Impact on manufacturing execution systems through the use of smart connected devices

by

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The recent development of smart connected devices, in this paper defined as cyber-physical systems (CPS), within the context of Industry 4.0 presents an opportunity for the manufacturing industry to reach new levels of efficiency. The introduction of novel technologies onto the factory floor will however affect the manufacturing execution systems (MES) currently deployed. There exists an uncertainty whether the existing MES are able to be integrated with these new technologies. This paper aims to identify and investigate the main areas affected by the integration of CPS and MES.

The results, gained through scientific studies as well as interviews with segments of concerned industry and researchers, allowed us to identify six areas that will be affected. Out of the six areas, two have evolved as to be of most interest, namely architectural integration of systems and the human resource area, since change within the other four areas depend on them. We found that an integration of CPS and MES will not be possible unless two key factors are considered, a standardization of communication between systems and a knowledgeable, open minded and inter-communicating workforce.
Den senaste tidens utveckling av smarta uppkopplade enheter, i texten benämnda cyber-physical systems, inom vad som kallas Industri 4.0 medför en möjlighet för effektivisering inom tillverkningsindustrin. Introduktionen av ny teknik inom tillverkningsindustrin kommer dock att påverka de befintliga produktionsstyrningssystemen och det råder idag en osäkerhet kring om en integration är möjlig. I denna uppsats är målet att identifiera och undersöka de områden som påverkas när smarta uppkopplade enheter introduceras i fabriker.

# Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>CPS</td>
<td>Cyber Physical Systems</td>
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<tr>
<td>CS</td>
<td>Control Systems</td>
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<tr>
<td>ERP</td>
<td>Enterprise Resource Planning</td>
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<tr>
<td>IoT</td>
<td>Internet of Things</td>
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<tr>
<td>M2M</td>
<td>Machine 2(to) Machine</td>
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<tr>
<td>MES</td>
<td>Manufacturing Execution Systems</td>
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<td>MESA</td>
<td>Manufacturing Enterprise Solutions Association</td>
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<tr>
<td>PLC</td>
<td>Programmable Logic Controller</td>
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<tr>
<td>PLM</td>
<td>Product Lifecycle Management</td>
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<tr>
<td>RFID</td>
<td>Radio-Frequency IDentification</td>
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<td>SCADA</td>
<td>Supervisory Control And Data Acquisition</td>
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Chapter 1

Introduction

1.1 Background

For more than 200 years, technology has played a dominant role in increasing industrial productivity. Over time, several industrial revolutions have occurred and brought mankind increasingly advanced technologies, see figure 1.1. From horse power to steam power, and from human labour to mass production made possible by powerful machines.

Figure 1.1: The Industrial revolutions up until today [1]
The third industrial revolution, often referred to as the digital revolution, introduced the Internet and electronics, as well as bringing linked computers into the factories.

Today, researchers argue that we face a fourth industrial revolution, often referred to as “Industry 4.0”, where humans, products and machines are communicating within a large system.

The term Industry 4.0 was coined by the German government as a strategy-related project, with the purpose of strengthening the current and future competitiveness of the German industry. This will be achieved through the computerization of today’s manufacturing. The transition is, by some experts, considered to follow ”Moore’s Law”. The law states that technology is doubling its capacity and performance every two years. [2, p. 3]

The enabler for Industry 4.0 is the on-going rapid development within the information and communication technology, and in particular Internet and the embedded system technologies. This development has given rise to several new technologies. The main technology being smart connected devices, in this paper defined as Cyber-Physical Systems (CPS). Other new technologies include cloud computing, big data analytics and the Internet of Things (IoT). These new technologies enable the creation of a smart, networked world where “things” are endowed a certain degree of intelligence, and more importantly, increasingly connected to each other through the use of the Internet of Things (IoT). In the field of industrial manufacturing, the widespread deployment of extensive software and sensors in industrial production unite the physical and virtual world, ultimately giving rise to CPS, i.e. physical objects with embedded software. [3, p. 1]

The fundamental idea of Industry 4.0 is to integrate manufacturing systems of different smart factories along a certain value chain in the form of CPS, in such a way that real-time data and information across the entire chain can be obtained and interpreted. This enables real-time and accurate decision-making. The main attributes of Industry 4.0’s CPS-based manufacturing systems are high flexibility, adaptivity, real-time capability and transparency of production processes. In theory this would result in factories capable of producing increasingly individualized products with higher quality and productivity at a lower cost. Industry 4.0 can be summed up to represent a highly digital and
networked manufacturing paradigm that can satisfy producers’ digital manufacturing and collaboration requirements between them and their business partners. [3, p. 5]

There is no doubt that the transition Industry 4.0 represents will have an impact on the way manufacturing companies structure their production. Today, plenty of different systems exist on different levels within a manufacturing company. Figure 1.2 above displays a factory divided into three system levels with the Enterprise Resource Planning system (ERP) on top, the Manufacturing Execution System (MES) in the middle and the Control Systems (CS) and the bottom level. [5, p. 527]

The ERP system is a package of computer applications, supporting the information needs of an organization. The roots are in the manufacturing industry, in which they are used for managing a number of critical activities. These include supply chain management, sales, customer service and long-term planning of staffing. It is in other words handling operations at a high level of the company where changes happen relatively slow, which leads to a cycle time in the order of days. [6, p. 2] [5, p. 527]

At the other end of the factory are the CS. They are used for handling individual processes within the factory, which makes the cycle-time a critical factor and in the order of milliseconds. [5, p. 527]

The MES exists at a level in-between the CS and the ERP-system. It has three main roles. Firstly, a function of monitoring the on-going processes within the production by collecting data such as operation times, maintenance status and usage of material from the plant. Secondly, it needs to communicate the collected data to the manufacturing environment. Thirdly, data relevant to the production in a longer perspective or relevant
to the company as a whole needs to be communicated to the ERP-system. The MES can be seen as a link between the factory floor, with a short cycle time, and the ERP-system with a longer cycle time. Thus, it has a cycle time in multiples of minutes. [7, p. 2-25]

An extended use of CPS can lead to a connected manufacturing plant, which is often called a smart factory. This will have an impact on all levels within the system structure, from the CS operating on the factory floor to the ERP system managing large amounts of data throughout the company. To avoid creating two separate pools of data and computational power, the mediator in terms of the MES plays a key role. The MES will, however, not be in a steady state, but needs to adapt to the new circumstances.

The main areas of change for future MES include increased demands for computational power, close to real-time functionality (a cycle time converging to zero) and a motion towards a more decentralized data structure. The last caused by assigning smaller mechatronic units a certain amount of intelligence. [5, p. 532] [8, p. 29]

1.2 Purpose

The purpose of this thesis is to identify and investigate the main areas of change in the manufacturing execution systems related to the implementation of smart connected devices within the manufacturing industry. The study will be made based on the views from the users, the developers and the implementers of manufacturing execution systems, as well as from literature and academic researchers. The expected outcome is an overview of the areas, useful for the mentioned three industry players in their future decision making.

1.3 Research question

What are the main areas of change when integrating smart connected devices to the manufacturing execution systems within the manufacturing industry?
1.4 Methodology

Since the topic of this paper is relatively new and lacks extensive records in today’s industry we have chosen to conduct a qualitative research methodology instead of a quantitative. The hypotheses that the qualitative method generates can later be tested with a quantitative method. For instance, since our topic does not represent something that is easy to measure directly, it is wise to first conduct a qualitative research in order to find key points that can be further investigated in the future.

Qualitative methods usually aim to understand the experiences and attitudes of concerned people towards a certain thing [9, p. 3]. The thing being smart connected devices here, and the concerned people being users, developers and implementers of MES, as well as researchers. Some key words here are ”what”, ”why”, and ”how”. Based on these key words we create questions that aim to capture the interviewee’s perspective on the topic, as well as their response to our views.

Based on the qualitative research method we conducted two types of studies, one scientific based on literature, and one empirical. The literature study contains literature on the topics of MES and CPS. The point of the scientific research method is to gather information regarding our research question from up to date scientific articles and identify key areas of change. The empirical study contains people either using, developing or implementing MES in today’s industry. A user of MES is typically a manufacturing company who uses MES in their factories. The implementer is usually a consulting firm that specializes in integrating systems in the factories. The developers are the ones who create and develop the MES. We also choose to include the researchers in the empirical study. The combination of both empirical and literature studies provide us with an answer to our research question. Below follows a more detailed plan for how the two studies were conducted.

1.4.1 Literature study

To get an overview of the topic, specify a relevant research question and to answer that research question we performed a literature study. We selected relevant scientific sources by searching on-line databases continuously during the work. Several sources which in the beginning seemed relevant were later dismissed. The literature consisted of both
primary and secondary sources, mainly in the form of technical reports and journals in the field of production systems and automation. We retrieved a majority of the material on-line, using academic databases accessed via the library at KTH. The manufacturing execution systems and cyber-physical systems were the main areas of investigation during the literature study. In addition, we also carried out an examination of the concept of Industry 4.0 and the so called Internet of Things.

1.4.2 Empirical study

In order to get a deeper understanding of the topic in general and to get a better view of the interconnections between the fields explored in the theoretical framework, we conducted several interviews with researchers within adaptive manufacturing systems and manufacturing engineering.

We then identified groups within the manufacturing industry likely to be affected by the implementation of CPS. Those are the users, the implementers and the developers of the MES. To fully understand their perspective we performed multiple interviews with representatives from each group.
The researchers and the groups within the industry will from now on be called the actors of change, see figure 1.3

During our search for interviews, we targeted companies typical for their group to give a fair presentation of their views. This means that we have excluded a large number of companies from presenting their perspective. It also means that the presented results from the empirical studies are in fact only a representation of what the interviewed actors have stated and might differ from what other actors believe.

We have chosen not to include the names of interviewed people and companies. Instead, we chose to aggregate the results and present them from each actor’s point of view. The interviewed companies are large within their field of expertise, and are considered to be among the largest players on the Swedish market.

The interviews were done using a semi-structured method. Open questions were prepared aiming at letting the interviewee answer freely. The goal of having the questions written down was to make sure that the most important parts of the subject were covered. If we received an answer to a question without it being asked we continued the interview.

In order to avoid confusion we explained the purpose of our thesis and our perception of the related concepts at the beginning of each interview.
1.5 Delimitations

Below is a bullet list, containing the major delimitations of this bachelor thesis.

- The main focus of this thesis is within the manufacturing industry. The empirical results are all limited to this industry.

- All the interviews within the industry were conducted in Swedish industries, however both national and international research regarding the advances within smart connected devices and MES was used.

- The topic of this thesis is partly new (CPS) and has partly undergone a transformation during the recent years (MES). As a result, old knowledge within this area is no longer relevant and we have chosen to focus on literature from 2012 and later. However, a number of earlier sources considered relevant have also contributed to the work.

- Throughout this paper we have chosen to use the term CPS in the theoretical framework. It is thus a synonym for smart connected devices in our definition.

- Since the definition of MES is quite vague, due to the industry often using only the modules they need, our definition of MES is based on MESA’s 11 principles, further discussed in the theoretical framework. We are however aware of the ISA-95 standard that also exists.

- The literature and empirical studies that were conducted when writing this paper were done using a qualitative method, with relatively few interviews. This implies that our empirical study lacks extensive data from several actors within the segments of user, implementer and developer of MES. This also implies that the results are dependant on the interviewees’ position at their company and on their personal views.

- Our paper consists of future outlooks for the MES, with regards to implementation of CPS. Thus it may be difficult to verify our results.

- For future research it would be valuable to conduct a more quantitatively focused study to be able to analyze the industry as a whole.
Chapter 2

Theoretical Framework

In order to answer our research question, a more theoretical explanation of cyber-physical systems (CPS) and manufacturing execution systems (MES) must be given. This chapter aims to enlighten the reader on the different subjects brought up in this paper, as well as show what definitions we use when it comes to topics without standardized definitions.

2.1 Industry 4.0 and the Internet of Things

The integration of Internet of Things (IoT) into the industrial value chain builds the foundation of the next industrial revolution, Industry 4.0. Although this concept is top priority for many researchers today, a generally accepted definition of the term does not exist as the concept is still relatively young. Even so, the predicted economic impact that Industry 4.0 potentially has is beyond comparable according to German Professor Dr. H. Kagermann, who is responsible for the "Industrie 4.0 initiative" initialized by the German government [1]. The idea of Industry 4.0 promises substantially increased operational effectiveness through real-time communication between humans, products and machines, as well as between producer, customer and supplier. The transition to Industry 4.0 brings about the possibilities of development of entirely new business models, products and services as well. [10, p. 3928]

The fourth industrial revolution, enabled by the communication between people, machines and resources, is characterized by a paradigm shift from centrally controlled
production to decentralized production processes. A key component here is the Internet of Things and its integration into the manufacturing process. IoT allows objects such as sensors, actuators, mobile phones and Radio-Frequency Identification (RFID) to interact and cooperate with their online neighbouring components [10, p. 3929]

2.2 Cyber-Physical Systems and Cloud Technology

In addition to IoT we have CPS, self-configuring connected mechatronic units that can store and analyze data. CPS are equipped with multiple sensors and actuators as well as often being network compatible. This in order to fuse the physical and virtual world together and communicate with other CPS through IoT. With integration of IoT and CPS into the manufacturing processes, we can create what is generally called a smart factory.

A smart factory is defined as a factory that assists people and machines in their tasks through context awareness. This is achieved by systems working in the background, accomplishing their tasks based on information coming from both the physical and virtual world. By connecting people, machines products and data, we can see new ways of conducting and organizing industrial processes emerge. [10, p. 3929]

Unsurprisingly, CPS provides a large amount of opportunities for manufacturers. However, it also brings and emphasizes several challenges. A key challenge is the ability to bridge the gaps between previously, more or less, isolated domains such as embedded systems. [11, p. 521]

Cloud technology, made possible by cloud computing, offers business models with applications, infrastructure, platforms and software in the form of services. The extent of cloud technology into the manufacturing context has lead to the innovation of several cloud manufacturing systems. The idea behind cloud manufacturing is an integrated CPS that can provide the manufacturer with on-demand manufacturing services, both physically and digitally, in order to best utilize the limited manufacturing resources. The possibility of storing data in the cloud from several factories, customers and suppliers in real-time will inevitably affect the MES and the decisions made by it. [11, 521]
A topic up for discussion today is the issue of cyber-security. It is considered vital for the continued advancements of CPS in industry. Wang et al. claims that security cannot be an add-on. Instead it has to be well integrated into the systems that it is supposed to protect at the very start of the design process. One example of the vulnerability of today’s industrial systems is the programmable logic controllers (PLC) since they often lack security software. If CPS and cloud technology are to be extensively used in the industry, the security concern has to be seriously addressed. [11, 522]

### 2.3 Manufacturing Execution Systems

Between the enterprise resource planning systems (ERP) and the control systems (CS) we find the MES. In recent years, enterprises have invested in extensive information systems in order to achieve productivity gains. This has resulted in the ERP systems gaining a major status on the market. For a long time however, few system developers payed attention to the factory floor. Instead, internal production departments developed custom-made software applications to fill specific needs as manufacturing support. Data collection systems using either databases or spreadsheets were commonly developed on the factory floor in order to monitor, as well as control, real-time and variable execution processes. Unfortunately, software maintenance and data consolidation is a complex task in a factory environment, since structure of used applications as well as numbers vary over time. Fortunately, the difficulty of integrating multiple systems on the factory floor brought software providers to package multiple execution management components into single and integrated solutions. These systems, known as MES, provide common user interface and data management for the user. [5, p. 525]
Historically, MES have been well implemented in process industries such as the pharmaceutical industry, since the system answers the needs of traceability imposed by authorities.[5, p. 525] Today they are used in most manufacturing industries. Early MES often had individual definitions based on the factory’s capacities or on the expectations of their customers. However, in order to meet the needs of a variety of manufacturing environments, the Manufacturing Enterprise Solutions Association (MESA) was formed. MESA gathered the major actors on the market and proposed a formal definition of MES, resulting in the identification of 11 principles, see figure 2.1.[5, p. 526]

Among these 11 principles, some are linked to the process directly, such as quality control and scheduling. Others, such as traceability and resource management are better described as cross functions. The difficulty in classifying the functions of MES has two main consequences. Firstly, the concept of MES as a whole is often difficult to perceive clearly by the manufacturers who use the systems. Secondly, manufacturers tend to bring in everything that is not already assigned to other areas, such as ERP and CS. In reality, this implies that all MES functions are not at the same level within system structure of the factory.[5, p. 527]

To give the reader a more concrete view of how MES is used, some short examples will be given here. In order to manage a factory, it is essential to be able to control the production flow. This can be achieved through various ways depending on the type of MES that concerned factory is using. However, it can be used both as a passive function that gives an update on what has been, and is being, produced as well as collecting data from machines and then manually ordering the next steps that concerned machines are to execute. The MES should also be able execute more specific tasks such as maximising the workload of equipment as well as releasing unnecessary tools that are not being used currently. [12, 647]

All MES functions should contribute to the achievement of on-time performance as well as adherence to customers’ order schedules. According to a survey carried out by MESA, MES systems have provided manufacturing enterprises with some of the most impressive benefits of any manufacturing software. Examples of this are the 45% reduction in manufacturing cycle-time, improved flexibility to respond to customer demands and the
realisation of certain degrees of agile manufacturing as well as customer satisfaction.[5, p. 528]

2.4 Cyber-Physical Systems in Manufacturing

CPS have application within several different fields, although it is often in an early state. These applications include communication, energy and manufacturing to mention some. [13, p. 2238] The focus in this paper is the implementations of CPS in the manufacturing industry, where there is great potential. Depending on how one defines CPS, it can be seen as already implemented within the manufacturing sector or as a system of the future. For example, sensor systems and collaborating robots can be seen as CPS. [11, p. 518]

![CPS maturity levels](image)

**Figure 2.2: CPS maturity levels** [14, p. 823]

Defining CPS to be a system working at a basic level, they can be viewed as already implemented within the industry in the form of embedded systems. That is a computer system working in real-time within a mechanical or electrical system. It can also be in the form of a PLC. If it communicates, it does not do so via a network, but rather directly with the intended receiver. For example the MES or another PLC. [14, p. 623]

The drivers for developing the technology to meet the more advanced definition of a CPS are, among others, higher demands on time-to-volume and time-to-market. This is due to a strategy-shift in many manufacturing companies towards a strategy based on introducing products to market in small batches. Only increasing the production
should the product be successful. Therefore, the increase in production has to occur in a short time span. Another driver is the increased interest in personalized products which requires the production systems to be adaptable to quick changes in the product produced. [11, p. 518]

![IntRoSys Multi-Agent System Architecture (IMASA)](image)

When giving the CPS a more advanced definition, moving up on the y-axis in figure 2.2, researchers and industry are currently in the process of exploring opportunities for implementations. Wang et al. describes a service oriented architecture, today implemented in the Ford Motor Company assembly line in Valencia, see figure 2.3. The technology used there is embedded agents within the PLC. They come in the forms of product agent, knowledge manager agent and machine agent. [11, p. 522-523]

The product agent receives the order, creates and controls the work flow before it distributes the orders. The knowledge manager checks if there is a physical ability to execute the work flow. As the last step in the execution sequence the machine agent creates machine instructions based on the work flow that has passed through the knowledge manager. A central component is the database of atomic skills, routines, that the product agent uses for constructing customized work flows based on the given order. It is made possible by the parametrization of skills, which entails the possibility of adding atomic skills without modifying the existing code. [11, p. 522-523]
Another example of CPS within manufacturing is the FESTO MiniProd, developed within the IDEAS (Instantly Deployable Evolvable Assembly Systems) project. It is an assembly system consisting of several different agents who communicate with each other. The purpose of the IDEAS project was to create an assembly system capable of supporting and adapting to different configurations without a need for reprogramming and supervision by a system at a higher instance. The MiniProd has four basic agents: (1) the machine resource agent, (2) the coalition leader agent, (3) the transportation system agent and (4) the human machine interface agent. [15, p. 127-128]

The machine resource agent handles the connections with the other modules plugged in to the system. It abstracts the skills hosted in the module and calls the system libraries needed for implementation of its skills. The machine resource agent is also responsible for the interaction with the transportation system agents, communicating how changes in the transportation system’s position affects the execution and vice versa. [15, p. 128-129]

In order to execute the abilities of the connected modules, the coalition leader manager handles the construction of execution logic based on the user input and the skills currently existing in the system. Any error that occurs in the modules and the removal of them is handled within the coalition leader manager. It thus also need an ability to adapt the system’s functionality to changes arising in real time. [15, p. 128]

The transportation system agent keeps track of the components to be processed currently placed in the transportation system, localizing and transporting them to the right place while keeping track of their position. The dialogue with the user is taken care of by the human machine interface agent. [15, p. 128]

As a result of this multi-agent structure a system which dynamically can adapt to different compositions of equipment was created. It is, in addition, considered to be the first system able to operate without a central control unit coordinating the work flow, the synchronization within the system is completely executed at shop-floor level. [15]

When used in the manufacturing industry, it is clear that there exists several definitions of a CPS, divisible into two main groups. Firstly the one where CPS have the form of an embedded system often implemented on a PLC, used widely in the industry today. Secondly, one where the CPS are defined as a more advanced system, as in the example
above, where CPS include the ability to use information technology, as software and networks, for communication and control of the systems’ physical processes. [16, p. 3]

In this text, from now on, we will use the latter definition of a CPS. Thus, we separate embedded systems from CPS and we can thereby define an on-going transition within the manufacturing industry, from embedded systems towards CPS. [16, p. 3]
Chapter 3

Identified Areas of Change

Figure 3.1: Areas of Change
The empirical study, conducted through interviews with developers, implementers and users of manufacturing execution systems (MES), as well as researchers, combined with a review of existing literature has resulted in the identification of multiple areas of change when integrating cyber-physical systems (CPS) with MES. The areas are Quantity of Data, Update Frequency, Security, Decentralization, Architectural Integration and Human Resources, see figure 3.1. The study was conducted with regards to the implementation of CPS within the manufacturing industry.

The main areas of change have been identified and stated from the perspective of each of the four actors of change, see figure 1.3. We performed interviews with multiple agents from each of the actors, their positions explained in table 3.1. Firstly, a short description of the area will be given, followed by the perspectives of researchers and industry.

### 3.1 Quantity of Data

With the introduction of CPS into a factory, an abundance of data will be generated. The challenge is whether today’s MES can handle this quantity of data, proposed by the literature review. [5, p. 530]

**Researchers**

Among the researchers the aspect of data quantities is not considered a problem. Today’s technology is already capable of managing great amounts of data. With the possibilities of an MES with computational power structured as a cloud, it should be able to manage

### Table 3.1: Interviews

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<th>Role</th>
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<tr>
<td>Researcher 1</td>
<td>Associate Professor, Manufacturing Engineering</td>
</tr>
<tr>
<td>Researcher 2</td>
<td>Professor, Adaptive Manufacturing Systems</td>
</tr>
<tr>
<td>Developer 1</td>
<td>Senior Manager Digital Supply Chain and IoT</td>
</tr>
<tr>
<td>Developer 2</td>
<td>Director Portfolio Development - Manufacturing Operations Management, Board Member MESA</td>
</tr>
<tr>
<td>Developer 2</td>
<td>Portfolio Developer MES/MOM</td>
</tr>
<tr>
<td>Developer 2</td>
<td>Nordic Business Development Director</td>
</tr>
<tr>
<td>Implementer 1</td>
<td>Consultant - Manufacturing, Automation and Industrial IT</td>
</tr>
<tr>
<td>Implementer 2</td>
<td>Senior System Developer Industrial IT/MES/MOM</td>
</tr>
<tr>
<td>Implementer 2</td>
<td>Senior Consultant / Project Leader</td>
</tr>
<tr>
<td>Implementer 2</td>
<td>Project Engineer, Industrial-IT</td>
</tr>
<tr>
<td>User 1</td>
<td>Senior Specialist Solution Architect - PLM</td>
</tr>
<tr>
<td>User 2</td>
<td>Head of Process Management</td>
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increases in the data generated.

**Developers**
The developers have different ways of looking at this area. One of the developers is working on a solution in the form of a cloud platform, processing data. It is defined as an IoT bridge connecting the data generating devices within the factory. How this implementation should be executed however, has not been discussed.

Another developer claims that the processing of the data itself is not really a problem today, the technology exists within their MES. However, this is not only about managing data, it is as much about downloading data to field devices such as the PLC, and to new products. A system developer needs to create new solutions at all times and test them in a digital factory, the virtual copy of the physical smart factory. This implies that the downloading and execution of data in both the physical and virtual world must be smooth and well organized. It is therefore more of a challenge to filter the most relevant data, rather than handling the quantity itself.

**Implementers**
One implementer of MES claims that the quantity of data will not be a problem for the existing systems. They mention an example of a power grid system handling large amounts of data, multitudes greater than the MES in the manufacturing industries. Thus they consider the technologies for this kind of data managing already developed.

Another implementer believes the MES is developing towards a more decentralized system, where the CPS takes over some of the MES functionalities. More connected devices will generate more data in need of processing. With the decentralization of the MES, more units are available to share the data processing capabilities, however the CS used in the industries today are not focused on data processing. Therefore the implementer suggests that, while the technologies for processing data in a centralized system exists, the development of the CS towards CPS containing a part of the MES, able to process large quantities of data, is a challenge.

**Users**
The MES solution that a user uses today has the ability to cope with even greater data quantities. The system in use is executed in a distributed way, meaning that the data is
updated in different parts of the factory and then sent, with a lower updating frequency, to a central database. This structure is something that the user will further develop if the data quantities increase. The result will then be that the MES collects the data, while a separate layer in between the ERP system and MES collects relevant data from the MES. To clarify - when looking at the systems level triangle (figure 1.2) this layer will exist between the MES and ERP modules. The data is then stored and analyzed in this separate layer before being sent to the ERP system.

Another user’s general view of data can be summarized as: the more the better. When it is not used, but only stored, it is a destruction of a valuable asset. However, it needs to be processed and analyzed in order to contribute to an improvement within the manufacturing process. With an increase of connected devices within the production they believe that the quantities of data will increase, thus creating the need for more computational power. The user does not believe that one central unit can cope with this increase. Neither do they believe that it is wise for the separate units to have high-level computational skills. They are therefore proposing a solution where the computations are made in a local cloud of computational units. The increased amounts of data generated within the CPS can then be directly sent to the local cloud for analysis, facilitated by the upcoming communication technologies such as 5G.

The user last mentioned believes that the advantages of a local cloud are considered to be mainly two. Firstly, the user sees a future with less energy consuming units and developed battery capacities leading the way for battery driven units. To then implement advanced computing technologies within each unit would be unwise since it would require more energy than sending unprocessed data and receiving processed data. Secondly, the computational power is increasing rapidly, and will in the user’s opinion continue to do so. If a computational cloud is used rather than giving each connected device computation capabilities, a lower number of units have to be replaced when updating the systems.

### 3.2 Update Frequency

The update frequency of data entering the MES varies from factory to factory. In general however, MES has a higher update frequency than an ERP system, but lower than
CS. The introduction of CPS into the factory enables real time updates and a more dynamic MES. The challenge is whether today’s MES is capable of handling a higher update frequency or not, proposed by the literature review. [5, p. 532]

**Researchers**

Researchers claim that we have the technology to update every fifth millisecond, and consider it to be enough for the near future. Through the use of a cloud based MES, one will always know which cells that are at work, at all times.

**Developers**

The developers are in consent regarding the update frequencies. They do not see it as an issue for their existing systems, claiming that the technologies exist.

**Implementers**

One implementer states that the MES is moving towards the automation level of the factory floor. This means that the MES will need to change from a system with a relatively low update-frequency, to one working with close to real-time capabilities. The MES existing today are often using out-of-date data storing systems, unable to cope with such high frequencies. In some cases even manual storing of data is used, making fast processing, storing and reading of data a challenge.

Another aspect, brought up by the second implementer regarding the update frequencies, is the difference between the developers of MES. The developers of MES originate from different levels within the hierarchical structure of the production system. They either originate from the higher levels (ERP-systems) or from the lower level systems (CS). The implementer states that the developers originating from the lower level tend to be better on taking real-time capabilities into consideration when developing new systems.

The implementers agree on that the systems will be able to cope with higher updating frequencies, although they are concerned by the current state among the users. One of them giving an example of a customer only connecting and updating their system once per work-shift. Even though the technology for high update frequency exists, it is not widely implemented in the manufacturing industry.
Users
A user’s current MES has the capability to work with close to real time frequency. However, the statistic data sent to the MES is stored and lies dormant in a separate database with an update frequency of a few times per day. With a future increase of CPS within the factory, the MES in itself is thus considered capable to cope with the higher frequencies, but the database containing statistics used for analysis needs to adapt.

Another user collects data in real time, but it is stored in a database before being sent to the MES. This leads to the data not being accessible in real time. Due to the fact that the data is only used in retrospect, this does not cause a problem today. The goal is to get closer to a real time updating frequency in the MES to allow for a proactive analysis of the data in order to predict adjustments and maintenance in the production.

The user’s current MES is thus not ready to cope with an increased need for higher update frequencies, mainly due to the IT-structure within the factories. Despite this, they do not see it as a serious obstacle since the development of faster wireless communication systems will allow for faster transmission of data. At the same time, the local cloud computing structure described in the Quantity of Data-section creates the foundations for a close to real time analytic tool.

3.3 Security
Through the use of the Internet, devices can communicate with each other not only within a factory, but also with other devices outside of the factory. The more connected the production becomes, the more important the topic of cyber-security becomes. A saboteur that gains access to one device could get their hands on sensitive information higher up in the hierarchy. If the idea of a connected factory is to become reality, the issue of cyber-security must be taken into account. This area of change was proposed by both literature and interviewees.

Researchers
Researchers claim that while most of the technology needed for the paradigm shift into Industry 4.0 exists today, the issue of cyber-security has yet to be addressed. A major problem is that the PLCs are extremely vulnerable, since they lack most forms of
Identified Areas of Change

protection. The reasoning behind that decision is that protection software will slow the systems down. This is a problem since the signals within the factory must be sent and received rapidly. In the future, with CPS containing better hardware, they will be able to use more advanced security software.

Developers
Neither of the developers believe the security issue to be a problem in the future. One of the developer says that all forms of data exposing is a potential security risk, though the data is not necessarily exposed to the public. The developer relies on its earlier gained knowledge from working with nuclear power plants.

Implementers
Earlier, the CS in the production have been separated from the rest of the computer systems to a large extent, often only allowing one-way communication. One implementer claims that the result of a MES collecting data and working close to the CPS is an increasing flow of information between the higher system levels, e.g. the ERP-systems, and the lower level systems, CS and CPS. This opens up for new potential security threats, where you can theoretically access most parts of the factory once you have entered the system.

The most effective way to keep a high security level while moving towards a connection between the MES and the CPS is, according to the implementer, to maintain a segmentation of the different parts of the factory. This relates to the concept of Ethernet, and the Ethernet of Things rather than the Internet of Things, meaning that each network is separated from the others. However, the implementers also implies that, by prohibiting data from exiting the factory, the possibilities of outside services and the use of collaborative cloud with suppliers and customers are lost.

Another important factor to take into consideration is the policies regarding cybersecurity. Both implementers suggest that within manufacturing companies, the awareness of cyber-security is to a large extent located at the administrative level. However, to take policies from the administrative level and apply them to the factory floor will not be a good solution since the systems work so differently. For example, the systems at the factory floor need to work in real-time and can not be slowed down by a heavy security system.
Identified Areas of Change

**Users**

The current use of connected devices at one user’s factory floor is divided into isolated islands, making it impossible to affect all systems at the same time. If you have access to the higher level systems (ERP/MES) it is easy to reach all data at that level. The strategy for the future is not clear, close to non-existent. The user defines itself as naive when it comes to the current work with cyber-security. It mostly relies on individual workers to take the right actions. The strategies currently implemented are the same at all levels of the company, both at administrative and shop-floor level.

The user believes that in the future, as they connect more devices to the network, the vulnerability to external infringements will increase. However, they are currently developing new firewalls.

The second user states that the main area of interest is not the information itself, since there is almost no way of extracting something useful from the data being sent on the CS/CPS level, but rather to make sure that there is no way to block or disturb data. This in order to avoid production stops and sabotage of expensive machines.

The second user’s suggestion of a future solution to the security issues is not to separate the systems in a vertical way, as isolated islands. They rather suggest that the separation should be done in a horizontal way, thus keeping information intended for the shop floor (MES and CS/CPS) in a separate structure. By doing that, the valuable information in the ERP-system and higher level systems will be kept safe. The lower level systems should then only be allowed to connect when in need of sending information, which in addition, should be done using the mobile networks since it is considered the safest way of information exchange.

The single most important task, according to the second user, is to physically separate the information intended for use within the factory, and that intended to be shared to actors outside the factory.

3.4 **Decentralization**

Since CPS will have the ability to communicate directly with each other, they could in theory bypass a part of the MES. This in combination with the intelligence within each
Identified Areas of Change

CPS could lead to the MES partially existing within the different CPS and partially as a small central unit. This area of change was proposed by both literature and interviewees.

Researchers
According to researchers, the future functionality of the MES will, to the most part, be integrated within each CPS. Each individual CPS unit will have enough intelligence to contain a part of the MES as it is defined today. The units will have the parts of the MES relevant to the CPS and the section of the manufacturing plant in question. The MES will be embedded into the production system as the sum of a set of cooperative components. This is made possible due to the fact that the CPS understand how to execute their tasks and, more importantly, how to coordinate with their environment.

One researcher claims that the challenge of today is thus to move from tightly-coupled-systems, to loosely-coupled-systems. We need adaptive systems that can co-exist as small islands with minor self-governing.

One of the greatest hindrances for the evolution of CPS and its integration to the MES is the outdated technology of the PLC, lacking enough computer power for future needs. The industry is conservative and wants to keep the PLC. One way to bridge the development is to create a service oriented architecture were you add applications on top of the PLC such as communication software and the multi-agent systems. In this way, the PLC can communicate with more devices. This is a first step on the road from a hierarchical system with multiple system levels to a distributed MES on the factory floor.

Another researcher says that the existing automation technology does not support enough intelligence for mentioned decentralization to take place. It needs a central system to keep track of all the on-going processes within the production. The future role of the MES will then be as one of a context provider. It will contain the flow of processes or goals, communicating them to the different subsystems in the manufacturing process without providing the exact execution orders.

Developers
The vision of one developer is to go beyond the segmentation of systems. Instead, the goal is to go in the direction of a digital enterprise where there are no boundaries between
the different systems. All systems are able to expose their capabilities to the environment, and these capabilities being certain services. A first look at this digital enterprise has been created today which mainly integrates Product life-cycle management (PLM) with MES and CS.

**Implementers**

One implementer says that the MES structure in itself is a rigid structure which is difficult to adjust. This is partly due to the MES standards, such as the ISA-95 standard, defining how the MES should be structured. This leads to a monolithic system, that can not easily be reconfigured based on the needs of the factory in which it is being implemented. The implementer is of the view that this will change and that the future MES will be a more dynamical system composed of several different modules.

The data generated from the production can be stored in a central database. Modules are built around the database, accessing the required data and managing it according to each module’s functionality. The premises should then be to build a system based on the needs in each specific case. This can be summarized as a modularized MES working at the same level in the production system as it is today.

Another implementer also claims that some of today’s modules within the MES will be taken out, creating a smaller and more compact MES. The implementer mentions that the assembly industry will have more use of a modularized MES approach, while the mass producing processing industry will still use a more standardized MES.

**Users**

The MES used by one user is today fully centralized, collecting data from the different units within the factory. A lot of data comes from the manual assembly line and from the machining units and is partly transferred manually. The user is of the opinion that the future of their MES will be a somewhat decentralized system. One example of a decentralization potential of the current MES implemented within the manufacturing is the hand held screwdrivers. They are today connected to portables computers that would be able to handle a part of the MES functionalities.

One aspect mentioned is the development of an RFID that can cope with more advanced components, keeping track of the individual tools’ abilities and statuses. Thereby they
can contain a part of the information currently stored in the MES.

The user transports heavy components within their production. This has previously been done by connected trucks, controlled by a central system connected to the MES. One possibility with these transportation systems is to give them a higher level of intelligence, allowing for them to keep track of their position and communicating directly with the other units within the production, for example when a transport is needed. This can be seen as bypassing the central MES. Even though the user is currently looking at different ways of developing their production, they consider themselves to be heavily dependent on what the leading developers of mechatronic units, machines and MES are working on.

The MES currently in use at another user’s factory is not centralized, but rather a modularized out-of-date system. The MES exists as isolated systems within different sections of the factory. The data is mainly collected from test stations. They are currently implementing a new, centralized, MES that will be able to collect data from all parts of the factory. This will lead to an easier access and storage of data.

The second user is thus currently moving towards a more centralized system. It does not believe in a decentralized MES, split up an integrated into the CPS. As described in the section Quantities of Data, the user argues that it is better if the computational power is in a cloud form. This sets focus on the transmitting speed and update frequencies within the factory.

The user rather believes in making the individual units at the factory floor less intelligent. Firstly, this will lead to a lower energy consumption, which will benefit the user when moving towards more battery driven devices. Secondly, it will be easier to upgrade the computational power if it is not distributed among multiple systems.

3.5 Architectural Integration

It is not easy to seamlessly integrate systems to work well with one another. Today, there exists a lack of standards for both the hardware and software parts of the communication, contributing to the difficulties with integrating the different systems. This section provides the concerned actors’ views on the issues related to having different
systems within the factories communicating with each other.

**Researchers**

One researcher claims that the CPS and the MES will not need to be integrated as two different systems, they will rather make up one tightly connected system. There is also a contradiction between the view of the MES as a distributed system and the ISA-95 standard which has made the MES a, to some extent, stiff structure that is not easily adapted.

Another issue with the development of the connection between the MES and CPS is the fact that the knowledge exists, but to a large extent as isolated islands. Within different areas, advanced technology exists that could be used both when it comes to the CPS themselves, but also in the connection with the MES. There are mainly three different fields where this phenomenon occurs. The first of those being within the communication technology. For example, the communication technology developed for personal mobile devices (cellphones) have the same kind of characteristics that is needed for the smart mechatronic units in the production to connect with the MES.

The second field is the embedded computing devices. The personal computers used today have more than sufficient computational power for control of a mechatronic unit and its’ interactions with the environment.

The last field is the programming languages. The programming languages used today are sufficient for fast development of new functionalities.

The architectural problem is, nonetheless, to create a proper aggregation of these existing technologies in order to assemble everything together. The researcher exemplifies it with a car analogy: To build a very good car it is not enough that you have experts developing the wheels, the engine or the chassis. You will also need people who are experts when it comes to the concept strategy, creating models and assembling the car. Without the latter, you will have a car consisting of excellent parts, but that might fall into pieces.

**Developers**

One developer argues that the key issues when implementing CPS into MES are to seamlessly integrate Machine learning, M2M communication, sensor data, and to make
automation technologies work together to create autonomous smart machines and connected factories. They have an IoT platform which combines adaptive applications, big data management and connectivity in packaged solutions across the factory. By doing that, they wirelessly connect the factory, but do not mention how it can be integrated with other solutions.

The second developer argues that the hierarchical system structure, with multiple levels, is a hindrance for a closer collaboration between systems. This hierarchical structure contributes to silo organizations. Instead we need a horizontal system which boosts communication within a factory, even opening up for collaboration with suppliers and customers. The developer is currently working hard on implementing their new systems into existing factories, but it is difficult in Europe. It is not possible to implement all the new systems, since they require the existing factory to scrap today’s systems, which is difficult mostly due to financial reasons. In Asia however, it is often possible to start from scratch and deploy these systems when building the factory.

Regarding standards in the industry, the developer is currently working with making their products integrate well together with competitors’ systems.

**Implementers**

Within the manufacturing industry, the people working with the production have not been focusing on understanding how the connected machines in use communicate with the IT-layer in the factory. This is partially due to the structure of the companies, where the IT skills and production skills are often separated. The result is a production plant with a lot of connected devices that, without the right infrastructure, are not used to their full potential. New technology is used and connected in an old way.

One solution, suggested by the implementer, is a focus on standardization within the industry. The larger companies sometimes work with in-house standardization, often handled by a separate section of the company, but the smaller ones do not have the resources and thus would benefit a lot from a more standardized way of connecting devices with each other. The main challenge when it comes to the development of these industrial networks is the fear of introducing more new IT-problems when trying to solve the old ones. This leads to companies holding on to the old, still working, solutions.
The implementer mentions that a problem regarding the integration of new systems into older factories, is that the physical layout and structure of the factory might not be easily modified to fit a more connected production system. The machines used can also cause problems, since it is not always easy to add a cyber-part to an old mechatronic unit.

When building new factories, the implementer mentions that there seems to be a strive to make them ready for more connected systems, even if the systems are not implemented at once. The life-span of a typical factory is of a multiple of decades, creating a natural inertia when it comes do adopting new technologies within the manufacturing industry.

Another implementer agrees with the first part and says that a structural challenge is to capture the data generated for other purposes. One example is the machines sending data to service technicians who uses it for maintenance prediction. This data can also be useful for the manufacturing company directly.

However, the second implementer does not agree regarding the standardization issue. They claim that the large companies are the ones who will mostly benefit from an increased standardization. This is because they have the financial capabilities of using the standardized modules, connecting their systems used on the factory floor. Smaller companies neither has the money nor the need for these large standardized applications, although they can use the smaller tailored versions. The implementer claims that we are going to see a transition from a large MES, to a smaller MES tailored to with the needed modules, tailored to communicate with the needed systems.

The second implementer is of the same opinion as the first one when it comes to adjusting an existing factory to new systems such as the CPS, it is not an easy task. The internal infrastructure within an existing factory is in most cases not based on the idea of digital communication. It is therefore difficult to implement multiple new ideas at the same time. Instead, a more incremental approach is recommended where CPS are implemented one by one when they are deemed necessary.

Installing the systems required for CPS will not be easy, according to the second implementer. Employees are concerned that several systems may not be able to communicate with each other while the new systems are installed, and may not even work after the installation is finished. Adding to this, the developers and implementers are not certain of
what the new system interfaces are going to look like in order to meet the requirements of the new systems, and to work well with them. A difficult task will be to coordinate specialists and workers from different departments, but also suppliers and customers, in order to achieve a successful installation of CPS.

**Users**

As one of the main issues with connecting more systems to the MES, one user mentions the standardization of communication. The different suppliers of connected devices all have their own way of managing the communication, for example with different protocols. The result is that the integration and creation of interfaces of the systems is left to the user. The user considers this mainly as a short-term problem, considering the solution to be a standardization on the market. In the meantime they are working with creating an in-house standard for the information flows.

The second user considers the task of connecting different kinds of devices to the MES to be one of the main issues today. With the quantity of different solutions for managing and communicating data, they are today forced to create a customized interface for almost every single unit that they want to connect to the MES.

Despite this, they are not worried for the development in the future. The user believes that the main actors on the MES market will sooner or later agree on a standard. They compare it to the development within the IT-industry, where it has been a continuous process.

### 3.6 Human Resources

Whether Industry 4.0 is a paradigm shift or not, it certainly requires the human resource of a company to rethink what manufacturing may look like in the future. This area of change was proposed by the interviewees.

**Researchers**

One researcher is of the opinion that the technological barriers with integrating the MES to the CPS can be closed if you work with the right people. The problem is that there is a small supply of people with the right skills, though the prediction is that today’s
technological advancements will promote the education of workers with the skills needed for a technological transition to a more CPS-oriented production system. One problem is that the companies developing the MES are focused on what is going to be on the market in a short time span. This, in one way, prevents them from realizing the full scale of the possibilities with the CPS.

With the right people, the researcher suggests that a production system solution with a distributed MES and fully functional CPS units can be developed within a couple of years. The reason this is not developed is mainly due to the coordination problems between the existing skills.

Developers
Only one of the developers discusses the human resources area. It says that, in order to achieve the removal of boundaries between systems, there are mainly two challenges. The first one being strictly technological, however the second one is more of a cultural workforce-challenge. Within the human resource area we need to change our way of looking at the MES, and switch from today’s ISA-95 inspired hierarchical system with multiple levels, to a more horizontal structure. This change is not an easy task since it challenges the industry culture of today.

When MES was first implemented, people did not fully understand how to use it properly, or what they had to change in their organization for MES to work. The issue of what MES is and what it should do is still debated today among promoters of different definitions. There are still complex problems regarding setup that need to be addressed before we can discuss technological and cultural challenges.

To embrace the new technologies of Industry 4.0, the developer claims that one must understand that it is foremost a cultural change, rather than a technological change, and that it is a change of paradigm. The change is therefore more of a radical nature, rather than incremental with regards to the previous digital industrial revolution.

Implementers
As mentioned earlier in this text, the first implementer is of the opinion that much of the development within the CPS and their relationship to the MES is depending on the cooperation between workers with different skills. They have identified that there exists
a division between the people working with the production systems and people working with the IT management at the companies. With the evolution of CPS the factories will need an advanced way of handling both the data itself and the transferring of it, requiring a cooperation between these disciplines.

In addition the quick development within the field of mechatronics during the last decades, has made it difficult for employees within the production to keep up. The level of knowledge is often fully sufficient for production execution. However, the full potential within multiple fields, for example the use of data generated, is not used. This will have to change in order to integrate the CPS with the MES.

The second implementer claims that a form of inertia exists in the industry today, not only in Sweden but also globally. This inertia is a resistance among the existing players on the market towards the adoption of Industry 4.0 technology. To understand why, one must look at the reason for this inertia. The manufacturing industry can in many cases be seen as a slow giant, where radical changes in the manufacturing process could very well result in chaos. A great number of systems have to cooperate at all times, and if one system is removed or radically changed it is difficult to predict the new outcome.

There also exists a widespread lack of knowledge regarding the possibilities of Industry 4.0, according to the second implementer. A reason why multiple aspects of Industry 4.0 has not yet been implemented in Sweden is because those who work in industrial production does not even know the technology exists, and even less what problems they can solve with it.

The aging workforce is another factor that creates the inertia within the manufacturing industry. The aging workforce has great experience within the present manufacturing industry, which the implementer considers to work well, and is not in dire need of Industry 4.0 technologies. The implementer claims that the older parts of the existing workforce may not be interested in changing the way they work by further digitizing the manufacturing industry. They have worked with pen and paper for a long time and may find the transition away from that difficult.

**Users**

One user considers the cultural challenges as one of the main areas of change when it comes to integrating CPS to the MES. The people working in manufacturing today have
difficulties when it comes to the understanding data driven potential and the relation that CPS has to MES. Today’s questions are mainly related to the expected results and how they will contribute to improvements within the manufacturing process.

Another user does not consider the human resources area a problem at lower levels. The employees at the factory floor level will remain more or less unaffected when implementing CPS. The main change will occur at the higher levels, when it comes to analyzing and interpreting the data. Within that field, most manufacturing companies will need an improvement of skills.
Chapter 4

Conclusions

As presented in the results, six areas have emerged from the empirical and literature studies. Within each area, the actors have different views regarding the change. In this chapter, we will present our conclusions of the results.

4.1 Impact on MES through the use of CPS

Besides answering the research question, the expected outcome of this paper is to provide an overview of the areas discussed, useful for the mentioned three industry players in their future decision making.

Quantity of Data
The researchers claim that today’s technology is capable of processing great amounts of data, especially if divided among multiple units. One of the developers agrees, while the second developer has a slightly different view. Their focus is rather on swift transmitting and filtering of data.

Among the implementers, one claims that the required technology exists in the systems today, while the second one focuses on the development of manufacturing execution systems (MES) towards a decentralized form. A higher number of units sharing their process capabilities will be able to handle greater quantities of data.

The users have different views on this topic. The first one argues that their current centralized system is ready for increased data quantities. The second user believes that
a centralized system will not be able to handle the data quantities generated by the cyber-physical systems (CPS).

**Update Frequency**

Neither the researchers nor the developers see the issue of update frequency as a problem. The technology needed to handle close to real-time frequency exists today in their opinion. Both implementers agree with the researchers on the updating frequency not causing a problem to their solutions, but they raise the problem of the users’ data storage solutions as being out-of-date and not ready for higher frequencies.

None of the users’ MES are today able to handle a close to real-time updating frequencies. This is due to their IT-structure, slowing the system down.

**Security**

All interviewed actors claim that the issue of security must be addressed when integrating CPS with MES. The researchers say that with the introduction of the more advanced CPS, the hardware will allow for more advanced security software without slowing the system down. None of the developers believe security to be an issue in the future.

Both implementers claim that factory floor and office cannot have the same security system. A focus of one of the implementers is the change in flow of data from only between CS and MES, to include the ERP-system. This opens up the system for threats, making segmentation important.

One user claims it to be impossible to reach all their systems, since they are split up in isolated vertical segments. The other user promotes a horizontal separation of the system levels rather than having vertical segments, ensuring the safety of the ERP. It also states the importance of protecting the information stream on the CS/CPS level from disruption.

**Decentralization**

The researchers propose that the MES functionality should, to the most part, be integrated to the CPS. The result is a distributed MES, where MES modules close to the factory floor are instead put in each CPS. One developer has a different ambition than proposed by the researchers. The developer aims to eliminate the boundaries between systems, proposing a horizontal structure where the different systems are able to expose and offer their capabilities to each other.
The implementers are more or less in consent with one another, and with the researchers. They all agree that a decentralized MES will be the most beneficial structure in the future. One implementer suggests a modularized MES with a centralized database, working at the same level as the MES is today. The second implementer points out that the decentralized MES is most useful in the dynamic assembly industry, but that a more centralized solution is preferred in the mass producing process industry.

While most interviewed actors agree that a more decentralized approach is preferred, the users are not in consent with one another. One user, who today has a fully centralized MES, considers the future MES to be a somewhat decentralized system. The second user uses a modularized out-of-date system. The user is today moving towards a more centralized system and does not believe in a decentralized MES, but rather one with low-intelligence units and computational power in a local cloud.

**Architectural Integration**

A researcher claims that a main challenge when integrating systems is to create a proper aggregation of existing technologies, in order to seamlessly assemble them. Most technology and knowledge exists today as isolated islands, whereas they could instead communicate with each other to help integrate MES and CPS.

A developer claims that one difficulty when introducing new systems in existing European factories is that most of the old systems become obsolete or stop functioning correctly. It is too expensive to replace them all, and thus the factory reject the new systems. This is not so much of an issue in Asia, where many new factories are built today.

The implementers agree with the developer and claim that we will see an incremental approach, where new systems are slowly added to the factory. Both implementers also agree with the researchers and says that IT and production people do not communicate. When it comes to standardization, both implementers argue that it is important but have different views on the benefits.

The users focus on different aspects of architectural integration. One user argues that we need a market standardization of MES, for the integration of MES and CPS to work. The second users believes it is a problem to connect many devices to the MES and has
to create individual interfaces for every device used. Both users do however believe that a standardization of the integration will eventually come.

**Human Resources**

The human resources area is brought up by one of the researchers, claiming that the problems with realizing a fully distributed MES is the small supply of people with the right knowledge, the coordination problems of the existing skills and that the developers of the MES are too focused on the short-term development. One of the developers claims that a cultural transformation within the workforce must be induced, if CPS is to be connected to the MES.

The first implementer agrees with the researchers. The second implementer has a different view and considers the inertia within the industry as the main issue. The inertia is related to the number of different systems, the general lack of knowledge of new technologies and an aging workforce, reluctant to digitization.

Both users consider the human resources as an area of change, but from different perspectives. Both users argue that the skills related to data analysis and management will need to be improved among all levels of employees.

### 4.2 Conclusions & Future Work

Through conducted interviews with concerned actors within the industry and researchers, as well as reviewing existing literature, we were able to find six key areas of change when implementing cyber-physical systems (CPS) onto manufacturing execution systems (MES). These are quantity of data, update frequency, security, decentralization, architectural integration and human resources.

Generally, the researchers have a greater knowledge within the area of CPS and its capabilities. The term itself is rarely recognized by the other actors, and even though many we interviewed were aware of the term IoT, few had actually worked with physical implementations of CPS.

It is worth noting the discrepancy between the researchers and developers in comparison to the users. The former is of the opinion that the MES are more or less ready for CPS.
The systems in use are though, in the user cases we have examined, not at all able to cope with the changes that come with CPS.

We have noticed that opinions differ in several of the areas of change. The tendency seems to be that the researchers and developers are often like-minded. For example in the areas of update frequency and security. None of them is concerned about the two areas, they believe that today’s technology is be able to cope with the issues brought up. The users, on the other hand, have systems that are out-of-date. They are aware of the problems, but are not sure how to tackle them. The implementers seem to have opinions similar to both the developers and users. This is quite understandable since the implementers work in between the two. The implementers are aware that the technology for CPS exists, but they do not know how the new technology is to be implemented in a real existing factory.

Two of the areas identified are in our opinion the enablers for the integration of CPS to MES, they must thus be considered before a change within the other areas can take place. These areas being architectural integration and human resources. Without the ability to aggregate the different technologies and have them communicate, it is impossible to assemble the systems into a well functioning factory.

As the implementers and users point out, the question of standardization of communication within a factory is essential for the area of architectural integration. As we brought up in our results, both users have implemented systems without having the knowledge of how to connect them, resulting in poor IT-structures. This lowers the overall performance of the systems. The issue is that systems of different types do not work well together. They need to be manually connected, often requiring the user to create an individual interface for each connection.

Within the human resource area, it is interesting to note that the researchers believe that the technology for implementing CPS and connecting it to MES exists. However, the actors from the industry are all in consent, stating that a cultural change is needed. This in order to spread the knowledge of the new technologies and how they can be used when connecting systems within a factory to each other.

If the cultural change is not made, we believe that a lot of the potential of implementing CPS and connecting it to MES will be lost.
We suggest that all four interviewed actors need to, first of all, ask themselves the question why, and where, CPS and their capabilities are needed. Secondly, they need to set up a structure for inter-actor communication, to spread knowledge and enable them to move in the same direction.

Parallel to the discussion on how to enable CPS implementation into factories, a topic we would like to bring up is the area of decentralization. It is the most debated topic in our results and it took up a great part of the interviews. We would like to point out the one user believing in a future with more battery driven units within the factory, allowed by the development of 5G technology. With battery driven devices, a focus will be set on energy consumption, making less intelligent units beneficial over the ones with high computational power.

The solution proposed by the user is a centralized local cloud to where the data will be sent and analyzed. In addition to an increased battery time, the cloud will make it easier when further upgrading the hardware since the number of units with advanced hardware is minimized.

This solution is a contradiction to what both the researchers and the literature we have reviewed proposes. In our opinion the possible introduction of battery driven units within the factories can very well induce a shift of focus. From making the units themselves more intelligent to rather minimizing their computational power and increasing their transmitting capabilities.

We would like to further investigate this topic in the future. The research would then be focused on looking at how researchers think the development of battery driven devices within the manufacturing industry can affect the implementation of CPS, as well as their integration to MES.
Bibliography


Conclusions


