Industry 4.0 Opportunities at Scania Production Meppel B.V.

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Preface

This thesis is the final work of my master study in Industrial Engineering and Management with specialization Production and Logistic Management at the University of Twente.

My master thesis is about Industry 4.0, a topic I was very curious about and knew little about at the start of my thesis. It was a pleasure researching this topic, which highly met my expectations during the thesis.

I would like to express my gratitude to my primary supervisor Peter Schuur and secondary supervisor Wieteke de Kogel of the University of Twente for supervising and supporting me during my thesis.

For Scania Production Meppel, I would like to thank my company supervisor Bram Bechtel and all colleagues that were extremely cooperating and friendly during my research. I have rarely witnessed such an open culture and the drive to continuously improve than at Scania Production Meppel.

Yours sincerely, Kelvin Jansen University of Twente, 15-05-2018



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1 Introduction

This research has been performed as master thesis from the University of Twente and takes place and at the company Scania Production Meppel. Section 1.1 provides background of the company briefly and the research motivation. Section 1.2 provides the problem context and core problems. Section 1.3 provides the research objective derived from the problem description. Section 1.4 provides the research (sub-) questions. In Section 1.5, the scope for the research objective has been determined. Section 1.6, elaborates on the research methodology.

1.1 Background

1.1.1 Scania Production Meppel

Scania Production Meppel was found in 2005 as subsidiary of Scania CV AB. At this subsidiary, unpainted plastic cabin and chassis parts for trucks are received from different suppliers. These parts are painted according to a fully automated paint process by 22 robots. This installation is fully operational since the beginning of 2007 and meets the highest environmental and quality requirements. All parts are painted on a steel rack, also called a skid. Figure 1.1 shows on the left-hand side the cabin and chassis parts that are painted. These trucks parts are divided into different T codes. The number "1" parts in Figure 1.1 are T2/T3 parts, which contain the front and side-deflector parts. The number "3" are called the T1 parts, which are the chassis parts. The number "2" parts are the cabin parts, which are painted in Scania Sweden and not in Meppel. The picture on the right side of Figure 1.1 shows how parts are placed on a skid for the painting process.



Figure 1.1: Left: 1&2 Cabin parts, 3 Chassis parts, Right: Parts on skid



The cabin and chassis parts are painted at two separated painting lanes in the customer's requested color. At these painting lanes, more than 500 colors are available for painting. When the parts are ready to be transported, these will be delivered to Scania factories in The Netherlands, France, and Sweden. Each part in the painting process is specified by the customer's requirements. Through the flexible use of workforce and balanced logistic systems, Scania can quickly react to varying a demand of painting parts of trucks. Scania Production Meppel strives for continuous innovation and wants to stay up-to-date of the latest technologies and methods available on the market. Scania is well known for its process improvement discipline and lean manufacturing. This means for example, production in sequence of order, minimizing waste, and just-in-time raw material delivering at the site. The logistic department ensures the material planning, receiving of skids, production planning, supplying the production departments with empty packaging and end products. This research is performed in order from the PaintShop. The Paint-Shop consist of e.g. capacity managers, process engineers, and business intelligence analysts. They are responsible for continuously production of the painting robots and to make sure that the PaintShop meet the highest efficiency and uptime.

1.1.2 Research motivation

While there is a lot of data available and a continuous strive for innovation within the company, the primary reason for this research is the continuous need to explore innovative techniques. Next to that, the organization provides this assignment as preliminary research for a PhD research. At global level the company Scania, the term Industry 4.0 (also known as Smart Industry within the Netherlands) is well known but there is a need for it to be researched to its full potential for different sites. The intention of the PhD research is a longer-term project in collaboration with the University of Twente about Industry 4.0 to connect theory with practice for Scania Production Meppel. This preliminary research is mainly for the company to explore Industry 4.0, and to determine future research and interesting areas for Scania Production Meppel.

1.2 **Problem description**

Before the truck parts are painted in the PaintShop, parts are loaded on different types of skids. The parts on the skids are first washed, dried, and cooled before they get painted. When the skid with the cooled parts arrive at the PaintShop, parts are painted by two robot arms at the same time. After all parts are painted at the PaintShop, the skid goes further to the inspection and where all parts are checked on quality and repair when required. When all parts are inspected and no errors are found, the parts will be unloaded and moved to the assembly department. Any downtime at the PaintShop process can lead to a delay in the production



planning for the entire production process, which makes this a critical process. The process of the PaintShop is described in more detail in **Fout! Verwijzingsbron niet** gevonden..

Scania global wants to stay competitive and lead against competitors by adopting the latest technologies. These days Scania Production Meppel is getting more familiar with Industry 4.0, but is also aware of the complexity and challenges of this industrial revolution, e.g. cybersecurity, Internet of Things, big data, autonomous robots, etc. Industry 4.0 is the 4th big revolution in technology innovation (bmbf, 2017). The goal for Scania Production Meppel is to produce complex products with flexible production systems that contain a high level of technology integration. Since Scania produces in more than 500 colors, each color having their own challenges and difficulties in practice. Also, Scania CV AB has just started to produce the new R-type truck. While the previous series contains 3 different types of front panels per truck, the new R-type has more than 15 different type of front panels per truck, varying from small to big parts. Since this new series of trucks are introduced, the previous series will be out of production soon. With the new R-series and the increasing expected demand for next year, complexity and flexibility is a major challenge at Scania Production Meppel.

The company supervisor of this research, which is the group leader of Paint Shop Engineering and Paint Application, argues the following for adopting industry 4.0 technologies: "To stay competitive and innovative as a company. We always want to produce our products efficiently. There are a lot of competitors, and we need to meet the highest quality standards at the lowest cost."

1.3 Research objective

The research objective of this research is to define and test a most potential Industry 4.0 opportunity. This will be done by analyzing the current state of the PaintShop and Logistics with respect to Industry 4.0, which provides the starting point to explore opportunities with respect to Industry 4.0. To identify Industry 4.0 opportunities, we have made a general understanding of Industry 4.0 is required by performing a literature research. Secondly, the current state of the processes Industry 4.0 at Scania Production Meppel should be determined. By combining the knowledge derived from the literature research with the current state of the processes regarding Industry 4.0, the most valuable Industry 4.0 opportunities will be identified. The research objective is translated to the research (sub) questions, which can be found in the next section.



1.4 Research questions

Several research (sub) questions are derived from the research objective as stated in the previous section:

1. What is Industry 4.0?

- 1.1. What technologies are fundamental for an Industry 4.0 transformation?
- 1.2. How does Industry 4.0 add value and how can it increase performance?
- 1.3. What are the main challenges regarding Industry 4.0?

2. What is the current state of the processes regarding Industry 4.0 at Scania Production Meppel?

- 2.1. How digitally mature are the current processes?
- 2.2. What current Industry 4.0 areas and improvement opportunities?

3. What Industry 4.0 opportunities provide the most value for the production process?

- 3.1. What Industry 4.0 opportunity is the most promising opportunity for a test case?
- 3.2. How can remaining Industry 4.0 opportunities successfully be evolved and implemented over time in the future?
- 3.3. What value can be obtained by the most promising opportunity to improve the current situation with Industry 4.0?

1.5 Research scope

The most promising opportunity for a test case regarding the main research objective is a result from the Industry 4.0 description and reflection on the organization Scania Production Meppel. For this research the current situation and most promising improvement is limited from the inbound process until the outbound process. These product processes in between the inbound and outbound consists are six processes. These six processes (Figure 1.2) are called: Loading, Painting, Paint distribution, Inspection & Repair, Unloading, and Assembly. The scope is shown in the grey striped box in Figure 1.2 with their interrelated flow direction.



From an Industry 4.0 point of view, the most promising improvement has several boundaries which the Industry 4.0 improvement must meet:



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- (1) High value in the automotive industry.
- (2) Applicable and feasible for Scania Production Meppel.

This research contains a broad exploring literature research part. From this literature research, only the necessary Industry 4.0 application areas for Scania Production Meppel will be taken into account. After scoping due to use of criteria, opportunities for Scania Production Meppel will be judged on Industry 4.0 importance and company strategic aspects. Only the relevant opportunities will be taken into a multi criteria model to choose the most promising improvement for a test case. This scoping is shown in Figure 1.3.



Figure 1.3: scoping opportunities

How these steps are performed is explained in the following section 1.6 Research methodology.

1.6 Research Methodology

The research methodology for this research is defined in five phases. The project starts at the first phase and continues until the fifth phase. The left side of Table 1.1 shows a description of the approach for each phase. The right side of Table 1.1 shows the name of the phase, the interaction between the phases, and the chapter number of the phase within the research report.



Table 1.1: Research Methodology





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2 Literature review

This chapter introduces a theoretical framework for future research at Scania Production Meppel and to answer the first research question: "1. What is Industry 4.0?". In Section 2.1 an introduction to Industry 4.0 is provided, and terminologies are defined or clustered as a uniform term. Section 2.2 answers the research subquestion 1.1., which describes the different fundamental and core technologies regarding to Industry 4.0. Section 2.3 answers the research subquestion 1.2., which describes the different performance indicators and applications. Section 2.4 answers the research sub-question 1.3, which are the main challenges regarding Industry 4.0.

2.1 Introduction

The first industrial revolution was from 1760 to 1840 in Britain when technical changes were made. These changes were: use of new material, use of new energy sources (steam machines), invention of machines, a new organization of work known as the factory system, and transportation and communication developments. (Britannica, 2017). The second industrial revolution was from 1870 to 1914 when mass production started, and the expansion of electricity, petroleum, and steel took place (Anon., 2017). The third industrial revolution started from 1970 when Programmable logic controller (PLC), electronics and IT to automation and manufacturing (Kagermann, et al., 2013) were introduced. Nowadays the fourth industrial revolution is a more familiar term in manufacturing and is first called Industry 4.0 (bmbf, 2017). All the four different industrial revolutions are shown in Figure 2.1 in a timeline overview. Industry 4.0 is the highest level of automation in manufacturing whereby products are monitored, controlled, optimized, and automated (Porter & Heppelmann, 2015). Industry 4.0 is based on smart products, smart factories, smart grids, smart mobility, smart logistics, and smart buildings in an Internet of Things (IoT) and Internet of Service (IoS) environment (Stock & Seliger, 2016). The different terms inside Industry 4.0 are used to come to the same goal, having an intelligent factory. In this report, Industry 4.0 is defined as the technologies and applications that enables and add value to the digital transformation of the industry.





Figure 2.1: The four industrial revolutions (Kagermann, et al., 2013)

Within Industry 4.0, four important design principles are described in a literature review to measure Industry 4.0 compliance (Hermann, et al., 2016). These are interconnection, information transparency, decentralized decisions, and technical assistance. Industry 4.0 scopes the entire supply chain (end-to-end) from supplier to client (Kim & Park, 2017). In the future, global networks of machinery and production facilities will consist of Cyber-Physical Systems (CPS) (Kagermann, et al., 2013). New IoTs are realizing the CPS that enables the control of movements in the real-world because of processing information (data) in the cyberspace without human intervention, rapidly expanding digitization and networking of things as well as human beings (Kim & Park, 2017). For example, a sensor can be attached to the control target and various data is send from the sensor with IoT tools. IoT and CPS are supporting certain applications through collecting and managing data. Furthermore, CPS are able to manage resources effective and efficiently by using data and communication technologies (Kim & Park, 2017). Furthermore, CPS are intelligent (smart) feedback systems that have different applications, for example, consumer, energy, healthcare, manufacturing, robotics, and transportation (Lee, et al., 2017). In order create and serve new leading markets with CPS technologies and products, the following features of Industry 4.0 are necessary: horizontal integration through value networks, vertical integration, and networked manufacturing systems (Kagermann, et al., 2013). From now on Industry 4.0 will be used in this



research report as universal term for both Industry 4.0 and Smart Industry to avoid confusion. Fundamental improvements especially for industrial environments can be realized in manufacturing, engineering, material usage, supply chain and life cycle management (Kagermann, et al., 2013). Industry 4.0 comes with potential benefits as: mass customization (meeting individual customer requirements), flexibility, optimized decision-making, continuous resource productivity and efficiency, creating value opportunities through new services, responding to demographic change in workplace, work-life balance, and energy efficiency (Kagermann, et al., 2013). In order to achieve these potential benefits, opportunities should be identified. (Hermann, et al., 2016) describes a way to identify and select industry 4.0 scenarios (opportunities) to due to several type of criteria. Before identifying and selecting Industry 4.0 scenarios for implementation, the first step is to create a common understanding of Industry 4.0 (Hermann, et al., 2016), as is shown in figure 2.2.



Figure 2.2: Industry 4.0 scenario based on design principles (Hermann, et al., 2016)

2.2 Technologies

Different definitions of technologies are found in the literature, for example in, (Group, 2017), (Cevikcan, et al., 2017), and (Wang, 2016). They all come to nine technologies, that are necessary for transformation of industrial production. To make use of uniform definition of these nine technologies, this report uses the terms as in (Wang, 2016). These nine technologies are shown in Figure 2.3.





Figure 2.3: Nine fundamental, and three technologies (Melanson, 2015)

These technologies are: autonomous robots, horizontal and vertical integration, additive manufacturing, cloud, Augmented Reality (AR), simulation, big data and analytics, industrial internet, and cybersecurity. (Cevikcan, et al., 2017) describes three more core technologies: sensors and actuators, RTLS and RFID, and mobile technologies. These three technologies are necessary to create a smart factory. All different technologies are described below in more detail.

Autonomous robots

In the future robots are expected to be more autonomous, flexible and interconnected. Industry 4.0 does not only contain machine-to-machine, but also machineto-human collaboration (Gerbert, et al., 2015). Adaptive and flexible robots in combination with artificial intelligence provides easier reorganization of the lower segments of each part and makes the system more flexible. Several benefits can be achieved, for example, decreasing production costs, reducing production time, and waiting time in operations (Cevikcan, et al., 2017). Adaptive robots are especially valuable in design, manufacturing and assembly phases (Wittenberg, 2015).

Horizontal and Vertical Integration

Horizontal integration is done across the entire network from customer to client. This integration can be an IT system that is used on different stages of the manufacturing, planning processes, energy, and information through this network. With the whole supply chain integrated, the goal is to deliver an end-to-end solution



(Cevikcan, et al., 2017). Vertical integration is done in networked manufacturing systems in a hierarchical way. This includes sensor level to corporate planning levels, and the levels in between. This is necessary to deliver end-to-end solution (Kagermann, et al., 2013). Products should be able to be traced anywhere in the system live and customer requirement should be reflected anywhere in the production (Baenaa, et al., 2017).

Horizontal integration can be achieved by connecting the following discrete activities: infrastructure, human resource management, technology development, procurement, inbound logistics, operations, outbound logistics, market & sales, and service. Resources, products, and material can be traced anywhere and at any time in these processes (Baenaa, et al., 2017). Vertical integration can be achieved through the connection of Enterprise Resource Planning (ERP), MES, SCADA, PLC, and sensors & actuators, which exists at different technology levels within organizations. MES is important in the first stages when transforming to industry 4.0 (i-scoop, 2017).

Additive manufacturing

Additive manufacturing (AM) is also known as 3D-printing. AM can be achieved by combining computer-aided design (CAD), modeling a range set of digital features of the product, and the submission of items to industrial machines (Cevikcan, et al., 2017). From raw material, different layers are built up by the 3D-printing machine, transforming the CAD design into reality. Additive manufacturing reduces material waste by producing only what is required (Cevikcan, et al., 2017). (Attaran, 2017) states that for the automotive industry several benefits can be gained through applications as: prototyping, component manufacturing, reducing vehicle weight, and cooling systems. The benefits that can be achieved are: help eliminate excess parts, speed up time to market, reduce the cost involved in product development, reduce repair costs considerably, and reduce inventory.

Cloud

Cloud consist of cloud computing and cloud-based design and manufacturing (CBDM) (Cevikcan, et al., 2017). (Hon & Millard, 2017) state that "cloud computing" essentially involves the use of computing resources over a network, typically the internet, scalable with demand. These resources are software applications which are accessible through web browsers for the customer but are running on a remote cloud server (Hon & Millard, 2017). The service model is called Software-as-a-Service (SaaS). Furthermore (Wu, et al., 2013) show a holistic view that connects CBDM types and their activities. These types are: SaaS, Hardware-as-a-Service (HaaS), Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS). This



cloud design refers to leverage cloud computing for consumers, servers, manufacturing, and software. This holistic view is shown in Figure 2.4.



Figure 2.4: Holistic view (Wu, et al., 2013)

(Liu, 2015) introduces a cloud manufacturing model which is a service-oriented networked manufacturing model. This model optimal allocates resources efficiently in a cloud of manufacturing resources. The objective of this model is to optimize time, cost, quality of service and load balance of equipment under certain assumptions. (Wang & Xu, 2013) defines the manufacturing resources as soft resources and hard resources. The soft resources are: software, knowledge, skills, personnel, experience, and business network. The hard resources are: manufacturing equipment, monitoring/controlling device, computational resources, materials, storage, and transportation. Security, privacy, control and interoperability are major concerns for the cloud technology (James & Chung, 2015).

Augmented reality

Augmented reality (AR) together with Virtual reality (VR) are expected to grow strongly till 2021 (i-scoop, 2017). These virtual technologies are computer-supported reflections of a real-world environment with additional information (Paelke, 2014). Augment systems support a variety of services and applications, for example, part selection in a warehouse and sending repair instructions over mobile devices, real-time information for improved decision making, and virtual training (Gerbert, et al., 2015). Visualization technologies focuses on three areas: video-based adaptation supported by a camera for augment assisting, optical adaption by wearing a display for additional information, and projection of stated objects (Paelke, 2014). More practical, these features can be used to track products and visualize current state by graphical interfaces, also interaction between operators, machines, and other devices. These interactions can be used for cyber visualization and to change parameters to better understand operational and maintenance instructions (Cevikcan, et al., 2017). AR requires low latency to let virtual objects stay in their position, which can be a potential issue with this technology (Nee & Ong, 2013).



Simulation

Simulation can be performed by simulate materials, product, machine behavior, and humans in 3D (Gerbert, et al., 2015). This means there is a virtual world that simulates the physical world of manufacturing. The simulation is based on real-time data and can be done to test and optimize machine settings. This can be done by changing certain parameters and visualize the decision-making process. These what-if scenarios can be used to improve the robustness of the processes. For smart factories, simulation is especially necessary since production processes consist of autonomous decision-making (Cevikcan, et al., 2017).

For overall performance optimization of the manufacturing industry, big data can be used within industry 4.0 in Discrete Event Simulation (DES) (Howard, 2017). With DES scheduling and different experiments can be done to control cost and quality in a virtual environment. Due to use of real-time information from the system, different plans and schedules can continuously be optimized to minimize unnecessary losses and disruption. Simulation tools are, for example, Siemens Plant Simulation, Flexsim, and Industrial path simulation.

Big Data and analytics

Real-time data can be found in nearly every industry (Cevikcan, et al., 2017). Many processes contain a lot of data on manufacturing, maintenance, logistics and more. With the basis of an IoT infrastructure and a big data platform, big data analytics can be made. The IoT infrastructure involves internet connections with devices as PCs, smartphones, tablets, WiFi- enabled sensors, wearable devices, and household appliances. Most devices visualize and some even create their own data. Collecting data from different equipment, systems, enterprise systems, and customer management system, is expected to be standard to support real-time decision making (Gerbert, et al., 2015). By sending and capturing data in a IoT infrastructure, data can be mapped, transformed, cleaned, and stored in a big data platform. These actions at the big data platform make sure that the right data can be explored, cleaned, analyzed, and shared (as in Figure 2.5).



Figure 2.5: Big data flow IoT (Ahmed, et al., 2017)



This is called big data analytics (Ahmed, et al., 2017). Furthermore, (Ahmed, et al., 2017) introduces a thematic taxonomy for IoT analytic solutions. Large data collection in manufacturing leads to optimizing production quality, saving energy, and improve equipment service. In Industry 4.0, big data analytics can support real-time decision making through identifying patterns in data (Gerbert, et al., 2015). More features of big data analytics in Industry 4.0 are easy and high scalability, and fast and various data sources (Cevikcan, et al., 2017).

Industrial Internet

Industrial Internet of Things (IIoT) consists of a network of smart objects, smart networks, physical object integration in manufacturing, and service processes. Currently IIoT is becoming an engaging topic for industry and end-users since the decreased costs for sensor networks, Near-field communication (NFC), Radio-frequency identification (RFID) and wireless technologies, communication and networking used. In an IIoT all computers and machines are in inter-related network whereby data is used in a reciprocity way. Requirements for this communication network are: distributed computing and parallel computing for data processing, Internet Protocol (IP), communication technology, embedded devices (RFID tags, Wireless Sensor Networks (WSN), and applications. Benefits from IIoT are enhanced quality and increased manufacturing output (Cevikcan, et al., 2017). A framework of a business model for the implementation of IIoT technologies is introduced in (Gierej, 2017). This can be used as a supporting tool to introduce IIoT technologies.

Cybersecurity

Cybersecurity means securing the data storing and transfer process in cloud technologies, machines, robots, and automated systems. This means securing data exportation, privacy regulation and standardization of communication protocols, personal autorotation level for information sharing, and detecting and reacting to unexpected changes and unauthorized access (Cevikcan, et al., 2017).

Cybersecurity is described in (Cevikcan, et al., 2017) in multiple layers. Security threats and vulnerabilities are described on levels as: perception, network, service, and application layer. It is expected that cyber-attacks become more strategic in future through bots, malicious codes, and morphing. Furthermore, (Cevikcan, et al., 2017) provide several solutions to cyber-attacks. Primary principles of IoT are addressed to the following six aspects: confidentiality, Integrity, availability, authenticity, non-repudiation, and privacy. Cybersecurity is strongly depended on the upcoming trends that consist in Industry 4.0, for example, IoT, Big Data, and



Cloud. Poor cybersecurity is a serious threat and needs to be taken very seriously when a factory is digital transforming to Industry 4.0.

Sensors and actuators

In Industry 4.0 embedded systems consist of control units, sensors, and actuators. Smart sensors and actuators are connected to a control unit. Smart Sensors send processing signals and actuators independently check the production status when necessary. These data are sent to a central control unit via buses. In a smart system, these sensors and actuators are the core elements of an embedded system (Cevikcan, et al., 2017).

RTLS and RFID technologies

Real-time Locating System (RTLS) and RFID are smart technologies for identifying, locating, and sensing products in a manufacturing to customer environment (Uckelmann, 2017). Unique serial numbers can be allocated to the RFID tags by matrix code, QR code or a standard barcode. RTLS and RFID in the industry can provide the following benefits: a high degree of transparency, real-time data flow for rapid support, process-optimized production, and increased functionally and flexibility on assembly (Cevikcan, et al., 2017).

Mobile technologies

Through to development internet, Wi-Fi, high quality cameras in mobile devices, mobile technologies nowadays can be used for processing large amounts of information. Data can be transmitted or received in a textual of visual way. These mobile technologies can be used to interact with process material, equipment, finished goods and parts through an IIoT system. Benefits from these mobile technologies are faster issue recognition, and the speed of information communication (Cevikcan, et al., 2017).

2.3 Value drivers

This section identifies the Industry 4.0 value drivers, the value levers that trigger the value drivers, and the main challenges regarding Industry 4.0. In Figure 2.6 a model is shown that helps to transform to industry 4.0 as company. To create an industry 4.0 roadmap and test-case, common industry 4.0 opportunities and threats are identified based on the digital maturity of the company. The digital maturity of a company can be measured in terms of technologies, data management, analytics, interfaces and business imperatives. In the following subsection common opportunities are explored that can be reviewed within a company.





Figure 2.6: Digital leadership steps (Capgemini, 2017)

2.3.1 Value opportunity

Different value drivers, and value levers are described by (Stricker, 2017) and (McKinsey, 2015). Key value drivers from (McKinsey, 2015) provide more explicit applications than (Stricker, 2017), which are shown in Table 2.1. These values drivers can be applied within companies for open discussion to find the best suitable value levers that solve problems and increase performance. Each value driver can be measured by a performance indicator. (Lindberg, et al., 2015) mention key performance indicators (KPIs) are defined on the level of energy, raw-material, operation, control performance, maintenance, planning, inventory and buffer, and equipment.



Value drivers	Value levers/applications			
Time to market	Rapid experimentation and simulation			
reduce time to	Concurrent engineering			
market	Customer co-creation/open innovation			
Service/aftersales	Predictive maintenance			
reduce maintenance cost	Remote maintenance			
	Virtually guided self-service			
Resource/process	Smart energy consumption			
increase	Intelligent lots			
productivity	Real-time yield optimization			
Asset utilization	Routing flexibility			
reduce machine down-	Machine flexibility			
time	Remote monitoring and control			
	Predictive maintenance (2)			
	Augmented reality for maintenance, repair, opera-			
	tions (MRO)			
Labor	Human-robot collaboration			
increase	Remote monitoring and $control(2)$			
productivity in technical	Digital performance management			
professions	Automation of knowledge work			
Inventories	3D printing			
reduce inventory cost	Real-time supply chain optimization			
	Batch size 1			
Quality	Statistical process control (SPC)			
reduce quality cost	Advanced process control (APC)			
	Digital quality management			
Supply demand match	Data-driven demand prediction			
increase forecasting accu-	Data-driven design to value			
racy				

Table 2.1: Value drivers (McKinsey, 2015)

2.3.2 Challenges

Next to the added value of Industry 4.0, there are also some challenges to face. (Masters, 2017) mention the following challenges (or some even threats) especially for the automotive industry, which require continuously automation and visibility in the supply chain.



Following from research, we have identified the following industry 4.0 challenges:

- Contractor integration Usually the automotive industry relies on contract manufacturing. This means that fast-changing demands changes with high flexibility is required and the use of contractor integration into supply chain.
- Data security/cybersecurity Before Industry 4.0, data never leaves an organization. With industry 4.0 a company is more vulnerable to cyber threats. This means that cybersecurity is important to protect companies, but also the buyer's data.
- Data management These days automotive companies have a wide range of data available. The major challenge still lies in gaining the useful insights through advanced analytics.

2.4 Conclusion

The conclusion of this chapter is based on the different research questions that are given in section 1.4.

1.1 What Technologies are fundamental for an Industry 4.0 transformation?

In section 2.2 we described the industry 4.0 technologies: autonomous robots, horizontal and vertical integration, additive manufacturing, cloud, Augmented Reality, simulation, big data and analytics, industrial internet, and cybersecurity. Next to these, there are three more called core technologies described: sensors and actuators, RTLS and RFID, and mobile technologies. These technologies are required for a successful implementation of Industry 4.0 transformation (Cevikcan, et al., 2017). However, it is not necessarily a requirement to have all technologies to digital transform a factory. Each technology for independently can add value to a factory. The strength of Industry 4.0 is to connect multiple technologies to each other in order to gain integral advantages and insights into the factory.

Additive manufacturing seems not as potential adding value technology or application for the automotive industry. Because of the long processing time of additive manufacturing, benefits from additive manufacturing are highly unlikely to be met.

1.2 How does Industry 4.0 add value and how can it increase performance?

Industry 4.0 comes with several value drivers as described in section 2.3: time to market, service and aftersales, resource and process, asset utilization, labor, inven-



tories, quality, and supply demand match. To increase performance, several applications areas are linked to the performance indicators (McKinsey, 2015). Not all applications add value for each specific factory. These applications should be reviewed specific for each factory, to identify what opportunities can provided the highest value.

Furthermore, these applications provide a more practical dimension to Industry 4.0. For most of these applications that drive performance, value can't be captured without a huge and reliable data source using electronics and IT. In other words, a strong 3rd industrial revolution compliance.

To tackle specific scenarios, (Hermann, et al., 2016) shows a model to provide a common industry 4.0 understanding for identifying Industry 4.0 scenarios.

1.3 What are the main challenges regarding Industry 4.0?

The main challenges regarding to Industry 4.0 are:

- *Cybersecurity* Cybersecurity is important due to the increasing cyber threats that we face these days. The right authorization levels for accessing and storing data play also a role in this part.
- Safety With the increased use of, machines, robots, and machine-robot collaboration within Industry 4.0, you want to be a 100% sure that what you implement in practices is safe. Not only how robots are programmed and calibrated and in a physical way, but also due to the fact when a robot is connected to an Industrial Network that allow maybe hackers to take over a robot. This is where cybersecurity and safety overlap.
- Data Management Data management requires not only storing data, but also storing the right and reliable data. Effectively and efficient data management is for each company-specific a challenge.
- *Contractor integration* Setting up a contract for customers against high flexibility and complexity can be very complex.
- *Education* It is overall known that technology innovates very rapidly. Since the topic Industry 4.0, and the use of these technologies and applications are quite unknown or new, we expect that an education is required when as factory digital transform.





3 Current situation at Scania Production Meppel

This chapter answers the research question "2. What is the current state of the processes regarding Industry 4.0 at Scania Production Meppel?". Section 3.1 describes Industry 4.0 opportunities in a scenario based way with application areas that can be found in the previous chapter.

3.1 **Opportunities**

This section identifies different Industry 4.0 opportunities (scenarios) that can provide added value for Scania Production Meppel. These opportunities are reviewed for all the different processes (Loading, PaintShop, Paint Distribution, etc.) and in relation to the process from an integral view (total from Inbound to Outbound). The different opportunities are derived due to the Industry 4.0 applications that are identified in subsection 2.3.1 (in Table 2.1). All opportunities are mapped in Table 3.1 on the different processes, where they have added value. The mapped opportunities are visualized by applying three colors in the table. In Table 3.1 the dark grey colored applications are analyzed for each process, the light grey colored applications are integral analyzed to identify opportunities, and the white colored applications do not apply to the corresponding process name.

		Process name						
Value Driver	Application area	Loading	PaintShop	Paint Distr.	l&R	Unloading	Assembly	Maintenance
	Rapid experimentation and sim-	18	22/23					
Time to market	ulation							
reduce time to	Concurrent engineering	26						
market	Customer co-creation/open in- novation	Out of scope						
Service/aftersales	Predictive maintenance							1
reduce mainte-	Remote maintenance							2
nance cost	Virtually guided self-service							3
Resource/process	Smart energy consumption				4			
increase produc-	Intelligent lots				5			
tivity	Real-time yield optimization				6	-	-	
A goot utilization	Routing flexibility		7	8	17			
reduce machine	Machine flexibility		10		9			
downtime	Remote monitoring and control				25			
downenne	Augmented reality for MRO		-		12			1
Labor	Human-robot collaboration	13				1	3	
productivity in	Digital performance manage- ment				14			

Table 3.1: Industry 4.0 applications per process



technical profes- sions	Automation of knowledge work		15					
T	3D printing							29
Inventories reduce inventory	Real-time supply chain optimi- zation	16						
cost	Batch size 1		27					
	Statistical process control (SPC)				11	1	9	
Quality reduce quality cost	Advanced process control (APC)				20			
	Digital quality management	28						
Supply demand	Data-driven demand prediction				21			
match increase forecast-	Data driver design to color	30						
ing accuracy	Data-driven design to value							



does not apply to the corresponding process name integral analyzed to identify opportunities Per process analyzed to identify opportunities

The opportunities of the different application areas are described in this section, which are divided into different Industry 4.0 scenarios. A scenario number is allocated to each scenario and mapped into Table 3.1. The analysis and description of the scenarios are based on the literature study in Chapter 2, job interviews, observations at the processes, and available company process information.

We have identified 21 scenarios that have potential Industry 4.0 application improvements. The potential scenarios will be considered to which one is the most promising improvement in the next section. The most promising improvement will be worked out in a test case.

3.2 Industry 4.0 Roadmap

Since this research covers mainly Industry 4.0 opportunities for Scania Production Meppel, the content of the roadmap also consists the defined scenarios. As a result, from the opportunity identification process (section 3.1), an Industry 4.0 roadmap has been derived for Scania Production Meppel to gain more insight into the Industry 4.0 opportunities and relations between the scenarios in a digital and time level. With the digital level is meant the digital layers that were found in literature, whereby for that example different processes have been mapped out into Technology integration, data management, advanced analytics, digital interface, and business imperatives). Furthermore, the different scenarios are plotted on a time scale that contains the start of this research (December 2017) until c.a. 2020. Therefore, each year has its own scenarios mapped into the roadmap. In Figure 3.1 here below the roadmap is shown. The mapped scenarios contain their corresponding scenario number and name that is defined in the previous chapter. To get a better



understanding of the roadmap, we will follow up with an explanation (including a legend) of this roadmap and a roadmap guide to for Scania Production Meppel. In Appendix D: Enlarged Industry 4.0 Roadmap an additionally enlarged roadmap is provided.



Figure 3.1: Industry 4.0 Roadmap

Roadmap legend

To understand the roadmap into more detail, the legend in Table 3.2 explains the different type of symbols that were applied in the roadmap. As explained in Table 3.2 there is a distinction between opportunities based on the scenarios that are defined in this chapter, general topics around the Industry 4.0 scenarios, and finished scenarios.

-	
Symbol	Meaning
	Scenario defined in this report as In-
	dustry 4.0 possibility. The box
	changes to green when it's an active
	test case or research.
	A general topic around the scenarios
	or Industry 4.0 that can be re-
<i>__</i>	searched.
>	Arrow indicates if there is an order
	of the topics/scenarios
	Indicates the time zone (in years)

Table 3.2: 1	Legend	of the	Industry	4.0	Roadmap
--------------	--------	--------	----------	-----	---------



When a scenario has an arrow pointed (also shown in Table 3.2) to itself, it indicates that a predecessor (where the arrow comes from) have first to be finished before starting a new scenario. So, the arrow determines in which order scenarios must be researched or executed. For example, Scenario 1 (PDA) is executed and worked out in a test case as an outcome of the AHP of this research of this report.

Roadmap Guide

Important about this roadmap is that this roadmap should be updated in the future. Updates should occur occasionally (several months) or after crucial organizational changes. Most of the scenarios that are shown in the roadmap, take place in the levels from technical integration to advanced analytics. Furthermore, it is important to set up requirements for each scenario in order to be worked out in a test case or research.



Test case Predictive Maintenance (Scenario 1) 4

As result of the previous chapter a predictive maintenance test case (scenario 1) is elaborated in this chapter. Section 4.1 describes the scope of the test case into detail.

4.1Test case scope

The four robots of the T2CC paints on two skid locations. In Figure 4.1 a top view is provided of the T2CC paint booth. A skid arrives the T2CC painting booth in cabin 1 on skid position 1630 where robot R11 and R21 paint from both sides a first layer on the parts on skid. Next the skid goes to the flash off on position 1640 where the paint dries. Finally, the skid will go to cabin 2 on position 1650 for a final paint layer by robot R12 and R22, and then the skid leaves the T2CC area. At the T2CC two layers of paint are added on the parts. This means that robot R11 and R21, use more or less the same amount of paint as robot R12 and R22.



Figure 4.1: top view - Paint booth T2CC

At Scania Production Meppel, Product Data Acquisition (PDA) is currently available at the T2CC robots. PDA registers and is able to show on screen: signals that are measured from the real-world condition of the robots and the equipment on it. Skid information is not tracked through PDA, but through the PDM system. The rest of the robots at Scania Production Meppel do not have this system in place but is yet being considered to be bought for the remaining robots of the PaintShop department. PDA keeps track of signals from PLC T2CC and four Robot Controllers of R11, R12, R21, and R22 (Figure 4.2). The robot controllers use the softwaredriven motion control of the robots. Which means that they control all the physical robot movements based on the programmed robot software. The robot software that controls the painting robots in the robot controllers is specifically created for the different type of skid setups.







Figure 4.2: PDA topology

The signals that go in and out of the robot controllers are robot specific signals, e.g. digital and analog robot position, electrical, pneumatic, and lightning cable signals. The PLC T2CC measures and controls skid positions due to a conveyor. Furthermore, the PLC keeps track of the common paint booth process for all the four robots together. However, due to the enormous amount of data stored, the data is available for a finite timespan until approximately a month back in time.

PDA tracks a lot of data from the robots which is only used after robot errors by the technical support and PaintShop operators. PDA shows a lot of data about pumps, valves, and more, that can possibly provide more insight to the technical support about the condition of robot equipment. Furthermore, Scania Production Meppel is not yet familiar with predictive maintenance, and there is a lot of costly stop times at the paint booth. The huge amount of data provides the possibility for a test case for predictive maintenance. For this test, multiple interviews were performed with technical support and PaintShop operators to take their experience and insight with PDA and the robots into account and verify to findings.

4.1.1 Predictive Maintenance

According to (Kothamasu, et al., 2006) a maintenance policy is defined as reactive and proactive maintenance (see Figure 4.3).

Reactive Maintenance

With reactive maintenance (RM) service workers repair or replace equipment when it fails. Scania Production Meppel does both RM activities: Corrective Maintenance (CM) and Emergency Maintenance (EM). CM is carried out after equipment failed. In this case the state of the equipment will be restored to an acceptable equipment condition. EM is carried out as fast as possible on the failure matter to avoid unnecessary (additional) damage and consequences.



Proactive Maintenance

Proactive maintenance is performed to prevent equipment from failing by repairing or replacing. Scania does Constant Interval Maintenance (CIM) at night while there is a planned production stop of an hour. CIM has a fixed time interval whereby equipment is repaired or replaced. Hereby the time intervals are determined by the maintenance office of Scania Production Meppel based on their data and experience. It is important to find a tradeoff between risk failure costs and preventive maintenance costs.

Predictive maintenance responses to real-time equipment conditions by conditionbased maintenance (CBM) and statistical failure rates due to Reliability Centered Maintenance (RCM). Scania Production Meppel makes use of several sensors to measure the paint booth environmental conditions, but predictability is still unexplored for all equipment.



Figure 4.3: Scope test case (Kothamasu, et al., 2006)

Since there is limited data back in the time from PDA, it is hard to make statistical estimations. To make predictions, the data on these equipment conditions need to be monitored or available. Since this is available, condition-based maintenance has the predominance in this predictive case.

4.1.2 Atomizer

The atomizer of the robot is the head of the robot. In the atomizer Figure 4.6 valves are switched on and off by the robot controller to spray the parts of the skids. The atomizer must deal with all different colors (more than 500) that Scania is able to produce. Next to the paint, there is also hardener to harden the paint on the parts. When the robot auto cleans, the rinsing agent valve opens to clean the inside of the atomizer, including the main needle. The red box striped box in Figure 4.6 shows the exact position of the main needle in the atomizer. Next to the atomizer, the atomizers are shown on the painting robots in Figure 4.6.







Figure 4.4: Left: atomizer, right: atomizer on the robot in the paint booth

There are no feedback signals of the valves, but from the main needle, there is. The time that the main needle in the robot atomizer takes to open and close, is sent through a binary feedback signal via a light conductor. After this signal is converted into an electrical signal and send to the robot controller. The robot controller sends this signal to PDA. When the data of the main needle is exported out of PDA, the timestamps give in a binary value if the main needle is on or off. This signal is illustrated in Figure 4.5. A revised atomizer gives often an initial open and close main needle signal of 80 milliseconds. The robot controller gives a signal when an error occurs. The main needle errors occur when the main needle time is equal or higher than 190 milliseconds. This holds for when the main needle open or close time exceeds this threshold. If this value exceeds 190 milliseconds, the brush properties of the robot is set too late and the paint will not fully cover a part that are being painted.





4.1.3 Approach to predictive maintenance

To perform CBM (Jardine, et al., 2006) explains that there are three key steps to execute. These steps are data acquisition, data processing, and maintenance decision making as shown in Figure 4.6. Below Figure 4.6 is explained how these steps are executed in this test case.



Figure 4.6: Condition-based maintenance (Jardine, et al., 2006)

Data acquisition

Due to the help of PDA at the robots, it is possible to receive the historical data of the main needle and other sensors of equipment. This data is registered each 10 milliseconds in PDA. The data can only be collected by opening the data tool at the PDA PC and exporting the selected to the following file formats: .xls (Excel), .txt (notepad), .accdb (Acces), and .m (MatLab). However since the .xls function is not working, this test case uses the exported to .txt files function with a time window of 12 hours registration of data. The PDA software often doesn't allow more than 12 hours of data per export. For this reason, exporting is 160 times executed to gather four weeks data for the four T2CC robots.

Data processing

After collecting all .txt files, we imported the data to Excel to clean the dataset. An Excel file is set-up with a corresponding name to the exported dataset. The Excel file contains a Visual Basic for Applications (VBA) code¹. In this code we made a translation is made from the main needle open and close signal as in Figure 4.5 per timestamp to the real main needle times in milliseconds. The additional variables that are taken into account are explained in the analysis of the main needle (subsection **Fout! Verwijzingsbron niet gevonden**.). To predict the main n eedle condition through data analytics, a predictive model is applied to the main needle condition (which is explained in section **Fout! Verwijzingsbron niet gevonden**.).

Maintenance Decision Making

Maintenance decision making for this study is based on one-month historical data of PDA. The goal of the predictive model in section **Fout! Verwijzingsbron niet g evonden**. is to optimize the decision for each time the atomizer will be replaced. From this point, an indication is required to predict the expected atomizer lifetime before failing.

¹ For the VBA code see code 1 and code 2 of Fout! Verwijzingsbron niet gevonden..



5 Reflection and Discussion

In this chapter, we reflect the test case and discuss what Industry 4.0 should offer and how it can offer opportunities for Scania Production Meppel. Section 5.1 provides what the test case means for Scania Production Meppel. Section Fout! Verwijzingsbron niet gevonden. provides two application opportunities we recommended further researching.

5.1 Reflection on test case

In this section, we reflect on the monitoring of the main needle times, the scalability of the used prediction model, and what test case tell about Industry 4.0 opportunities in general at Scania Production Meppel. After reflecting the test case, we will define some recommended opportunities for Scania Production Meppel on the topic Industry 4.0.

5.2 Industry 4.0 future development

In this section, we describe how future opportunities can be developed. First, we tell what steps we think are necessary to find new Industry 4.0 opportunities. Second, we shortly describe two scenarios from this research in corresponding with the steps we defined. Finally, we tell what this means for the Industry 4.0 roadmap at Scania Production Meppel.

Finding new industry 4.0 opportunities

To development such applications in the future for Scania Production Meppel, we have defined several steps to find Industry 4.0 opportunities. These steps are exclusively based on the information of this research. This means that we have defined these. The steps to define the new Industry 4.0 opportunities are shown in Figure 5.1. The figure consists of five different steps that we think are important to successfully develop new Industry 4.0 opportunities.





Figure 5.1: Find Industry 4.0 opportunities

Finding opportunities should be done by starting at step 1 until step 5. Influences from step 5 should be coupled back to step 1. We will explain all the individual steps of Figure 5.1 here below, and after that will describe an example with the test case predictive maintenance and another defined industry 4.0 opportunity from this research for Scania Production Meppel. The five steps we defined to identify opportunities for Scania Production Meppel are as following:

1. Strategy - the company strategy, mission, and vision can vary in the future due to external influences such as innovation of technology, changing competition, environmental issues, etc. Recall that have defined several strategic criteria in Table 5.1 which can be used to measure the importance of industry 4.0 applications. These strategic criteria should be checked and updated on the selection of criteria and their weights.

Category	Criteria				
	Interconnection				
Industry 4.0	Information transparency				
compliance	Decentralized decisions				
	Technical assistance				
	Cost				
Ctart	Sustainability				
Strategic vision	Feasibility				
	Quality				

Table 5.	l: Inc	lustrv	4.0	strategic	criteria
1 4010 0	· · · · · · · · · · · · · · · · · · ·	rastry	1.0	Strategic.	0110011a



These criteria are based on the company strategic year plan and the Industry 4.0 criteria from research (Hermann, Pentek, & Otto, 2016).

- 2. Goal when it comes to Industry 4.0, the goal(s) of the organization can be chosen in the form of performance indicators. From the literature, we have found several Industry 4.0 applications that are able to drive such performance indicators: time to market, maintenance cost, machine downtime, productivity, inventory cost, quality cost, forecasting accuracy. In this step we select one specific performance indicators to find an Industry 4.0 opportunity.
- 3. Information based on a chosen goal, define what the problem is, what information is available, and how are the current business and production processes. For example, what causes the biggest downtime in the production process. In the test case (predictive maintenance) we have found useful data from the robots to tell something about the equipment (main needle) that causes the most downtime in the production process. Further, from this test case is known in this test case that there is a preventive replacement policy with a time interval of four weeks.
- 4. *Functions* the functions that are described should be based on the information and some industry 4.0 application that match the performance indicator from step two. The function should describe an application we have found in this research or in new-found application from research.
- 5. Technology after knowing what functions can improve performance indicators, the application and technologies can be described into detail. Describing for example, what additional technologies or applications are still missing or already exist. In this final step alternative solutions should be presented to consider in a test case. After all these steps are performed, finally a test case to a specific application of technology can be performed to plan, design, exercise on implementation and evaluate results (Mussa & Khendek, 2018). From the digital maturity model, we can be concluded that standardization, governance, architecture, infrastructure of data of very important to include in such technology and data integration (Van Thienen, Clinton, Mahto, & Sniderman, 2016).

To decide what function with what corresponding technology and application is the best for the test case should be determined by an AHP. In the AHP as in this research, the strategic criteria and weights should be used from step 1.



6 Conclusion and recommendation

This chapter describes the conclusions and recommendations as a result of the master thesis. Section 6.1 provides all the answers to the research questions of section 1.4. Section 0 describes all recommendations of this research and for further research.

6.1 Conclusion

In this conclusion we answer all the research question:

1. What is Industry 4.0?

Industry 4.0 is the 4th industrial revolution, which is also known as Smart Industry within the Netherlands. Based on fundamental technologies, a digital transformation of the current factories worldwide will be the future. Currently, there is a lot of literature on Industry 4.0, but there are also a lot of different interpretations and focusing areas of Industry 4.0. For this research we have described technologies to form a technical basis of information and feeling with Industry 4.0, and value drivers and applications to form a specific as possible fundament for identifying opportunities with Industry 4.0.

Industry 4.0 technologies are for example autonomous robots, cloud, Industrial Internet of Things, additive manufacturing, and more. These technologies can be seen as individual improvements for companies but does not always suit each type of company. For example, Additive manufacturing is still not recommended to use in the automotive industry, especially when it comes to printing huge truck parts. However, combining multiple technologies is seems to be the strength of Industry 4.0 to gain integral advantages for the company.

The value drivers that were found in the literature, tend to improve when using such applications. The value drivers to increase performance are time to market, maintenance cost, productivity, inventory costs, quality, and forecasting accuracy. An application example is a human-robot collaboration. By using such application, productivities could be increased due to a robot that can support a human in practice. These applications can be complex, dangerous, and requires for this reason more research.

Several Industry 4.0 challenges have been identified. These are safety, cybersecurity, data management, contract integration, and education. Safety and cybersecurity can be seen separately but also together when it comes to robot arms. Humans need to be careful when standing around a robot, but also needs to be connected



to an industrial internet of things network when it comes to Industry 4.0. With the growing trend of technical innovation, education within the company will become more important in order to stay along with the competitors that make an Industry 4.0 digital transformation.

2. Recommendation

In this section, we have described several recommendations based on the Industry 4.0 study and the test case predictive maintenance on PDA data. As result of this research, we have set three recommendations regarding the Industry 4.0 study and explored opportunities for Scania Production Meppel. Subsequently we have three more recommendations regarding the predictive maintenance test case. We recommend carrying these three recommendations in ascending order of 3 to 5.

Recommendation 1: Identify and research technology and data structure regarding Industry 4.0

Recommendation 2: Using roadmap to identify and develop current and new scenarios.

In section 3.2 we have introduced a roadmap to identify and develop industry 4.0 scenarios from now to 2020 for Scania Production Meppel. The current explored scenarios from this research are mapped into the roadmap. Five categories of digital maturity are taken into account in this roadmap. The lowest level is from Technical integration and the highest level is business imperatives. Most of the scenarios are all mapped in the lowest three levels of this digital maturity level. According to this research we recommend using this roadmap to identify and execute research topics around Industry 4.0. The more Scania Production Meppel develops the more research and test cases on a higher level can be executed. It is important to first have a strong technology and digital fundament before doing advanced analytics on such data, to make sure all variables can be considered. The most promising opportunities we have defined in the roadmap are horizontal integration and smart monitoring. These two opportunities can increase the integral view on the production process by coupling more data to each other to one a product.



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