al., (2015) CPS is defined as *"A new generation of systems with integrated computational and physical abilities the can interact with humans through many new approaches."* Lee et al., (2014) has the following definition for CPS, *"Transformative technologies for managing interconnected systems between its physical assets and computational capabilities."* Yue et al., (2015) define CPS as *"Combination of embedded computers, networks, sensors, and actuators."* Monostori (2014) has complex definition of CPS as *"Systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its ongoing processes, providing and using, at the same time, data-accessing and data-processing services available on the internet."*

The common points in different definitions of CPS are, CPS are complex networked solutions that integrates machines, human, and data in order to serve the data-accessing and data-processing at the same time. CPS uses internet of things, big data in order to store the continuous data from machines to cloud for later usage. Baheti and Gill (2011), as shown in figure 5 explained how the communication takes place in a CPS assisted manufacturing systems. Machine data is transferred to computational elements in the cyber world where the machine performance is monitored. Any abnormalities in the machine are transferred to controlling devices. The control devices fix the problem and stores the solution in cloud for later reference. It's a closed loop organization of manufacturing systems ensuring information availability to users and manufacturers always on the internet. CPS observes the physical actions and performing computations to alter the behaviour of next process. The devices that cyber part of CPS can contain sensors, actuators, computational devices and big data. The physical entities can be machines, vehicles or any human made physical systems. During the years of developments in control system some authoritative control systems are developed which can be adopted in CPS are; state space analysis, optimization, estimation, resilient control systems, methods in frequency and time domains (Baheti & Gill, 2011). In the following section different existing architectures of CPS are presented.

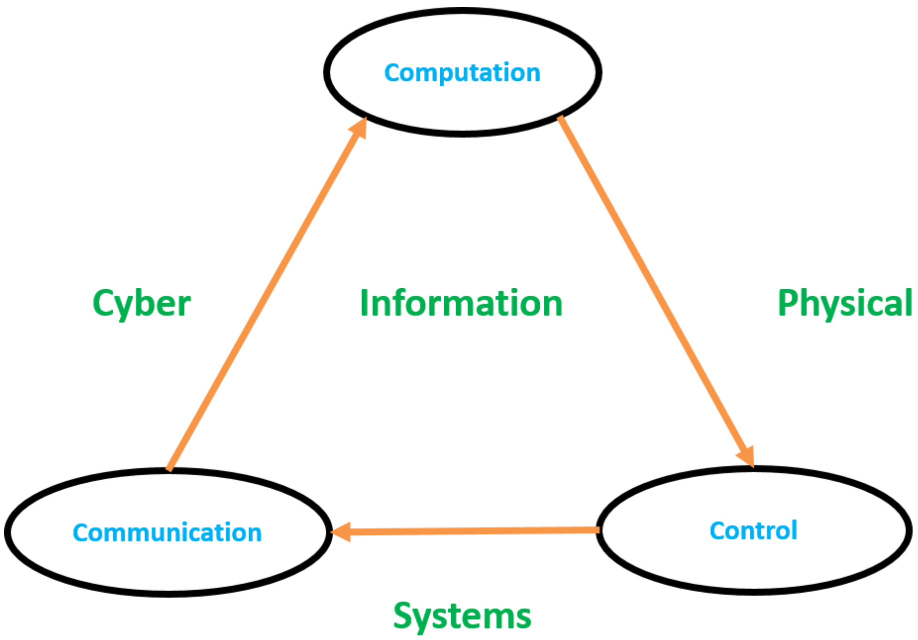

Figure 5: Communication in CPS

3.2 ARCHITECTURE OF CPS

In this section different architectures of CPS are presented. Figure 6 represents the general architecture of CPS based on monitoring and networking (Shi et al., 2011). Figure 7 represents developing and deploying architecture for CPS for manufacturing industries (Lee et al., 2014). Figure 8 represents service oriented cloud assisted Industrial Cyber Physical Systems (ICPS) (Yue et al., 2015) and Figure 9 is a cloud based ICPS via existing software solutions (Leitão et al, 2015).

3.2.1 Layout Based Architecture of CPS

Layout based architecture by Shi et al (2011) is based on communication among the entities of CPS. This is very basic model illustrates the dynamics of physical processes integrated with IT. Layout based architecture differentiate the desktop computing, real time embedded systems and wireless sensor networks (WSN) with CPS. This model explains different feature of CPS; in CPS computations and physical processes are tightly integrated, the capability of CPS is *resource constrained*, networks in the CPS varies from wired/ wireless, Bluetooth, Wireless Local Area Networks (WLAN) etc. complex networks constrained by spatiality and real time, high degree of *automation,* and highly vulnerable for cyber security attacks. Figure 6 shows layout based architecture of CPS.

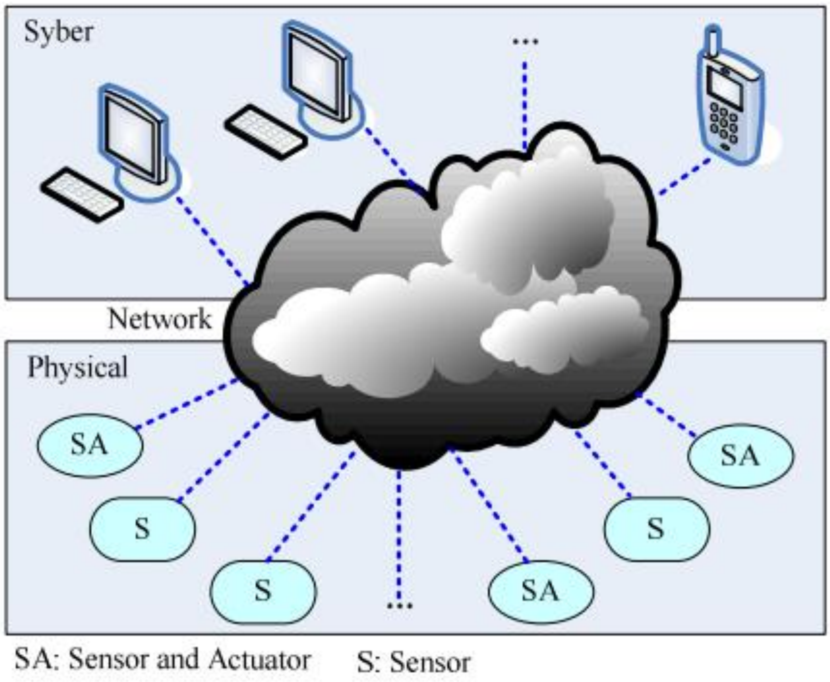

Figure 6: Layout based architecture of CPS

3.2.2 5C Architecture of CPS for Manufacturing Industries

As mentioned in previous chapter CPS is in the initial stage of development and so it is important to specify the structure and architecture for developing and deploying CPS in manufacturing industry. Lee et al., (2014) proposes a 5C architecture for manufacturing application. The five C's stands for Connection, Conversion, Cyber, Cognition, and Configure. 5C architecture claims two major functional units of CPS; 1. Intelligent networking that ensure data-acquisition from physical world, 2. Data management by computational capabilities of cyber space. Figure 7 shows the architecture of CPS for manufacturing application.

The first step towards implementing CPS in an industry is to acquiring data from sensors and controllers. This level of architecture is mainly establishing connection between sensors and machines to gather valid data. Data may be of different types and hence it has to be transferred to a server for differentiation. On the other hand, selecting proper sensor plays a major role in the *connection* level.

The second level is *conversion* level where meaningful data is converted to information so that this level brings self-awareness to machines.

The third stage of developing CPS in manufacturing industry is to transferring data to an information hub where the information from different machines is analysed to extract better information that brings the actual status of machines. Complex things raging from comparison of machines, future behaviour of the machinery can be predicted based on the historical data. This stage provides self-comparison capabilities to the fleet of machines.

The next and very important stage in 5C architecture of CPS is *cognition.* In this stage experts from different fields can be able to prioritize the tasks and make an optimized decision based on the information available from the previous stage.

The 5th stage is *configure,* where the feedback from cyber space is sent to physical space and act as a supervisory control so that the corrective and primitive decisions are implemented from the previous stage.

Advantages of this architecture are, it clearly specifies the steps should be taken to implement CPS in manufacturing industry. It is possible to implement 5C architecture with available technology solutions. 5C architecture is suitable for new and SME's but passing through all the stages for existing big organizations is challenging. The conversion stage is confusing for the readers as no specific technology or software solution is mentioned to implement stage 2.

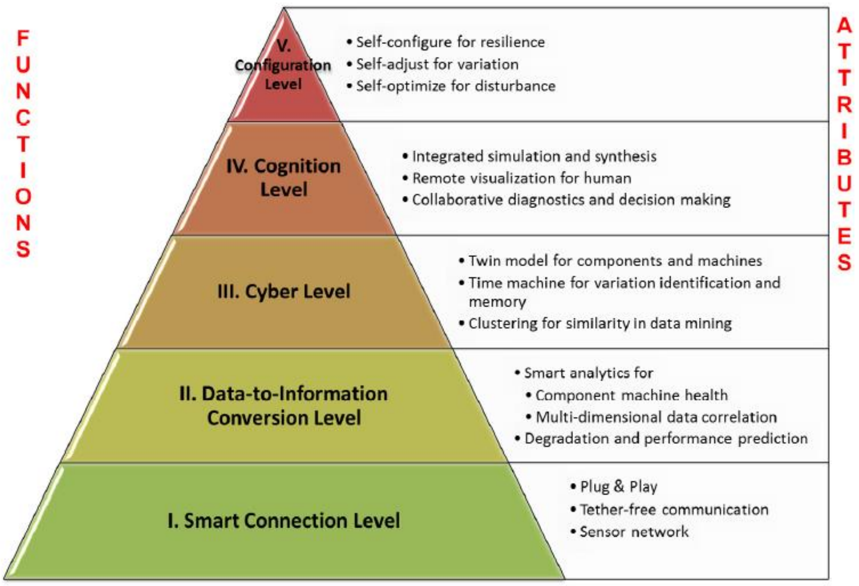

Figure 7: 5C Architecture of CPS for Manufacturing Industries

3.2.3 Service Oriented Cloud-Assisted ICPS

Yue et al., (2015) claims that sustainability of industrial systems depends upon service oriented architecture and CPS. This is the only architecture speaks about collaborations among smart factories in order to enable high degree of social resource sharing. Figure 8 depicts the structure of cloud-assisted ICPS. Optimization of ICPS depends on three major factors; distributed fast computing, flexibility and scalability services, and security. The argument of this architecture is, smart factories need to be collaborated in order to generate accurate information and reduce costs. As the collaboration may cause secure data to be vulnerable, end-to-end security should be ensured before collaboration.

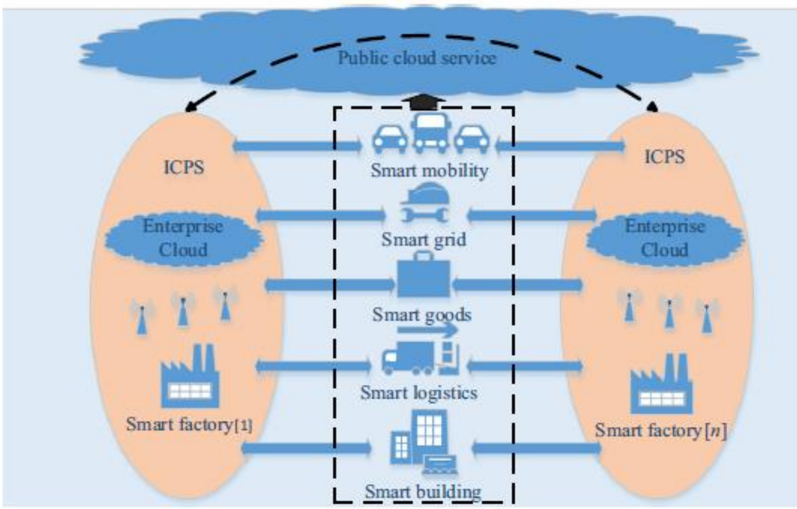

Figure 8: The structure of cloud assisted ICPS

By having the information related to Product Life Cycle Management (PLCM) in the cloud, the customer demand can be calculated. If the smart factories are collaborated through public cloud services, it is easy to get the information related to what machines have to be collaborated and where is the best place to sell it. In the Service Oriented Architecture (SOA) of ICPS, data servers, cloud storage and ERP plays major role to be able to exhibit the projected qualifications. Some of the existing technologies that can be used in this architecture are, ScraperWiki, Needlebase, Hadoop and Thingspeak.

The advantages of this architecture are collaboration among smart factories ensures information availability to all factories and precise information about customer's demand. This architecture is very optimistic about collaborations among smart factories and in reality it's a challenging issue. Security problems are not very easy to tackle with available IT.

3.2.4 IMC – AESOP Architecture of CPS

IMC – AESOP is a collaboration project under European Commission which is based on service oriented approach discussed in the previous section. This architecture uses the next generation software and Service Oriented Architecture (SOA) in order to bring the balance between physical and cyber parts of the system. Other advantages of this architecture includes, services can be split into services running in CPS and out of CPS which enables 3rd parties to utilize the services. The architecture shown in figure 9 depicts the IMC-AESOP view of cloud based Industrial CPS (Leitão et al, 2015) via modern engineering practices and software. The efforts are made not to create customized services but more general. The architecture is modular based and so can be evolved over time.

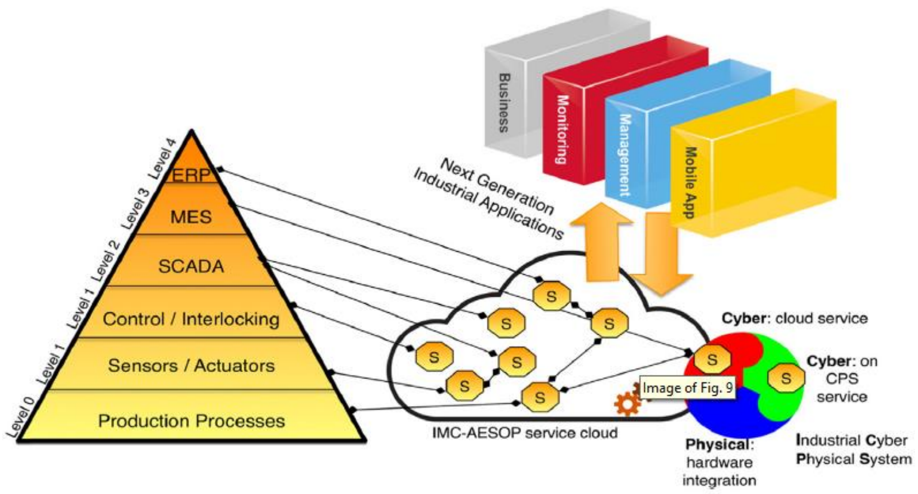

Figure 9: IMC-AESOP view of cloud based ICPS

The advantages of this architecture are availability of ICPS on device and in cloud creates a gate way to 3rd parties to utilize the services. As the architecture is modular based implementation is not complex and different stock holders can implement different modules individually. As per Leitão et al., (2015) the architecture is prototyped for processing and energy management domains and it is not tested for manufacturing industry yet.

In the next section major difference between current industry and industry with CPS are compared. The differences are based on the estimated potential of CPS.

As mentioned above implementation of CPS changes the work behaviour, culture and life style of entities in manufacturing systems. Table 1 shows the comparison of today's factory with factory with CPS in future (Lee et al., 2014), (Yue et al., 2015).

Type	Today's factory	Factory with CPS
Production System	Semi-automated, Manual control, Productivity, Quality, and Lean: waste reduction etc.	Networked manufacturing systems, Remote control, Flexible production line, Automation, In built quality systems and Collaborative production
Working Style	Individual machine operations, Not possible to track product life cycle, Manual maintenance, and Condition based monitoring	Cooperative machines, information transfer and troubleshooting through network, Smart products and possible to track the product life cycle, Self-detection – Self regulation – Self Control systems, and predictive health monitoring
Components	Use of sensors is to have the precision and fault detection, Controllers are to increase production and performance of the machine	Use of smart sensors to self-aware, self-regulate and self-control systems, Smart controllers for predictive health monitoring systems (early warnings and regulations)
Flexibility	All the designs are controlled by design department and once the production is started it's not recommended to change the design, Product services manual are time consuming	Customer can optimize the design whenever wanted and can alter the next production steps through network, Product services are networked and instantaneous
Production Cost	Suitable for mass production, production of small quantity of items is expensive	Cost and material for each product is same
Real-Time	Products are produced by enterprises	Customer can locally print the product using 3D printing with the support of manufacturer on internet
Data	Data from machines are stored in log books and not available for customers	Data is stored in cloud using big data and is available for customers and interested parties for future analysis, preventive maintenance and services

Table 1: Comparison of traditional manufacturing with CPS

3.3 CYBER RISK IN CPS

The survey conducted by Deloitte (2014) among 50 manufacturing companies in Switzerland revealed that the cyber risk of networked systems under CPS is considerably high when compared to traditional manufacturing systems. On a scale of 5, 36% respondents gave 4 and 48% respondents gave 5 rating when asked about security risks in CPS. In this section security of CPS and issues are detailed.

3.3.1 Security of CPS

In traditional IT systems confidentiality, availability and integrity are the elements of security which are mutually exclusive or isolated based on the application (Conklin, 2009). The balance among these trio elements are essential for the business processes. CPS need an appropriate security strategy which is different from one system to anther system. In traditional IT security systems confidentiality and integrity are important some time at the expense of availability (Krishna et al., 2015) but in CPS availability of information in cloud is a primary requirement with a strong focus on confidentiality and integrity. So, adapting traditional IT security for CPS is neither sufficient nor supports the goal of CPS. CPS needs different security levels for different systems. For example, securing the data from defence equipment manufacturer comes under the *confidentiality* level and protecting the financial data of the company is *integrity* level. As a whole availability and integrity are the major requirements in securing CPS and confidentiality applies only in specific manufacturers. Adopting traditional IT security systems in CPS creates problems such as; preciseness of CPS is under danger, communication problems and desired levels of protection can't be achieved. The following considerations must be taken while designing security architecture for CPS,

- CPS are not designed to protect the information in open networks
- Life time of CPS is huge and the security aspects must be designed for long term
- Availability of data and information is essential requirement besides protecting the integrity of customers

Therefore, current available IT security solutions can't be implemented in CPS. The personnel working with security development for CPS must be able to differentiate between traditional IT security and security of CPS.

3.3.2 Security Issues of CPS

In CPS the networks are open and organized among different users, this feature intensifies the security risks and attacks. The consequences of the threat are high as CPS in future builds the manufacturing infrastructure of the whole nation. The delay in information availability and imbalances are not accepted in CPS (Krishna et al., 2015) and hence the requirements are strict during normal operating conditions and improvement processes. So the designed security for CPS must be long term oriented as mentioned in the previous section. Therefore, designing security provision for CPS is challenging when compared to typical distributed information systems. The following security issues are identified (Conklin, 2009) and the security control of CPS is dependent on these issues.

Data Interpretation: Large data from the machines is stored in big data/ cloud and the security state of CPS is depending on the low-level data. This data includes cyber and physical parts of CPS which means machine data and data from software which is used to analyse machine data. Interpreting valid information from the large data is a tedious task for the IT of CPS.

Information and Control Sharing: Various entities of the CPS perform different jobs and so they have different rights on data. For example, users of a particular system don't want to transfer the data related to particular process to the cloud should be able to restrict the data transfer from their side. Therefore, information sharing must be controlled with respect to every entity in the CPS.

Containing Compromises: As the CPS networks are open to the tertiary parties of the network some compromises must be considered when a license exploitation by a malicious actor is found. The actor must be restricted to access the data or permanently removed from the network. These decisions are dependent on security strategy and legality of data misuse.

Maintaining Timeliness: The base system on which CPS is running must guarantee good working conditions under normal conditions, malicious attacks, intrusion, maintenance, and overload conditions.

Validation: The security systems under CPS should be audited for their validity so that safety is guaranteed for the entities of the network.

3.3.3 Security control for CPS

Generally, CPS must hold basic features such as, ability to sense the physical world using sensors, actuators etc. for example in a driver less vehicle, sensors should be able to detect the distance between obstacle and vehicle. On the other side, making decision based on the interaction with physical part of the system. In continuation to above example, the control system in the car should be able to decide what to do next. Finally, the ability to execute behavioural change in physical world. Like, braking the car in front of a pedestrian. Imagine, CPS in a bigger picture. What more is a collaborative network of many companies. The risks are much hard to deal with when we implement CPS in industry.

Firstly, take example of existing CPS such as Supervisory Control and Data Acquisition Systems (SCADA). SCADA systems usage in in oil and gas industry, water and electricity distribution systems are increasing everyday with the involvement of wireless sensors and actuators. These systems are sensitive to safety (Krishna et al., 2015) and focus is on to prevent the attacks. The case of Industry 4.0 is different, here the security of CPS should not only focus on preventing attacks but also control systems operation under attacks. The frameworks or model that will discuss security of CPS need to follow precise steps as follows (Conklin, 2009),

- Current status of security risk, reasons and intensity should be identified before jumping into actions
- Possible affects in numbers to be identified
- The plan to reach the desirable situation from current situation has to be identified
- The plan has to be validated throughout the execution process

Moreover, all these steps must be done automatically by analysing continuous data from physical world. Public policies and regulations influence the actions to be undertaken under cyber-attacks on CPS. While developing security for CPS it is also important to consider the optimized solution even though it is time consuming. Suboptimal solutions increase the risk of attacks and the consequences are not effective in terms of cost and time. In the next section a hierarchical security architecture for CPS (Zhu et al., 2011) is discussed which will be later used in the development of new architecture for CPS in Norway.

3.4 A Hierarchical security architecture for CPS

It is very important to see the already operational SCADA networks and their security issues before moving to discuss security architecture for CPS. Wall street journal posted (Gorman, 2009) on their website that intruders from China, Russia and other countries penetrated to their electrical grid and left behind the software program which will allow them to disrupt the whole electric grid during a war. In Georgia an inappropriate software update caused a nuclear power plant to shut down for 48 hours (Krebs, 2008). In both occasions the plants have to be stalled until the problem is fixed. CPS are critical infrastructures and in general IT solutions neither sufficient nor fulfils the goal. Therefore, CPS needs a unique and proprietary security solutions to fill the gap between security tools of traditional IT and CPS.

Hierarchical security architecture for CPS by Zhu et al., (2011) is designed to understand the research problems and challenges that need to be addressed while designing security architecture for CPS. Zhu et al., (2011) proposes a layered security architecture for CPS with decentralized functions at each layer. Figure 10 depicts the hierarchical structure of Industrial Control Systems (ICS) with physical layer containing physical elements such as production systems, power grid and water treatment system etc. at the bottom and management layer at the top. The main function of ICS is to monitor, analyse and control the physical elements using cyber solutions.

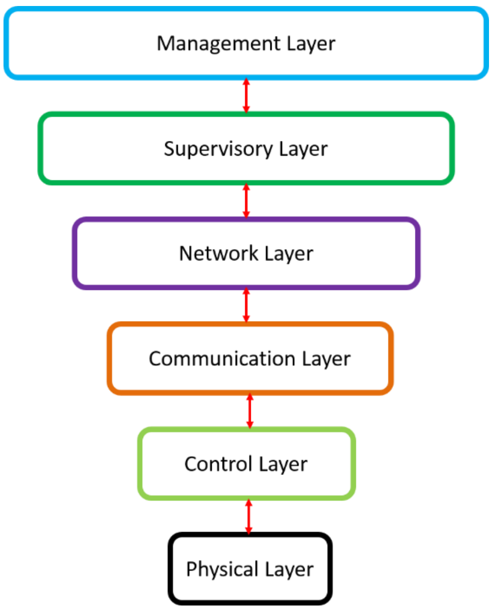

Figure 10: The hierarchical structure of ICS

Physical Layer: A physical layer is a plant or system to be controlled. For example, power grid, production system etc. can be in the physical layer of the hierarchy. First and important thing in securing physical layer is protecting it from environmental change and unexpected attacks (Zhu et al., 2011). Measures and counter measures need financial requirements and cost and benefit analysis to able to assess the particular attack or unexpected event. On the other side, while designing physical layers, engineers need to consider physical systems that are possible to connect with cyber layer of the system. The decisions related to physical infrastructure and maintenance is between management and physical layer

Control Layer: This layer contains sensors, actuators, attack detection systems (ADS) and different intelligent control systems. Sensors continuously senses data from the physical layer and estimate the current status. The data will be sent to supervisory level and saved to cloud for future reference. Any abnormality in physical layers' behaviour is detected by ADS and immediately alerts the supervisory layer while defending the attack by intrusion prevention systems.

Communication Layer: This layer brides control and network layers. This is interface between physical and cyber layers of CPS. Communication can be wireless, wired or Bluetooth depends on application.

Network Layer: According to Zhu et al., (2011) network layer related to the topology of security architecture. Network formation and routing is done at this layer. In order to confuse the attackers, the routers can be randomized and achieve security with minimum delay.

Supervisory Layer: This layer sends the commands to remaining layers based the data received from the physical layer. The control layer controls the physical layer upon receiving commands from supervisory layer. In centralized control there exist one supervisory layer and in distributed control there exist many supervisory layers.

Management Layer: This layer makes the decisions related to security policies and resource allocation etc. to achieve the goal.

The major limitation of this security architecture is having sensors in control layer. Sensors must be in physical layer to sense the continuous data from physical systems. On the other hand, the hierarchical security architecture for CPS didn't consider the security aspects of cloud/ big data where the possible vulnerabilities are maximum. The new architecture of CPS proposed in chapter 7 will address these limitations.

3.4.1 Multi agent layered architecture

In order to achieve increased performance Zhu et al., (2011) proposed decentralized multi agent layered architecture as shown in figure 11. Every agent can be a different manufacturer and has own UAV control system. UAV systems from different manufacturers collaborate in a networked environment. The collaboration between agents achieves the global goal while each UAV system serves the control and security for particular agent. The architecture didn't explain the collaboration policies, trust worthiness of agents, robustness of security systems and during intrusion how agents reacts together.

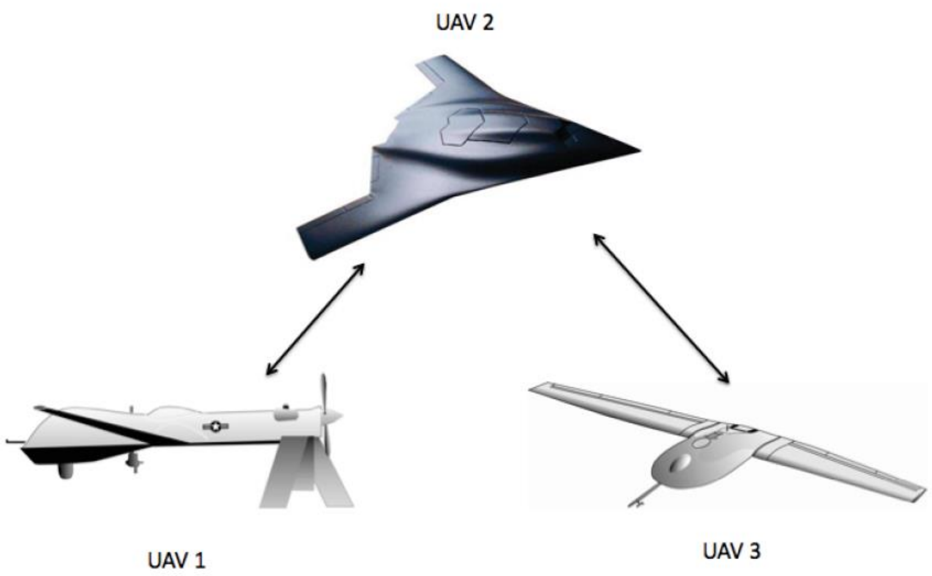

Figure 11: A multi-agent UAV system

In the next chapter opportunities and challenges while implementing CPS are presented. Real time applications and limitations of already implemented CPS are discussed briefly.

4.0 OPPORTUNITIES, CHALLENGES AND APPLICATIONS OF CPS

The future manufacturing systems with CPS brings new opportunities, challenges, and applications. This chapter is dedicated to present opportunities, challenges and applications of CPS from various studies.

4.1 OPPORTUNITIES

4.1.1 Customer and Supplier integration

Demand for customization is continuously growing and in future this trend going to spread rapidly. According to a survey conducted by Deloitte (2014) among Switzerland's manufacturing companies, 29% of the respondents agreed that their value chain failed to integrate customers and feel this is where they can improve. With CPS customers will be able to know how their products are being designed and manufactured and will be able to optimize the product as they want. The scope of networking in Industry 4.0 facilitates companies to become more extensive, efficient, intelligent and flexible to increase customization than their current performance. A similar survey by PwC and Strategy& (2015) among 235 companies from German manufacturing industry points that by 2020, 80% of the companies will have digitalized value chains. The report also emphasis that irrespective of size of the companies, they need to digitalize their value chains in order to maintain competiveness. The proposed strategy in chapter 7 considers digitalizing value chains as a prerequisite for implementing CPS in Norway.

It is equally important to integrate suppliers to ensure material availability at the right time. Digital integration with the supply chain networks will benefit in many ways, shorter time to market, efficient division of labour, increased co-operation, higher innovation speed, minimization of risk and access to science (PwC and Strategy&, 2015).

4.1.2 Resource efficiency

Long term manufacturing efficiency is key feature of successful manufacturing industries. Analysing the machine data, monitoring health of production systems, utilization of fewer raw materials, and using less energy help to increase the resource efficiency. PwC and Stretegy& (2015) claims that their survey results indicates digitalization increases the resource efficiency by an average of 18% in next five years. Implementing CPS will reduce the redundancies in the process, increase quality of products by monitoring the health of the machinery, flexible process and focusing on core areas. CPS also offers controlling physical systems by analysing the big data which reduces the rejection rate in production. The other benefits of CPS that increases resource efficiency are, increased cost benefits, safety, and life cycle of product off grid etc.

4.1.3 Investments and Profits

Digital transformation to Industry 4.0 is very expensive but comes with myriad opportunities. 235 German companies surveyed by PwC and Strategy& (2015) found out that the companies want to invest on an average 3.3% of their annual revenues towards digital transformation until 2020 and these investments will double in the next decade. The survey also revealed that manufacturing, automation, process, information, and electronic companies are focussing more into these investments. The companies surveyed are optimistic about the gains from the very first year of investments. Around 18% of the companies agreed that the gains will be as high as 20% in five years but on an average 12.5% increase by 2020. Moreover, some of the companies surveyed already have digitalized solutions and have seen an increase of 6-10% revenue growth per year.

4.1.4 Data availability

As mentioned in the previous chapter availability and integrity are the key features of CPS and availability shouldn't be restricted for security reasons. Data availability increases with integration of value chains, increasing number of sensors and electronic systems connected to physical systems. In the report by PwC and Strategy& (2015) half of the companies surveyed agreed that analysis of data is highly important for business models and it significantly affect the way present industries operate. CPS is estimated to have potential competence in efficient exchange of data, effective utilization of labels, real time data availability, analysis of large data and creation of new data for future reference.

4.1.5 Digital business models

In the course of digital transformation, digital service elements will increase in particular connectivity between physical systems as well as manufacturing elements. The consequences are ultimate value added services to customers. The current business models will be changed permanently and new business models shall evolve. The business models not necessarily incremental sometime disruptive too. These disruptive business models enable disruptive innovations so that industry will change permanently in a short time. The survey by PwC and Strategy& (2015) concluded that business models shall change in Industry 4.0 and facilitates stronger digital networks with customers and suppliers, expansion of digital services, and secured networking. New business models with CPS will expand the portfolio of existing products to ensure the future demand of the products.

Baheti & Gill (2011) foresee plenty of opportunities that CPS can offer in the fields of medicinal, biomedical, neuroscience, healthcare, and air traffic etc. As the scope of this thesis is on manufacturing industry the details are not deviated to other fields. It is further recommended to read Baheti & Gill (2011) at reader's convenience.

4.2 Key challenges

Implementation of CPS in future manufacturing systems holds many challenges in the fields of standardisation, infrastructure, employee qualifications, security, investments, unclear profits, data mining, legal status and various R&D challenges. The following sections briefly presents key challenges that CPS facing today.

4.2.1 Technology integration and Standards

Important feature of CPS is to integrate production engineering, mechanical engineering, process engineering, automation engineering, and Information and Communication Technologies (ICT). In order to integrate the cooperation among the entities is necessary. Even though many standards exist in individual fields yet the common strategies to integrate them are still lacking. When surveyed 253 German manufacturing companies lack of standards in CPS is agreed as the 3rd most serious challenge with 26% of respondents agreed on it (PwC and Strategy&, 2015).

4.2.2 IT Infrastructure

Implementation of CPS goes hand in hand with IT infrastructure and maturity of the technology. When Deloitte (2014) surveyed Swiss manufacturing companies 48% of the respondents has partly supported architecture and 20% has no architecture for digital transformation. In most of the cases implementation of CPS needs completely new architecture which has to be developed from scratch. Different business segments such as supply chain, logistics, finance, manufacturing, and R&D needed to be integrated with

CPS which is time consuming and tedious. In a collaborative CPS, different manufacturers produce different formats of data and it is impossible with current infrastructure and technology to integrate and analyse such data (Yue et al., 2015). A simple, scalable, secured, and affordable broadband infrastructure for users is an effective requirement for CPS (Kagermann et al., 2013).

4.2.3 Talent

Digital transformation brings new challenges to companies especially with the competence of employees. The industries are unclear where they need skilled workers because of uncertainty about the technology infrastructure of CPS. In their survey directed to German manufacturing companies PwC and Strategy& (2015) reported that 30% of the companies have insufficiently qualified employees to fulfil the requirements of CPS. In the survey directed to Swiss manufacturing companies by Deloitte (2014) reported that 80% companies said that they have skills in certain areas and 16% accepted they lack sufficient skills to digital transform. Educational reforms are necessary to implement CPS in manufacturing industries. Chapter 7 discusses the possible strategy for training and development for employees to work with CPS.

4.2.4 Cyber risk

CPS are prone to attacks and the consequences are destructive. Security challenges are different from technological challenges as they have to address commercial, psychological and educational issues (Kagermann et al., 2013). At present tailored security solutions for CPS are non-existing because so many discrepancies in the architectures of CPS. In previous years', smart power grid applications powered by SCADA suffered cyber-attacks by malwares such as Stuxnet and flame. As mentioned in the previous chapter 36% and 48% of Swill manufacturing companies respectively agree and strongly agree that the CPS further increase the cyber risk (Deloitte, 2014). In CPS all the machineries are connected and run by prewritten program. If an attacker runs a malicious software to the machineries, it could give a devastating blow to companies. It is equally important to segregate useful data with rubbish to avoid latency in the data security (Yue et al., 2015). The security solutions in CPS should not only prevent the cyber-attacks but also address how to deal with them. Security is given highest priority in the proposed architecture of CPS.

4.2.5 Miscellaneous

Some other challenges in implementing CPS are mentioned in PwC and Strategy& (2015), Yue et al., (2015), Monostori (2014).

In the survey by PwC and Strategy& (2015), 46% of the respondents said the economic benefits of CPS of unclear and the initial investments are very high. 30% of the respondents are curious about the legal situations in different countries regarding access to external data. The countries policies regarding open access are different from one another, so it is very tedious task to bring countries to consensus about external data. 18% of the respondents claim that top management not prioritising digital transformation to Industry 4.0. Network stability and data backup are also seen as major challenge among 6% of the respondents.

Data mining is a key R&D challenge and the aim of data mining is to discover novel, useful patterns from the large data and extract meaningful information from it. Data mining also aims to generalize the results to new data. In CPS large amount of data with different formats is received by big data, it's a very huge challenge to segregate useful data from received data. Most of the time received data is redundant and has no significance in generalization. Moreover, it's not guaranteed that the data received is structured. Sometimes, semi-structured or unstructured data is received and to extract meaningful data it has to run through a different algorithm. This may increase latency in data mining or stall the whole process.

Some other R&D challenges are development of context-adaptive and autonomous systems which means intelligent data recognition, analysis and generalising IT systems. Development of cooperative production systems, human-machine interface, and human-robot symbiosis. The other R&D challenge which is a point of discussion in few literature is real time processing and reliability. Each industry is different from another and so there must be different algorithms to monitor and control these systems to ensure reliability, efficiency and high throughput to the process. Real time processing can be achieved to remote control through mobile devices, and wearable devices etc. Model based development is one of the key challenges so it is important to spread awareness of models, methods and tools, especially in SME's to optimize their manufacturing processes. The next section discusses existing and potential applications of CPS.

4.3 APPLICATIONS OF CPS

CPS will have ample benefits in the fields of transportation, manufacturing, medical, electric power, water distribution, navigation, and logistics. Automation is a part of CPS but CPS doesn't only mean automation. Some of the existing benefits are mentioned below.

4.3.1 Health care and Medicine

Digitalization in the field of health care and medicine is not new. The health care system network includes electronic patient record, home care and an operating room (Shi et al., 2011). In future CPS in medical and health care services can make use of wearable devices to monitor the health condition of patient continuously. Expert services can be offered remotely using CPS. Figure 12 shows a CPS architecture for healthcare system (Haque et al., 2014). More complex healthcare architecture based on CPS can be found at Wang et al., (2011).

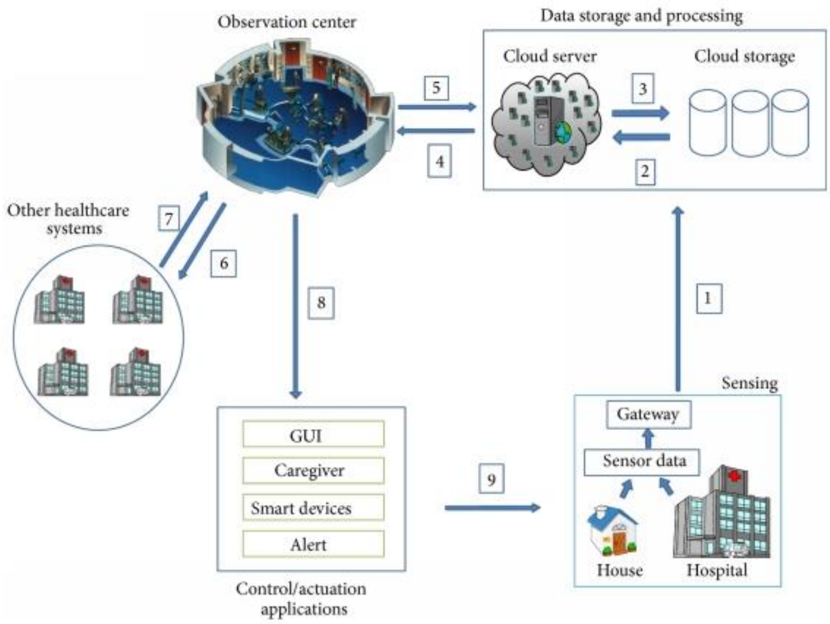

Figure 12: CPS architecture of Healthcare system

In the figure 12, 1) data collected from patients sent to cloud 2) Processed data sent to server and queries are answered real time 3) data retrieval when necessary 4) calculated data is analysed and sent to observation centre if necessary 5) Help from observation centre 6)7) interactions with other healthcare systems 8) control and actuation 9) necessary treatment conducted on patients

4.3.2 Structural collapse and Natural disaster management

Collapse of civil structures such as buildings, bridges while construction as well as after construction is dangerous to people and assets. Smart miniaturised sensor nodes can be developed using cost affective microcontrollers to measure vibration, moisture, temperature, pressure, and force etc. (Krishna et al., 2015) and the data can be transferred to centralized gateway to monitor structural health and pre warn as well as suggest to avoid above situation.

Natural disasters like Tsunami, Cyclones, Floods and Earthquakes costing thousands of lives every year. CPS can provide effective disaster management systems through integrated sensors like acoustic, ultrasonic, and vibration sensors. These sensors can pre warn places where natural disasters occur frequently based on historical data regarding the potential occurrence of the disaster.

4.3.3 Intelligent driverless vehicles

Google is working on self-driving cars by using the advanced sensor and embedded technology and their testing fleet already drove 1.5 million miles (Google, 2016). Driving patterns of the vehicles can be stored in order to enhance driving experience. Shi et al., (2011) extends the concept to intelligent roads with unmanned vehicles to provide more safety solutions to unmanned vehicles. These vehicles can be used in advertising, taxies, home delivery services, and transportation with added value to customers. Figure 13 shows a prototype architecture of intelligent road and unmanned vehicles powered by CPS.

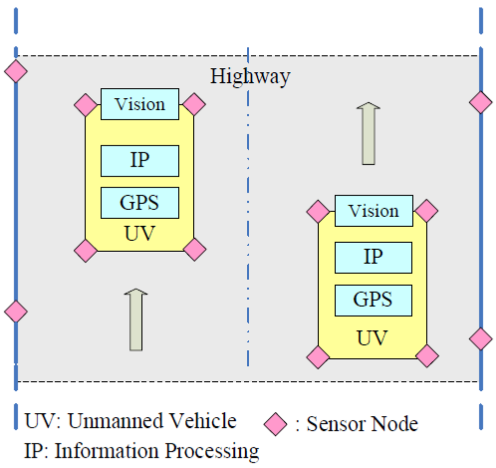

Figure 13: Application of CPS: Intelligent road with unmanned vehicles

4.3.4 Custom manufacturing

Today's automotive industry is characterised by static manufacturing lines. The use of IT systems such as Manufacturing Execution Systems (MES) designed based on the production lines' functionality and can execute predefined action. These monotonous systems restrict the mass customization to include an element from another production line. For example, car A has good mileage and car B has appealing seat design, it is not possible for the customer to include the element from car B to car A. As shown in figure 14, tomorrow's production lines are digitally connected using CPS. The systems are designed to configure and reconfigure based on the customer needs. The IT systems in tomorrow's production line from design to assembly and operation (Kagermann et al., 2013).

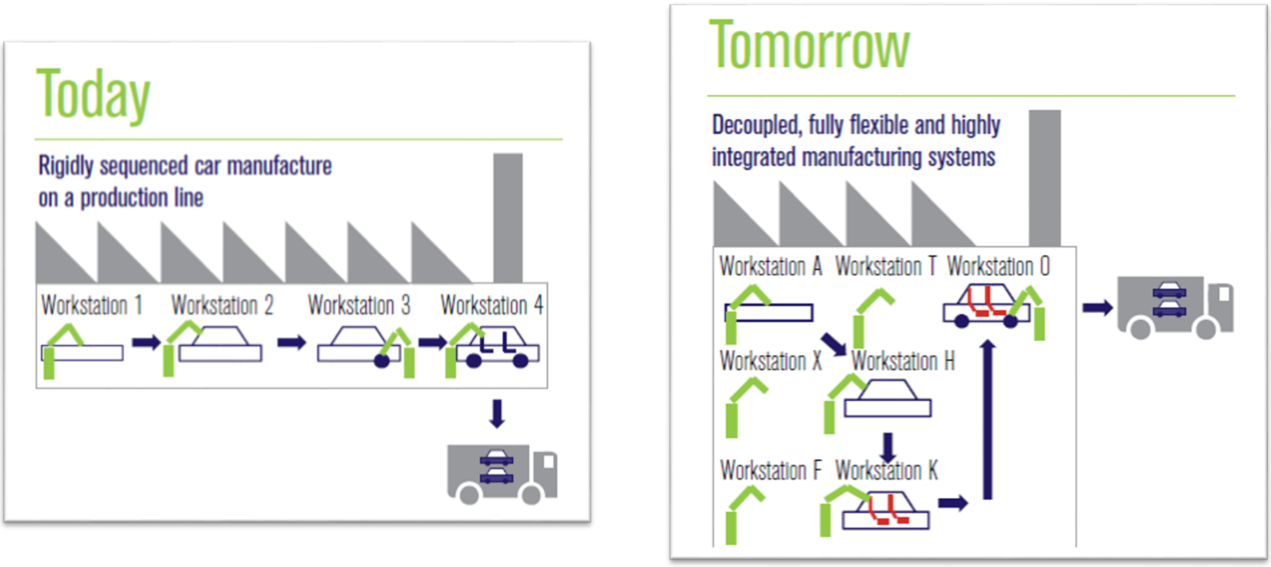

Figure 14: Today Vs Tomorrow's production lines

4.3.5 Supplier crisis

Some circumstances are beyond manufacturer's control such as supplier failure or crisis during manufacturing. Lean manufacturing systems suggest to have at least two suppliers for the same product but still many manufacturing companies are dependent on single supplier and whose failure drags manufacturing in a jeopardy for some time. Industry 4.0 powered by CPS will simulate all inventory levels, transport and logistics based on historical patterns. In the sudden crisis of supplier, CPS's extensive network will be beneficial to use. It is always possible to have alternative suppliers and their capacity in real time (Kagermann et al., 2013).

4.3.6 Telepresence

Remote services have been integrated into manufacturing industries to provide fast and effective services to customers by accessing and controlling machines remotely using modems. This approach has reduced unexpected stoppage and downtime of several customers across the world. The expected potential Industry 4.0 no longer require technicians to manually access and control the machines instead machines will connect to networks in order to search for experts. The experts can integrate knowledge platforms and engineering methods to perform maintenance remotely and efficiently. At the same time machine under maintenance enhance its own capabilities by updating related function via standardised platforms. Figure 15 (Kagermann et al., 2013) depicts difference between today's and CPS powered tomorrow's remote service platforms.

Figure 15: Remote services: Today vs Tomorrow

Research projects under European Commission (EC) focussed on experiments to address the challenges while implementing CPS in manufacturing industry. Workshops and projects under EC can be found online at (EU, 2016) & (EU2, 2016).

Next chapter clearly explains the methodology followed to carry out this research in manufacturing companies.

5.0 METHODOLOGY

This chapter is dedicated to present and discuss the choice of selected methodology for this research work. Research purpose, research approach, and data collection methods are outlined along with validity and reliability of the research is justified.

5.1 RESEARCH PURPOSE

The purpose of the research is to answer the questions posed using scientific procedures with an aim of finding out the truth which is hidden and not discovered yet (Kothari, 2004). According to Saunders et al., (2007), depends on how research questions are formulated the purpose of the research either exploratory, descriptive or explanatory study. Moreover, they illustrated the research purpose is to answer the research questions and objectives of the research. Therefore, according to the research questions posed in the chapter 1 exploratory and descriptive study is conducted to answer the research questions and research objectives.

According to RQ 1, the purpose is identified as exploratory as it was described to explore the possibilities of implementing CPS in Norwegian manufacturing industry. CPS are under developing stage and they are not yet implemented anywhere in the world. In this scenario choosing explanatory study to justify the implementation of CPS is invalid. Therefore, exploratory studies are conducted for the research.

RQ 2 focuses to integrate lean and CPS which are assumed two different manufacturing systems and RQ 3 aims at describing the strategies future manufacturing systems in Norwegian manufacturing industry to produce sustainable products and overcome societal challenges. Therefore, in order to answer RQ 2 and RQ 3 descriptive research is carried out.

Appendix B defines explanatory, exploratory and descriptive research methods.

5.2 RESEARCH APPROACH

According to Bryman & Bell (2011) deductive research is used to understand the relationship between the theory and research, whilst, inductive research is to arrive at a theory from findings of the study. In this research, the approach of inductive research is carried out as the CPS are relatively new in Norwegian manufacturing industry. In particular cases such as security management, sensor technology, lean manufacturing, and CPS architecture the study uses prior research to establish suitable reference architecture for Norwegian manufacturing industry. Therefore, this research is a combination of inductive and deductive approaches. Moreover, research strategies are as important as research approaches. The following are the four potential research strategies that are widely used in research: logical theoretical approach, quantitative experimental approach, qualitative, observational approach, and participatory action research (Idi.ntnu.no, 2016). Look up appendix B for the definitions of different research strategies.

As this research is a mixture of inductive and descriptive approach the strategy is chosen as qualitative, observational research strategy. The design opted for the research is case studies of different manufacturing and R&D organizations in Norway and structured interviews with them. Case studies and interviews are conducted in order to understand the scope of CPS in Norway, manufacturers own perception about CPS, R&Ds vision about CPS, and real time challenges in implementing CPS. Therefore, multiple case studies are carried out in this research which allows to explore common areas of interest and unique challenges that can be prioritized.

5.2.1 Multiple case study approach

Saunders et al., (2007) illustrates the purpose of multiple case study as, "whether the findings of the first case occurs in other cases and, as a consequence, the need to generalize from the findings". Moreover, multiple case study approach is more favourable than single case study (Yin, 2003) because of the strong justification is indeed results from it. In order to justify whether the theory will be generalized among a set of population, in multiple case study comparisons of two or more cases are to be conducted (Eisenhardt, 1989).

In this research multiple case study approach is adopted as a part of qualitative, observational research strategy. This approach investigated different focus groups from manufacturing industry to R&D organizations in order to understand the perspective of manufacturers towards research trends in next decade, to explore the possible opportunities and challenges of CPS in Norwegian manufacturing industry, to find how to integrate lean and CPS, and also to observe the digital transformation to Industry 4.0

in depth. This study is designed to explore in depth knowledge with regards to suitability of CPS in Norwegian manufacturing industry and inputs to SRA 2030.

5.3 Data collection

Data for this research is collected from different sources to answer the research questions and meet the objectives of the research. The data includes direct data from relevant respondents and indirect data from reports and literature online. The data collected in this study can be divided into primary data and secondary data as per the source of the data.

5.3.1 Primary Data

Primary data is first hand data collected from relevant experts in the area of research, in this case, CPS and manufacturing strategy. The source of data in qualitative, observational research strategies can be from structured interviews, qualitative questionnaire, and site observations. In order to gather the data, in this research, structured interviews are conducted with relevant industries and R&D organizations at Raufoss industrial cluster, Norway. As per Saunders et al., (2007), structured interviews consist of set of predetermined questions and the answers can be processed to derive information and a semi structured interview uses a list of themes whereas in unstructured interview, discussion can be carried out on a subject without any questions. In this study structured interviews (Appendix A) are used to collect the data in order to focus on key arears of research based on literature study.

The respondents are selected based on industries and R&D organizations in Norway that are actively participating in conferences related to CPS/ Industry 4.0. Some of the companies are selected based on their expertise in lean manufacturing. The respondents are divided into manufacturing and R&D categories in order see the diverse views about CPS and future manufacturing strategies in Norway. The respondents have basic knowledge about the research area which is a basic before gathering data (Kvale & Brinkmann, 2009). Site visits are also conducted in order to understand the manufacturing process of respective companies. As the CPS is at a stage of development, respondents are chosen from the top management level such as research directors or departmental heads who take part in carving companies strategy for future. Table 2 presents the brief overview of companies interviewed to collect data.

S.no	Name	Designation of the respondent	Focus group	Number of employees
1	SINTEF Raufoss Manufacturing AS	Research Director	R&D	90
2	Kongsberg Automotive	Global head R&D	Manufacturing (Automotive)	>200
3	Nammo AS – Raufoss	Project manager	Manufacturing (Defence)	650

Table 2: Overview of the companies participated in research

5.3.2 Secondary Data

Saunders et al., (2007) defines secondary data as "the data collected by third party which can be realized to gain better understanding of research area". Therefore, the secondary data used consists of reports, reviews, and recommendations made by previous researchers in the area of CPS/ Industry 4.0. In this study numerous reports from Deloitte (2014) and PwC and Strategy& (2015) are used as secondary data sources.

5.4 DATA ANALYSIS

According to Saunders et al., (2007) qualitative analysis need to collect non numeric data which has not been quantified. Structured interviews with the respondents is aimed at exploring the possibilities of implementing CPS in Norway as well as carving future manufacturing strategies. All interviews are face to face, except on respondent emailed the responses. The interviews are performed in English and they were recorded and later transcribed. The data not related to research area are omitted while transcribing the recordings.

Once the data is gathered from recordings, each case is analysed to retrieve the highlights and key points of the research. Then, common areas of challenges, needs, and advantages of CPS and future manufacturing strategies are used to answer the research questions. Cross case analysis is performed while developing reference architecture for CPS, framework and while making inputs to SRA 2030.

5.5 VALIDITY AND RELIABILITY

According to Bryman & Bell (2011) there are four types of validity: *Measurement validity* which controls "whether the measure being used really measures what it claims", *Internal validity* examines whether the conclusions drawn from the research are true reflection of causes, *external validity* examines if the results of the research can be generalised for other groups beyond the scope or context, and *Ecological validity* explores if the findings of the research are applicable to people's everyday life. Therefore, validity focuses on the integrity of findings of the research. However, Bryman & Bell (2011) extends the criteria for qualitative studies by replacing internal validity with *Credibility* to confirm the trustworthiness of the findings. Moreover, *Transferability* replaces external validity, which explores the suitability of results with other contexts. *Dependability* in place of reliability, whether the findings are true for other times and *Confirmability* in place of objectivity, to cross check the influence of researcher on the study and results.

Throughout this research all the dialogues and discussions are documented either soft or hard versions of documents and wherever necessary are produced to supervisors. This way trustworthiness and transparency is maintained so as to fulfil credibility and confirmability. Transferability is assured by clearly specifying the underlying assumptions, in this case, future manufacturing systems in Norway. Applicability of the findings in this research on other contexts depending on how close their policies and circumstances are with Norway. Dependability of the study for near future, let say 5 years is assured and it is subjected to change with the time and advancements in technology.

Reliability is by definition is the degree in which the data collection, analysis will allow consistent findings or McKinnon (1988) defines it as the trustworthiness of the collected data. All the data is collected from academic generals with licensed access, open reports online and experts in the field of R&D and Manufacturing at Raufoss industrial cluster which ensures the reliability of the data.

The interview guide (Appendix A) is of two parts. First part contains 7 general questions related to vision, manufacturing and research needs, and technological developments during 2020-2030. In the second part of the interview guide, the questions are related to industry 4.0/ CPS. The respondents are requested to extend their thinking beyond today's wisdom to answer the questions.

6.0 Results

6.1 Organizing results

The results from interviews with different respondents are organized in a way to explain different expectations about future manufacturing in their companies. As mentioned in the previous chapter the interview guide has two parts. Interview guide is attached in Appendix A for reader's reference.

This section presents a brief overview about the companies and R&D organizations that responded for interview.

SINTEF Raufoss Manufacturing AS (SINTEF, 2016) is a part of largest independent R&D organization in Scandinavia. The organization is certified in accordance with ISO 9001: Quality management and ISO 14001: Environmental management. The centre is owned by SINTEF (50.1%), industry (39.9%) includes Benteler Automotive, Hexagon Composites ASA, Hydro Aluminium AS, Kongsberg Automotive AS, Nammo Raufoss AS, and Raufoss Technology AS, and SIVA (10%). The present R&D projects involves, NAP – to develop technology with zero defect in the fields of automation and industry. SFI manufacturing aims at demonstrating sustainable manufacturing is possible in high cost countries like Norway. Other projects include, development of composite gas pressure vessels for the partners, next generation extrusion and moulding processes for aluminium and composites, adaptive manufacturing, hybrid manufacturing by integrating additive manufacturing with conventional manufacturing, robotic technology, and parallel development of products and processes.

Kongsberg Automotive AS (KA) (2016) in Raufoss is a part if fluid transfer and manufacturing compressed air couplings for brake systems for some of the biggest manufacturers of trucks and trailers. They are continuously working on developing couplings with composite materials in order to reduce wait with increased system efficiency.

Nammo Raufoss AS (2016) is a defence manufacturing giant with around 650 employees and their production activities include, manufacturing medium calibre ammunition, artillery ammunition, rocket motors, environmental and ballistic testing, and non-destructive testing methods. The following section presents the results of part 1 of the interview guide as objective as possible and no interpretations are drawn.

6.2 PART 1

6.2.1 Vision

When asked about their vision for next decade all the respondents want to improve their productivity and innovate new processes for manufacturing. SINTEF thinks that their customers also working on to integrate their global production networks as some of them are currently dispersed. On the other hand, steps towards collaborative manufacturing are initiated in KA. According to a respondent it is very difficult to imagine the vision for 2020-30 because automotive industry is fast changing but they are sure that hybrid solutions like interactive electro-mechanical systems will dominate in the automotive industry.

6.2.2 Research needs and challenges

To the vision mentioned above the manufacturers and R&D organizations working on sorting their research needs along with the challenges. The respondents think that research need to be carried out in processes improvements, development of new composite materials, adoptive production lines (having single production line for multiple products), flexible manufacturing, and interactive automation. The challenges are ranging from high investment cost, high skilled workers at all levels, balance in theory and practice, and reducing offshoring of production.

6.2.3 Technological developments

The respondents were asked what technological developments required to meet the challenges mentioned above. The respondents think it's difficult to mention a few technological aspects but they are confident that new developments are needed in flexible and adaptive production equipment, interactive and cooperative machines, and development of indigenous technology in order to know *how* and *why* locally.

6.2.4 Research topics

The respondents are asked to name any three research topics that ensures the future competence beyond todays potential. SINTEF thinks that their customers need to know the *user patterns* of product in order to know if the product is operating as desired. These user patterns will help the manufacturer to know the life cycle of the product and enable the product improvement initiatives. The respondents also think that *sustainability* tools need to be updated as the current tools are very old and subjective. Concurrency between design and development processes in future need to be addressed in the view of networked manufacturing systems. Smart products and smart processes are also key research interests of automobile sector. The respondent from Nammo thinks that research need to focus on educational reforms to address what kind of workers will the industry need and what kind of education they need to have because of behavioural change in future manufacturing industry.

6.2.5 Competitiveness

The respondents are asked to visualise the competitiveness of manufacturing industry in Norway by considering the significant behavioural changes might occurs in 2020-30. Adopting automation, robotics, and reducing waste levels to zero are obvious answers from respondents. Apart from that, creating new business models where manufacturer can communicate with products in order to sell more services can increase competiveness of the company and adds more value to the customer. It also increases job opportunities because new services need people or SMEs that can work for a big manufacturer. Mass customization and mass production will be the key features that decides how competitive is a particular industry.

6.2.6 Status of lean and Sustainability

Lean manufacturing systems are very well implemented in the companies that responded for interview guide. When asked about the status of lean in 2020-30, the respondents believe that lean is basic platform for any manufacturing model that comes in future. Productivity, reducing waste, increasing quality, and adding value to customers will be key features whatever is the manufacturing model. The present lean systems support *one-piece flow* and *semi automation* but in future manufacturing systems with the advancements of technology and integration of sophisticated IT tools will support lean manufacturing with *many-piece flow* and *complete automation*. Therefore, the basics of lean manufacturing will still survive at every level of future manufacturing systems between 2020-30.

When comes to efforts towards reaching the challenge of sustainability, R&D organizations are becoming part of projects to create awareness in the customer's base. Automotive industry focussing on developing new materials with reduced weight and enhanced strength so that reducing fuel consumption as well as enhancing driving experience. All the companies responded have proper arrangements for health and safety of their employees at work.

In the next part of the interview the respondents are asked 10 questions related to Industry 4.0/ CPS.

6.3 Part 2

6.3.1 Definition of CPS

CPS are in the conceptual stage where different researchers has different definitions. The respondents are asked to define CPS or Industry 4.0 in order to see their perception or expectation of CPS in manufacturing sector.

"It is a bundle of relatively known technologies (Respondent A, 2016))"

"Controlling systems and processes by smart devices (Respondent B, 2016)"

"Connect all machines to a central system. Have total overview over the production and the products at all time (Respondent C, 2016)"

The respondents think that CPS somehow connects all their systems and processes and controlling them becomes easy using smart devices like mobiles, wearable devices, and remote controls.

6.3.2 Impact of CPS

The respondents are asked if the CPS would impact future manufacturing systems in Norway. The responses are mixed. SINTEF thinks that CPS will definitely impact manufacturing systems in Norway. Automotive industry will have earlier impact then process industry and finally home based businesses. KA thinks that CPS alone won't have any impact in the near future and the integration of usage of sensors, robotics, and smart devices is a challenging task. Nammo thinks that its basically evolution rather than any new adoption and the systems and processes are changing for several years already.

6.3.3 Readiness

Respondents are asked how ready are they to digital transform to Industry 4.0, SINTEF believes that in their customer base automotive partners are well prepared to adopt CPS. The other customers may not be adopting it in next 10 years because of challenges such as high investment and unclear potential. KA already has adopted systems towards CPS and in Nammo some departments are well prepared and others are not.

6.3.4 Advantages

According to the respondents, CPS will be advantageous with regards to better process control, real time product life cycle management, tracking user phase product patterns, savings, safety, better quality, customized products, continuous health monitoring of the products, and competitiveness.

6.3.5 Challenges to implement CPS

Some of the respondents are started adopting CPS several years before but the respondents think the following challenges need to be addressed before the implementation: Analysis of big data, not enough skilled employees, security, new recruitment, uncertainty on payback, time consuming, and many interlocks. It Is not possible to switch the plant to CPS overnight but it has to be done incrementally.

6.3.6 Miscellaneous

Currently the lean is implemented in respondent's companies so when asked about integrating lean and CPS, SINTEF thinks that they go hand in hand especially having RFID to know the exact demand fulfils the Kanban and error prevention in manufacturing, monitoring, and smart logistics are called as Poke yoke in lean systems. Quality at source will be ensured in CPS which is again a basic lean principle. The respondents also think that their employees need to be trained and they would like to have one level up in operator's level i.e., an engineer would require to operate CPS at operator's level. Other benefits to customers with CPS are less expensive products, optimization at every level. Smart products will also improve sustainability as they are continuously monitoring the emissions from the product and any abnormalities are reported to manufacturer so that preventive action can be taken earlier. Table 3 summarises the results.

S.No	Topic	Entities
1	Vision (2020-30)	Increasing productivity Global networks Collaborative manufacturing Interactive manufacturing systems Mass customization and mass production Development of interactive processes
2	Research needs (2020-30)	Development of new composite materials Adoptive production lines Interactive automation Sustainability tools Smart products and processes Educational reforms
3	Challenges in implementing CPS	Analysis of big data Skilled employees Security Uncertainty on payback Many interlocks at production Time consuming
4	Advantages of CPS	Better process control than today Real time product life cycle management Tracking user phase product patterns Savings Safety Better quality than today Customized products Competitiveness

Table 3: Summary of results

7.0 DISCUSSION

Implementing CPS as future manufacturing systems in Norway is a challenging task and barriers such as investments, policies, standards and payback need to be addressed clearly before taking any step further. It is identified from results that the challenges are different from different types of industries. Automotive industry will be the earliest industry to adopt CPS in Norway. In terms of digitalization and automation the companies can be divided into 4 groups as follows;

Pioneers are the companies with advanced technology involved in developing suitable technologies for CPS. Unfortunately, Norway doesn't have any notable pioneers in CPS. The barriers are shortage of specialists in the field of big data and data analysis, advanced sensor and control technologies. Current policies in Norway such as *iKuben: Manufacturing Network 4.0* (Ikuben.no, 2016) are aimed to strengthen their existing manufacturing problems such as competitiveness and high production costs by digitalizing the value chain and adopting ICT solutions but the focus is not on developing digitalization solutions. Interested pioneers in Norway should focus on research and development funds from European commission, for example H2020 and collaborate with Industry 4.0 technology centres such as *Catapult Centres* in UK and *Pilot Factories* in Germany.

Early adopters are the companies who adopt CPS in their industries while the technologies are in developing stage. Early adopters are risk takers ad they test and validate CPS and their suitability in manufacturing industry in Norway. Early adopters will effect policy design of manufacturing industry in particular countries. NCE Raufoss (2016) is an industrial cluster of 17 partner companies developing lightweight materials and automation in Norway. The respondents of this research are also situated in this industry cluster. Automotive industry in Norway will be the early adopters to test CPS in manufacturing industry. It is beneficial for early adopters to incrementally integrate CPS in the system but not whole plant at a time. Infrastructure and skill set of workers for test facilities is still a barrier in early adopting CPS in Norway. Early adopters will be the pioneers for new business models of CPS in manufacturing industry in Norway. The project iKuben falls under adopting CPS in Norwegian manufacturing industry to overcome the existing challenges.

Late adopters are the companies that adopts CPS in their operations when they get to see advantages from early adopters. Late adopters also facilitate testing and validation of CPS just before mature technologies available for everyone. In Norway, process industries such raw materials processing, paper companies, chemical industry, and food processing can be late adopters. The risk on returns is comparatively low when compared to early adopters but a key barrier is investments and time until first return on investments.

Followers are the companies who adopt mature CPS in their manufacturing industry. The risks are comparatively less or negligible because of developed and proven technology but key barriers include skill set of employees, customization at desired level, and lack of risk capital. Implementation of CPS will give enough opportunities for the establishment of new SMEs and start-ups in the fields of analysing big data, managing backups, training and certifications, and service industry. New employment opportunities to skilled employees can be guaranteed.

7.1 Strategy for future manufacturing systems in Norway

Currently Norwegian manufacturing industry is organized to overcome the challenges like reducing production cost locally, create more opportunities, innovation through product networks, fusion to global markets, and increased use of IT solutions in manufacturing industry. The proposed strategy focussed to address these challenges based on the potential of CPS.

7.1.1 Global networks

Most of the Norwegian industries get funding from Norwegian innovation cluster program supported by government. These clusters play a major role in deploying CPS into Norwegian manufacturing industry which will not only increase the efficiency of the production but also increase the productivity. CPS offers wide variety of information related to suppliers, services, and customers. The key here is to have them connected through digital solutions. Global networks have the information related to suppliers from various countries and competition among suppliers will be the driving force of innovation. Key feature in connecting global networks is that the IT technologies needed to be adoptive to the specific requirements of manufacturing and continue to evolve with the same agenda. The current business models don’t support digital transformation and so new business models need to be developed in collaboration among industrial clusters in Norway.

In order to gain global customer base, it is not only important to provide quality products but also provide end-end engineering services throughout the value chain. CPS provides platform to connect to the products in user phase. These off grid connections to products offers to monitor product life cycle, future demand, and increase cost savings to customers. To analyse data and segregate useful data from rubbish new people with expert skills are required. New start-ups and SMEs will have an opportunity to grow providing thousands of jobs in Norway. The future manufacturing strategies need to prepare SMEs for structural transformation which is a prerequisite for CPS in order to integrate large enterprises with SMEs. Therefore, technology transfer from large scale to SMEs is inevitable with which both parties have advantages.

7.1.2 Digitalization of hybrid value chains

Actual benefits of CPS will only be possible to deliver if the entire value chain of the manufacturing systems are coordinated. Therefore, the strategy to implement CPS should consider the four key features as follows,

- Integration of horizontal value chain networks
- Integration of vertical value chain and manufacturing system within business
- Through-Engineering services throughout the value chain networks
- Adopting exponential technologies to the value chains

Integration of horizontal value chain networks: Supplier, company and customer are the parts of horizontal networks. Digitally integrate them optimizes the flow of materials from supplier to company, company to customer and back. Entire value chain will be aware of product at any time through internet of things. Optimization and mass customization, transparency, fault tolerance and value addition to customer are obvious benefits of it. The data related to product from raw material extraction throughout the life cycle are stored in big data for future use. This integration needs a completely new business models, standardized strategies, and staff training programs. Legal issues and questions of liabilities are not addressed by current laws in Norway and lawmakers need to collaborate with business clusters in order to enact new laws to protect the integrity of manufacturing systems in Norway.

Integration of vertical value chain and manufacturing system within the business: On the other hand, vertical integration integrates total business system from sensors on the machines to ERP. When vertical value chain is digitalized and connected to CPS all other parts of the organization becomes transparent to suppliers and customers. For example, analysis of big data forecasted the demand for next month and the data is available for specific suppliers on the cloud. It makes it possible for suppliers to supply raw material on time.

Through-engineering services throughout the value chain networks: Services add value to customers. CPS make sure that all the necessary services throughout the product life cycle are available at right time enabling new scenarios where customers need not worry about future system failures. Through-engineering services will directly be reason for the establishment of new SMEs and start-ups providing new job opportunities.

Adopting exponential technologies to the value chains: The technology is changing exponentially these days and Industry 4.0 in Norway should be adopting the new solutions time to time. Technologies such as artificial intelligence (AI), advanced robotics, 3D printing, sensors, and actuators need skilled employees to work them. AI will help not only driverless transportation in the smart factory but also reduces the time and cost in supply chain management. In analysing big data and increasing interface between machine and human will also be possible with AI.

The available work force in the researched companies are not trained to work under CPS. Therefore, the next major step is to have a teaching factory with the collaborations of academia and R&D organizations. Teaching factories facilitate knowledge-based manufacturing by training employees to gain multidisciplinary skills. The objective of a teaching factory is to provide qualified personnel to the CPS powered manufacturing industry. these factories will become the platforms for knowledge transfer, and innovations in many different fields.

Figure 16 shows the digitalization of hybrid value chains and Figure 17 shows the teaching factory paradigm for CPS.

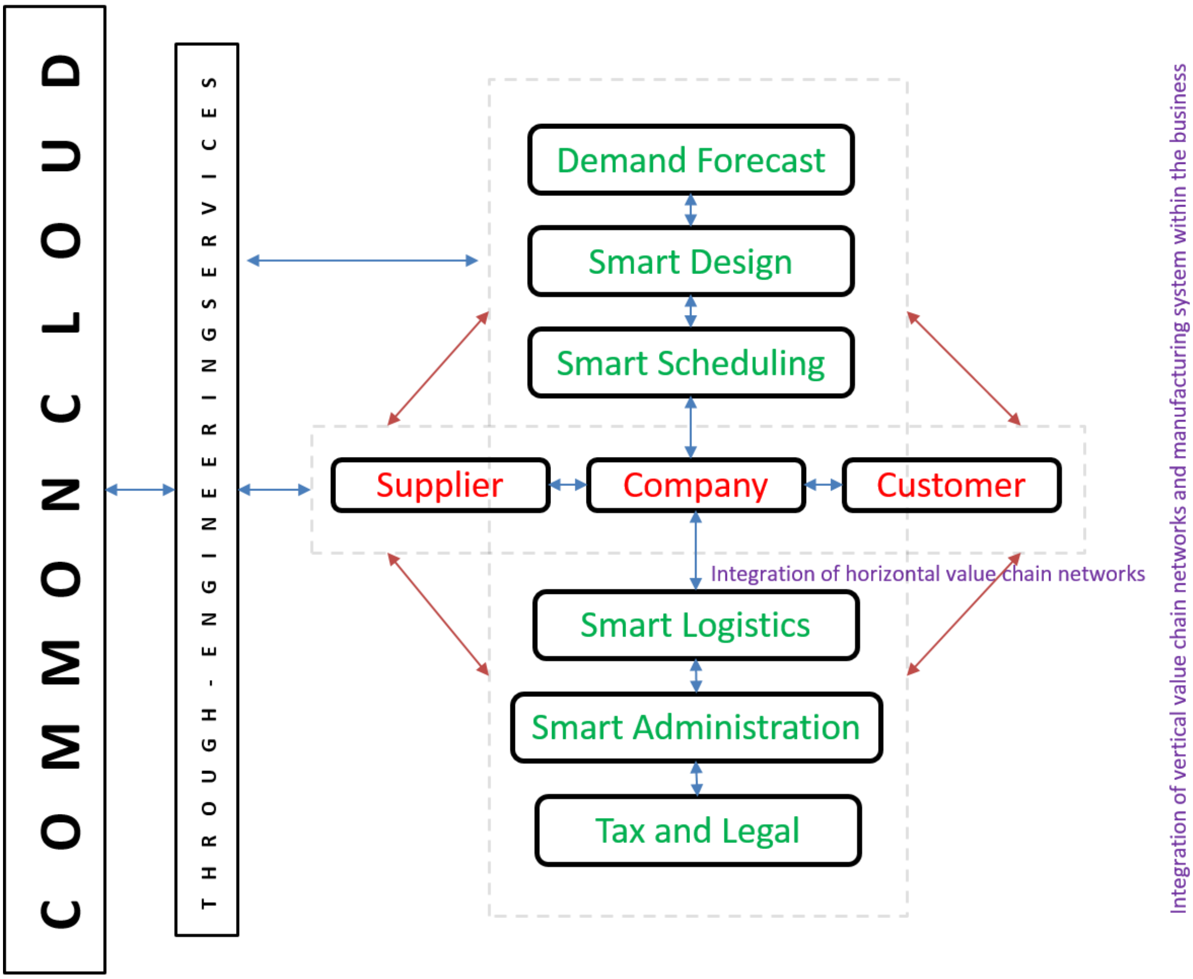

Figure 16: Digitalization of hybrid value chains

In the figure 16 all solid arrows represent bi directional information flow among the value chains. For example, if the company received an order for 20 products it will be updated in the cloud by demand forecast and smart design section starts design which can be altered at any stage of manufacturing. Smart scheduling will be done by proper estimation of stages in the manufacturing and the information is updated to the cloud. Supplier will get the information on need for raw material once the order is placed by customer through the cloud and supply of raw materials will be just in time (JIT) in order to reduce the excess inventory at company. Customer can optimize the design at any stage as per the emergencies, once the manufacturing is done smart logistics will update the delivery date so that the customer is aware of when the product will be delivered at their place. The sensors on the customer's product will continuously monitor and update the machine performance to the cloud so that company can offer value added services to the customer to prevent unnecessary damage.

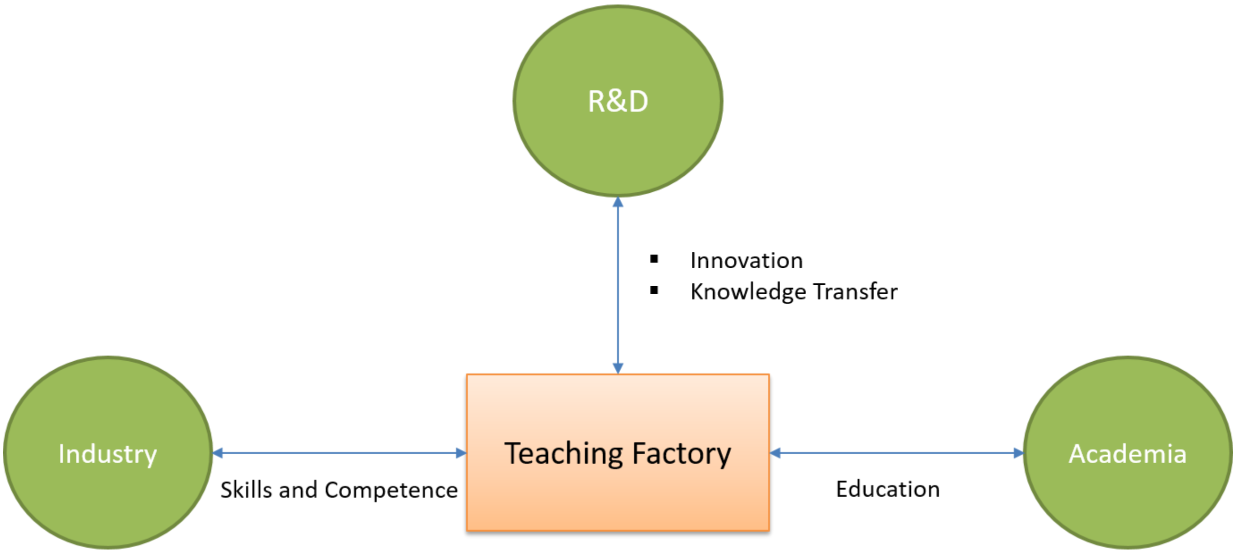

Figure 17: Teaching factory paradigm for CPS

The teaching factory paradigm provides a platform to integrate Innovation, knowledge transfer and education and deliver skills and competence to Norwegian manufacturing industry to adopt CPS. Teaching factories are very well implemented in the health care and prehospital systems and have seen enormous benefits out of it. Teaching factory can be internal and external to the industry but this research supports external teaching factories in order to enable collaborative manufacturing among industries in Norway. Teaching factories also play a major role in establishing new business models in industry, updating industries with exponential technologies, and provide services whenever necessary.

The next section is dedicated to developing a feasible architecture for CPS in order to answer the challenges that Norwegian manufacturing industry while adopting CPS. According to strategy mentioned above collaborative manufacturing, security issues of CPS, and teaching factory paradigms forms basis for the architecture for CPS in Norway.

7.2 ARCHITECTURE FOR CPS

The proposed architecture concentrates on two main features, 1) security, 2) collaborative manufacturing. The reasons are to address the challenges while implementing CPS in Norway. Figure 18 shows the reference architecture for CPS.

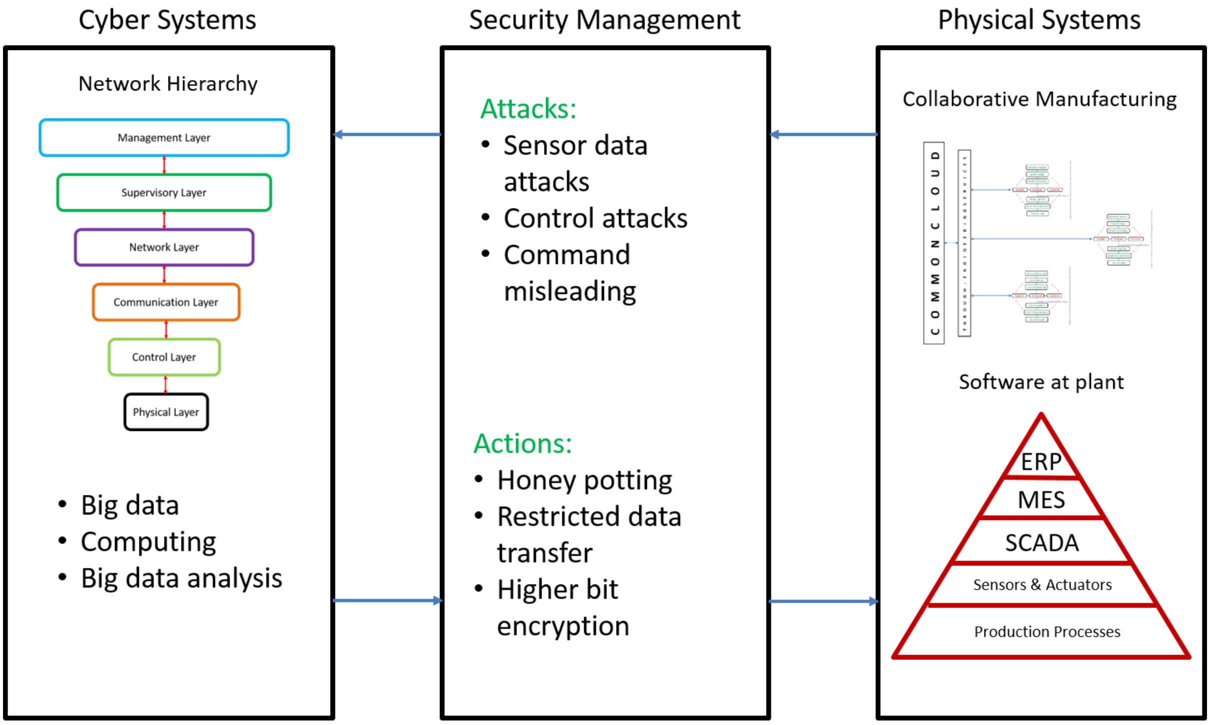

Figure 18: Architecture for CPS

The architecture includes different entities of CPS: Cyber systems, Security management and Physical systems. In physical systems collaborative manufacturing among industries is given a major priority. Collaboration means coordinating with different entities and through CPS one industry can collaborate with another through common cloud. Communication, coordination and cooperation are three characteristic entities of collaborative manufacturing. Communication helps to in information sharing, sense making in complex situations. For example, sharing inventory data with suppliers ensures the raw materials available just in time and in any complex large scale simulation projects companies can use the competence between collaborative partners. Coordination among industries help to extend business services where company physically not presented but through partners. The third entity, cooperation indicates the overall goal and the importance of reaching it. The competence of a company in the global markets depends on their cooperative partners and services. Collaboration also increases the decision making capacity of industries in Norway. Figure 19 separates collaborative manufacturing from the reference architecture of CPS for the visualization purpose.

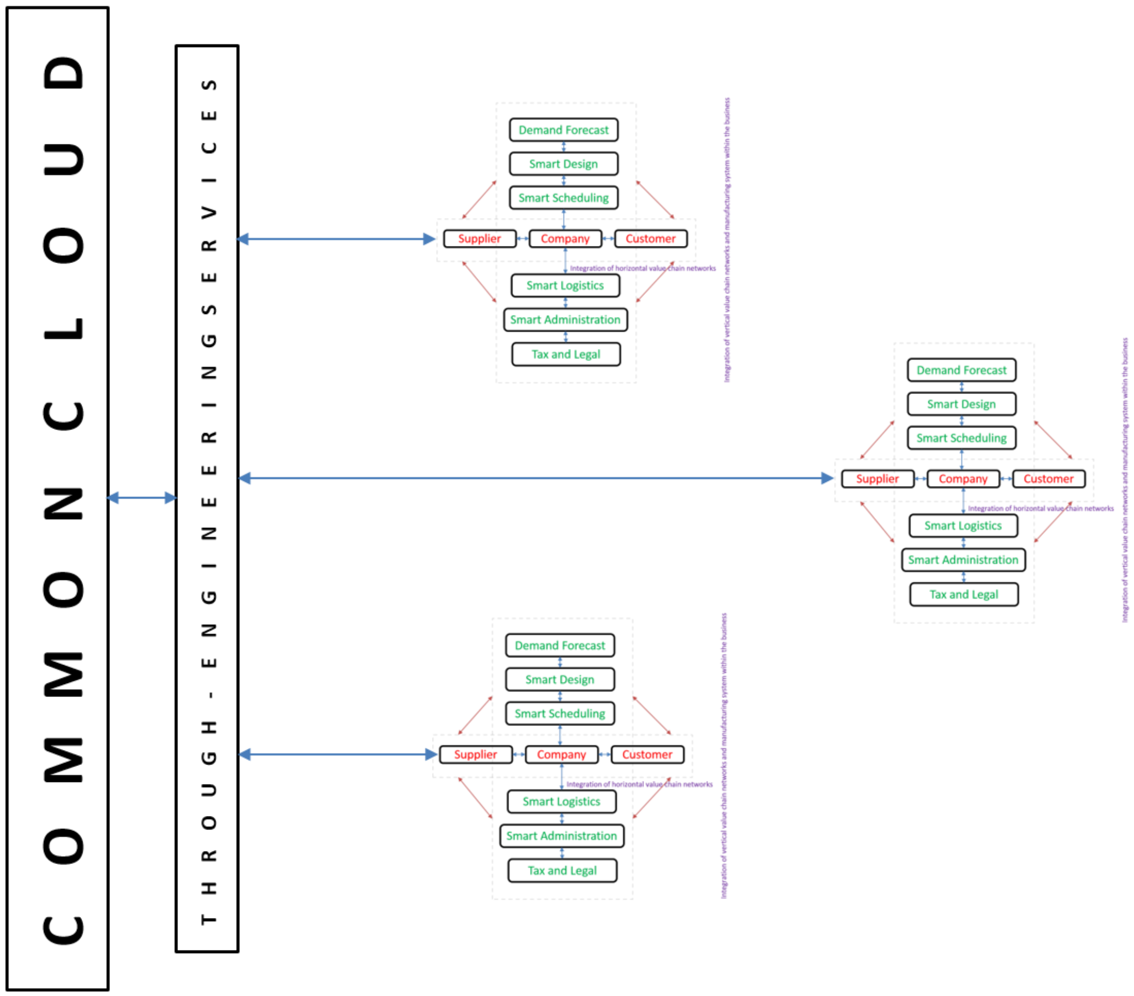

Figure 19: Collaborative manufacturing in CPS

The next entity in the architecture is *Security management* which is widely considered as the greatest challenge while dealing with CPS. CPS need custom made security tools and current IT security tools can't fulfil the desired goal. The areas which are most vulnerable to security attacks are: sensor data, control signals and commands from cyber systems. Attack on these crucial parts will not only stall the manufacturing but also destroys the infrastructure. Honey potting, restricted data transfer, and higher level encryptions can be adopted to prevent cyber-attacks. This research is limited to further discuss on security management as the focus is only on identifying different entities of architecture.

Cyber systems are advanced IT systems which are key for behavioural change of future manufacturing systems. Data storage, computing and big data analysis are performed in the cyber space and based on the results control commands are sent to physical systems. Network hierarchy is included in the cyber systems to deal with security issues. Each layer of the network hierarchy has different data access. For example, sensitive business data related to strategies and policies are only available to management layer. This enhances the possibility of restricted data access/ transfer which is an important issue in security management of CPS.

7.2.1 The impact of CPS on industrial services

CPS can affect different business affordances in the manufacturing industry in Norway. As the condition of equipment is monitored continuously resulting in better understanding of performance and status of machines which intern enables engineering better equipment for future by leveraging performance data. Historic performance patterns can be used to prevent the future damage as well as optimization of processes. The customer can be offered with remote controlling services from any part of the world and hence individual services in remote parts of the world can be covered. Maintenance and service activities of the machines can be scheduled more efficiently in order to prevent the undesirable damage to the machines so that equipment downtime is minimized. Increased automation and intelligent control systems enable continuous production even on weekends and holidays. Wearable devices and smart mobile devices provide valuable information to service technicians supported by CPS data in order to increase the service efficiency. Big data can provide data driven services by SMEs and new start-ups to create opportunities and services anywhere in the world. To sum up, CPS can offer enormous benefits in manufacturing, at customer base, and enhance the effectiveness of industrial services.

In the next section driving forces of CPS and necessary solutions are presented as a framework.

7.3 FRAMEWORK FOR CPS FOR MANUFACTURING DOMAIN

The aim of this framework is to identify driving forces that challenges the implementation of CPS and propose valid actions. Figure 20 shows the framework for CPS for manufacturing domain.

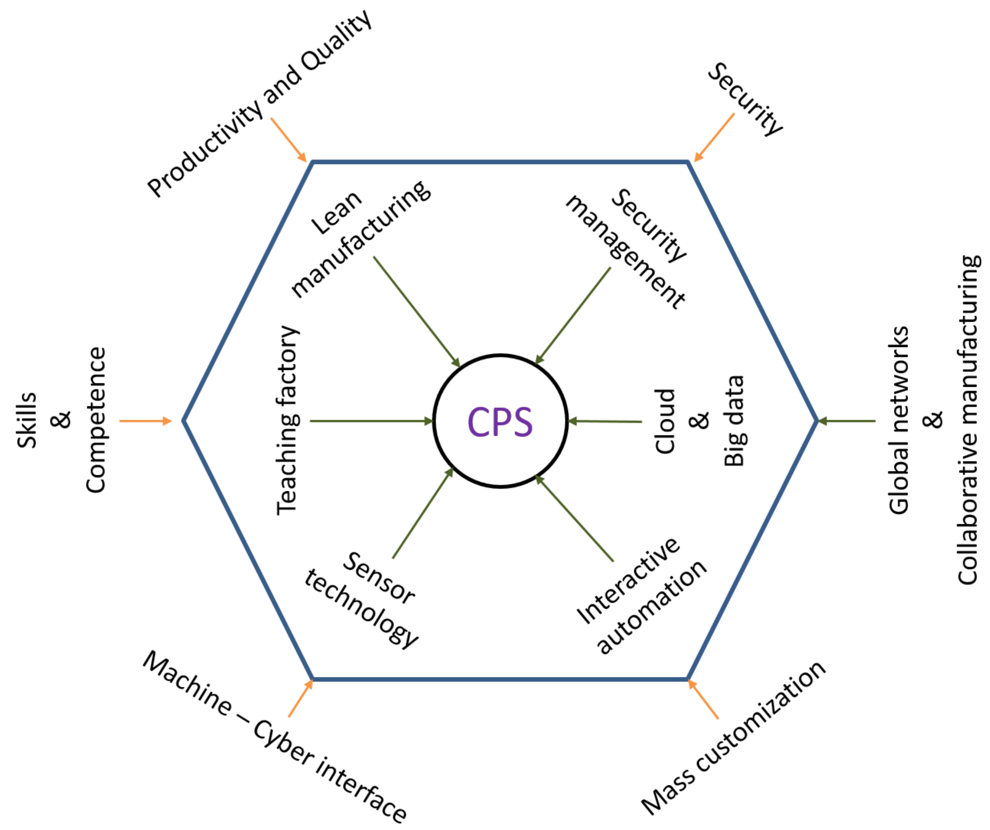

Figure 20: Framework for CPS for manufacturing domain

In Norway, manufacturing industry initiated the efforts towards collaborative manufacturing and entering into global markets where CPS offers cloud & big data solutions. Social, business and technical concerns of the stakeholders must be addressed in order to adopt CPS. Having CPS opens enormous opportunities for cyber-attacks which damages the infrastructure of country and has a strong effect on its GDP. Security management mentioned in the previous sections address this problem in an effective way. Productivity and quality are two never lasting demands of manufacturing industry. Lean manufacturing tools are effective and the same can be adopted in CPS with digitalized techniques. For example, smart Kanban, identifying KPIs based on sensor data, smart logistics, smart scheduling, smart control through mobile devices, and smart process control for quality assurance. Skills and competence lacking is also a driving force and it can be addressed by teaching factory solutions. Advanced sensor technology, interactive automation can give solutions to machine-cyber interface and mass customization. The following recommendations help Norwegian manufacturing industry to effectively implement CPS.

7.4 RECOMMENDATIONS

The following recommendations help manufacturing industries in Norway in the digital transformation towards Industry 4.0/ CPS. As a first step a steering committee with 2 project groups should start working on exploring challenges in implementing CPS. It is strongly recommended to collaborate with different industries to explore challenges which is also a primary step towards collaborative manufacturing at a later stage. Establishing two **project groups** and a **common group** working on different pressing issues in implementing CPS is a first step in digital transformation. Steering committee formed by CEO or managing directors of different companies is to oversee the project groups and support whenever it is required. CPS must be in the CEO agenda before any steps are taken to initiate the implementation.

Responsibilities of project group 1,

- Make a representative survey and explore the pressing issues in modelling CPS in different industries and involve SMEs in the survey. In later stage SMEs will come in handy to provide through engineering services across the entire value chains.
- Contact software, big data and security management providers and propose a common group among them in order to deliver a potential tool to the industrial cluster.
- Analysis of survey results give recommended actions and guidelines.
- Start initiating the implementation in a part of industry as a project in order to explore the real time challenges and benefits.
- Develop a primary framework for implementation of CPS and make it available for public and stakeholder comments.

Responsibilities of project group 2,

- Work towards training employees in gaining interdisciplinary expertise and initiate the development of training factories with the support of common groups, R&D organizations, and academia.
- Provide guidelines to teaching factories on implementing the socio-technical approach together with project groups.
- Establish regular dialogues between all the stakeholders, take feedback and maintain transparency throughout the implementation process.
- Oversee the operations of teaching factory and perform external auditing regularly.
- Initiate work towards exploring the legal issues of data sharing in Norway and support policies towards open data sharing throughout the value chains. Using trade unions as a part of this can accelerate the process quickly and effectively.

Responsibilities of common group,

- Develop security and safety strategies in order to support the architecture for CPS. Research need to be conducted on developing collaborative, open subsystems of different manufacturers.
- Develop security standards and coordinate closely with project groups to see if those standards match physical environment of CPS.
- Develop in collaboration with two project groups a new reference architecture for CPS based by modifying the old architecture.
- Develop tools for security management of products, processes, and all physical devices in the manufacturing industry.
- Before deploying the tools to manufacturing industry conduct pilot test of the tools with real time operators. People tend to avoid non-user-friendly tools and services.
- IT security is a key competence that every employee in organization must know. Common group will develop basic training material for IT security and deploy it to teaching factory.
- Develop solutions towards risks associate with the damage caused by IT failure. It is encouraged to establish IT failure insurance services.

The steering committee also take responsibilities to formulate strategies to migrate to Industry 4.0 with a goal of collaborative manufacturing and data sharing. Include SMEs in all efforts towards digital transformation. In global markets a successful product is prone to piracy and therefore intellectual property protection and necessary steps towards it are an important agenda in CPS.

7.5 INPUTS TO SRA 2030

In the perspective of next framework program in EU (2020 onwards), it's important that every participating country should have inputs to shape a Strategic Research Agenda (SRA) for 2020-2030. These inputs are to SRA are related to manufacturing industry in Norway for next decade and based on the results of first part of the interview guide (Appendix A). The following suggestions explains the needs of Norwegian manufacturing industry to Norwegian government, Norwegian research council and EU to shape future manufacturing systems in Norway.

7.5.1 Objectives

In order to tackle the challenges that Norwegian manufacturing industry facing today such as productivity, global markets, skills and competence, and unemployment the following objectives can be considered in the next framework of EU.

- Encourage innovation in SMEs and connecting them large scale industries.
- Integrate the knowledge quadrangle research, academia, industry, and teaching factories.
- Increase the contribution to research and innovative activities for future manufacturing systems.
- Increase funding to digitalization efforts in large scale companies as well as SMEs.
- Increase contribution to megatrends such as global markets, mass customization, collaborative manufacturing, digitalization, and cyber physical systems.
- Specific focus on legality of open source data sharing to increase communication, cooperation and coordination among manufacturing industries across EU.
- Focus on new sustainability tools for increased reliability of life cycle analysis of products.

- Initiate contribution to development of new standards of digitalization in manufacturing industries.

7.5.2 Research and Innovation needs

In order to address the challenges faced by Norwegian manufacturing industry the following research and innovation domains have to be considered for funding.

- Advanced manufacturing processes in order to reduce the lead time to customer and to increase the productivity.
- Cyber physical systems in order to enhance the corporate base, increase global markets, and more value added services to customer.
- Rapid prototyping and 3D printing.
- Advanced materials research in order to reduce the weight of products and increase strength at the same time.
- Mass customization to increase productivity as well as competence in the industry.
- More sophisticated sustainability tools to find the impact of products on environment.
- Smart products and processes which enables to interact with products in the user phase so that the more value added services can be provided to customer.
- Educational reforms and behavioural research towards teaching factories to enable multidisciplinary competence at the industry level.

7.6 Answers for the RQ's

RQ 1: How to implement Cyber Physical Systems in Norwegian Manufacturing Industry?

Ans: The current Norwegian manufacturing policies support digitalization to face the challenges such as productivity and competitiveness. As mentioned above Norwegian manufacturing industry is placed in *early adopters'* level with regards to CPS. Industry in Norway should actively adopt the developments from pioneers in Germany and UK. In order to implement CPS in Norwegian manufacturing industry, the above recommendations should be considered. Concentrating on teaching factory and developing skills and competence required for CPS through integration of knowledge quadrangle, R&D, academia, industry and teaching factory is advisable. On the other hand, collaborative manufacturing and efforts towards adopting common cloud solutions can be a smart move towards digital transformation to CPS. The suggested strategy in section 7.1 to integrate hybrid value chains with digital networks enables new opportunities for Norwegian products at global markets. The proposed reference architecture for CPS in section 7.2 considered most of the challenges mentioned during interviews with Norwegian R&D and manufacturers. The framework mentioned in section 7.3 is a preliminary study to identify the driving forces and required actions in implementing CPS but it can be modified according to the government policies and regulations of collaborative partners. It is advised to implement CPS as a development project in one part of the industry and incrementally to whole industry.

RQ 2: How to integrate Lean manufacturing systems with Cyber Physical Systems?

Ans: Before this research is initiated lean and CPS are seen as two different manufacturing systems because of the behavioural change in manufacturing. After interacting with experts from R&D and manufacturing industry on how to integrate lean and CPS, the primary hypothesis is falsified. Productivity and Quality are never lasting demands of manufacturing industry. The behavioural change in CPS with the adoption IT tools is an extension of existing lean tools. The change is so rapid that two systems look different but the underlying philosophy is the same. The basic difference in lean philosophy is the flexibility of human labour is used along with one-piece flow, semi automation etc., CPS explores the possibility of utilising flexibility of robotics with the advancements in technology and enables full automation at industry. On the other hand, CPS focussed on digitalizing the value chains and supports collaborative manufacturing by means of common cloud solutions. Usage of sensors, actuators, and smart devices in CPS can be seen as a result of advancements in IT systems.

RQ 3: How to formulate future manufacturing strategies in Norwegian Manufacturing Industry to produce sustainable products and overcome societal challenges?

Ans: The future manufacturing strategies in Norway should be based on the structural and behavioural change of the manufacturing industry. The strategies should focus on digitalization at every level. CPS are model based systems, so the strategies should support best practice sharing particularly among SMEs to promote fundamental importance of modelling. The future strategies should also consider the recommendations mentioned in section 7.4 and establish project groups and common groups for different purposes. R&D and teaching factories supply skills and expertise to the future industry and efforts towards establishing should be considered immediately. Increase the contribution towards collaborative manufacturing in order to enhance communication, cooperation and coordination among industries. Open sharing of data carries legal issues with it therefore work towards proper legal laws to support digitalization are recommended.

Figure 21 (123RF, 2016) shows the interconnection between Research Questions (RQs), unknown X and unknown Y are several uncertainties that are not covered by this research in order to formulate strategies for future manufacturing systems in Norway.

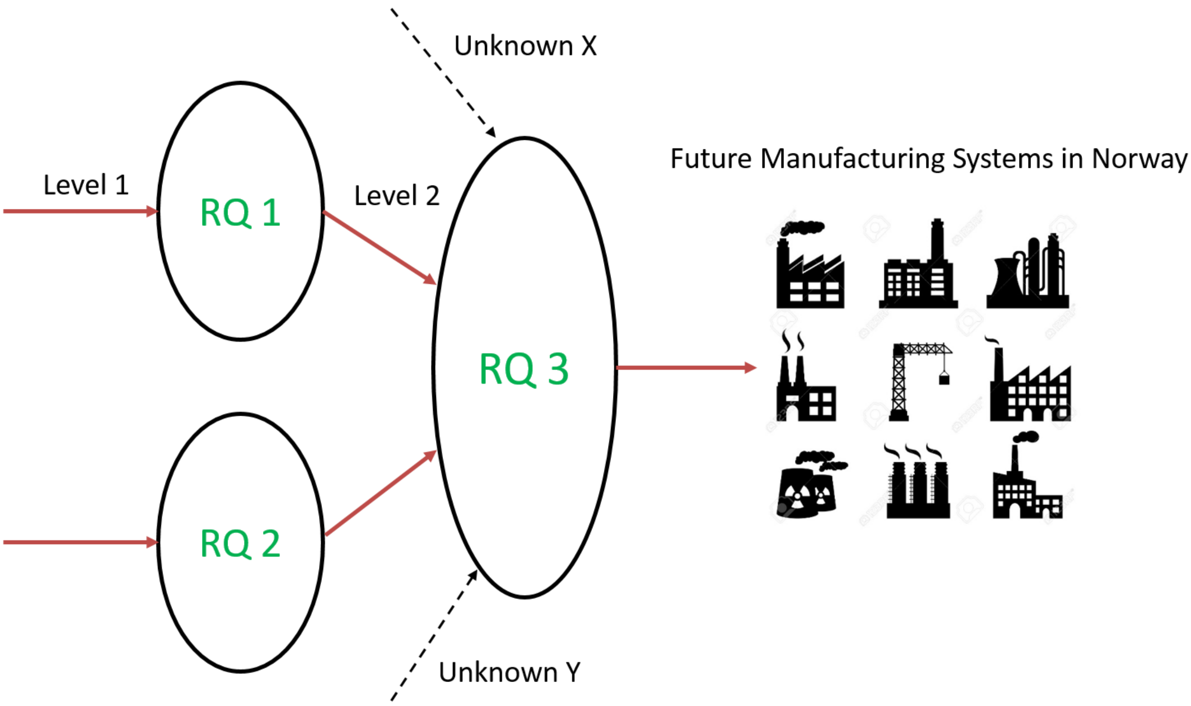

Figure 21: Interconnectivity of RQs

The next chapter concludes the findings of this research along with future work and limitations.

8.0 Conclusion

This thesis presents a deep insight of Cyber Physical Systems and its suitability to future Norwegian manufacturing industry. It emphasis on the integration of SMEs and large scale manufacturing companies to extend today's industrial services to end – end engineering services throughout the entire value chain. Adopting CPS in Norwegian manufacturing industry not only solves real time manufacturing challenges but also increases the number of jobs and new SMEs.

This research provides a strategy to implement CPS by considering the real time challenges in the Norwegian manufacturing industry. Then, the idea of digitalizing hybrid value chains is presented as an enabler for experiencing the actual benefits of CPS. A knowledge quadrangle concept to integrate industry, academia, R&D, and teaching factory is illustrated as CPS needs specific skills and competence from employees. Considering the Norwegian manufacturing industry and its current potential for digital transformation, a reference architecture for CPS is developed with relatively new concepts such as collaborative manufacturing, security management, and network hierarchy in CPS. The idea of keeping a good track of performance patterns of the product during user stage is described to prevent future damage of the product as well as to reduce the equipment down time. Tracking user patterns help the manufacturer to optimize the product to contribute to the sustainability. A key framework for CPS in manufacturing domain is presented with driving forces and recommended actions after carefully analysing the current manufacturing and R&D status in Norway. A step by step implementation guide for CPS in Norway with steering committees, project groups, and common groups is presented which can be effectively utilized in any industry for digital transformation to industry 4.0/ CPS.

As a part of this research inputs to shape a strategic research agenda in the perspective of next framework program in EU between 2020-30 are presented. The inputs to SRA 2030 contains objectives, research and innovation needs of Norwegian manufacturing industry in next decade. These inputs will be used to explain the needs of Norwegian manufacturing industry to the Norwegian government, the Norwegian research council, and the EU commission as background information for shaping future frameworks.

8.1 LIMITATIONS

Some of the areas related to CPS, particularly, analysis of big data, uncertainty on payback, back up mechanisms, and technological aspects are not covered by this research. The qualitative responses are collected from 3 major companies from Raufoss industrial cluster in Norway. The work can be extended to more respondents in order to generalize the conclusions to whole Norway. Suitability of CPS in process industries and home based businesses in Norway are not addressed by this research.

8.2 FUTURE WORK

As CPS is a relatively new area in manufacturing sector this basic research opens the door for further research on CPS. Research on following areas is recommended for future researchers.

- Conduct a quantitative study to confirm the conclusions of this research.
- Develop the reference architecture for big data analysis in order to manage and analyse the continuous data from machines to the common cloud.
- Establishment of teaching factories for CPS.
- Conduct a separate research on suitability of CPS in process industry, SMEs, and home based businesses.
- Development of unique IT and security tools for CPS.
- Development of new standards for CPS in manufacturing domain.
- Work with government to enact new laws that support access to external data throughout the entire value chain.
- Research can be carried out reducing the latency in data mining of big data solutions.
- Research on disaster management using CPS can provide more benefits to society.

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APPENDIX A

Focus Group: Manufacturing Industries and Research & Development organizations

The objective of this survey is to map the inputs from manufacturing industries, research and development organizations and provide a vision of manufacturing needs, strategies and challenges during 2020-2030 in Norway. There are many new trends that experts in the academia are saying but in reality manufacturing needs, strategies are vivid and different from expectations. As a respondent of this survey we want you to **extend your thinking beyond today's wisdom** and think about what your company need to adopt to be competitive in the market. We also would like you to think about what changes may appear in the different segments of the company for example R&D, production, design, marketing, supply chain, services, sales and administration. The change comes with consequences therefore spend some time thinking about positive and adverse consequences of the change.

In part one of the questionnaire 7 general questions are asked and you are requested to think 3 important ideas for each question and discussion will be carried out on the common ideas of the focus group.

1. Describe your **vision** for the company during 2020-2030?
2. For the vision you mentioned what are **the manufacturing needs, research needs** and **challenges** that must be met?
3. In order to meet the manufacturing needs and challenges, what are the major **technology** developments are needed?
4. What research topics must be focussed to develop these technologies (continuation of question 3)?
5. Describe your vision about competitiveness in the manufacturing industry in Norway during 2020-2030 considering significant changes and events that will have occurred by then.
6. Describe the status of lean manufacturing tools that are currently used in manufacturing industry during 2020-2030?
7. How your company planning reach European union's sustainability and societal challenges?

In the second part of the survey 10 questions are asked related to future manufacturing systems/ industry 4.0/ cyber physical systems.

1. How do you define industry 4.0/ cyber physical systems?
2. Describe how strong the impact of cyber physical systems is observed in manufacturing industry?
3. Describe the readiness of your company in digital transformation to industry 4.0?
4. Describe the advantages of cyber physical systems?
5. What are the 5 major challenges of implementing cyber physical systems in existing manufacturing industry?
6. Describe the educational, research and innovation needs in view of future manufacturing systems?
7. Describe how you will integrate lean techniques in fully automated cyber physical systems?
8. Describe the additional benefits for customers after incorporating cyber physical systems in your company?
9. Describe the security issues, consequences and actions in future manufacturing systems?
10. Describe how cyber physical systems help in creating a sustainable manufacturing at your company?

APPENDIX B

Descriptive Studies: "Descriptive studies have more guidelines. They describe people, products, and situations. Descriptive studies usually have one or more guiding research questions but generally are not driven by structured research hypotheses. Because this type of research frequently aims to describe characteristics of populations based on data collected from samples, it often requires the use of a probability sampling technique, such as simple random sampling. Data from descriptive research may be qualitative or quantitative, and quantitative data presentations are normally limited to frequency distributions and summary statistics, such as averages. Customer satisfaction surveys, presidential approval polls, and class evaluation surveys are examples of descriptive projects. (sagepub.com, 2016)"

Explanatory Studies: "The primary purpose of explanatory research is to explain why phenomena occur and to predict future occurrences. Explanatory studies are characterized by research hypotheses that specify the nature and direction of the relationships between or among variables being studied. Probability sampling is normally a requirement in explanatory research because the goal is often to generalize the results to the population from which the sample is selected. The data are quantitative and almost always require the use of a statistical test to establish the validity of the relationships. For example, explanatory survey research may investigate the factors that contribute to customer satisfaction and determine the relative weight of each factor, or seek to model the variables that lead to shopping cart abandonment. (sagepub.com, 2016)"

Exploratory Studies: "The goal of exploratory research is to formulate problems, clarify concepts, and form hypotheses. Exploration can begin with a literature search, a focus group discussion, or case studies. If a survey is conducted for exploratory purposes, no attempt is made to examine a random sample of a population; rather, researchers conducting exploratory research usually look for individuals who are knowledgeable about a topic or process. Exploratory research typically seeks to create hypotheses rather than test them. Data from exploratory studies tends to be qualitative. Examples include brainstorming sessions, interviews with experts, and posting a short survey to a social networking website. (sagepub.com, 2016)"

Logical, Theoretical research strategy: "By a logical theoretical research approach is meant formal deduction of logical consequences from a set of initial assumptions (axioms). If the axioms are true and the rules are logically sound, the consequences are true as well. Idi.ntnu.no. (2016)"

Participatory action research strategy: "Participatory action research refers to a set of approaches to research on social systems in which the researcher actively engages in the process under investigation. Idi.ntnu.no. (2016)"

Qualitative, observational research strategy: "Qualitative, observational studies refer to traditions that base their research upon qualitative data (as opposed to quantitative research) and do not actively and purposely manipulate the phenomenon under investigation. Idi.ntnu.no. (2016)"

Quantitative, experimental research strategy: "A quantitative, experimental approach to doing research is within the classical scientific paradigm of natural, "hard" sciences like physics. The scientific method implies postulating hypotheses, doing quantitative experiments, and then either sustain or reject the hypotheses based on statistical analysis of the measured data (verification or falsification of hypotheses). Idi.ntnu.no. (2016)"