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Quality data management software is a tool for driving improvement activities

Master's thesis in Production Engineering

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MASTER'S THESIS 2020

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Abstract

The fourth industrial revolution has changed the possibilities for the manufacturing industry during the last decade through digitalisation. Real-time data can be accessed from production processes and monitoring as well as analyses can be made instantly. The data can be used in the proactive work to identify critical parameters before they cause errors. This thesis investigates how a Swedish manufacturing company can digitalise their measurement data by introducing a quality data management software. Through a literature review, an interview study at the case company and a benchmarking study at an industrial leader in the area, this thesis has been conducted. The study shows how the current situation regarding measurement data at the case company has not reached its potential to use it for improving their business due to the lack of an evaluation software as well as lacking IT infrastructure. Though, by implementing a quality data management software and new equipment, the measurement data can be used for visualisation and analyses to drive improvement activities as it becomes digitalised. This makes the use of the data value-adding, which creates a completely new environment where it is easier to base decisions on facts.

Keywords: digitalisation, Industry 4.0, quality data management software, production, smart manufacturing.

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Contents

Glossary

This glossary explains important concepts and abbreviations used in the thesis.

Coordinate-measuring machine (CMM)
A device that measures the geometry of physical objects by sensing discrete points on the surface of the object with a probe.

Control plan
Shows which parameters to measure, how many to measure and how frequent.

Digitisation
Digitisation is the process of converting analog data into digital format so that computers can store, process, and transmit such information.

Digitalisation
Digitalisation is the process of using digital technologies (e.g. quality data management software) to improve and transform business processes by adding value to the digitised data.

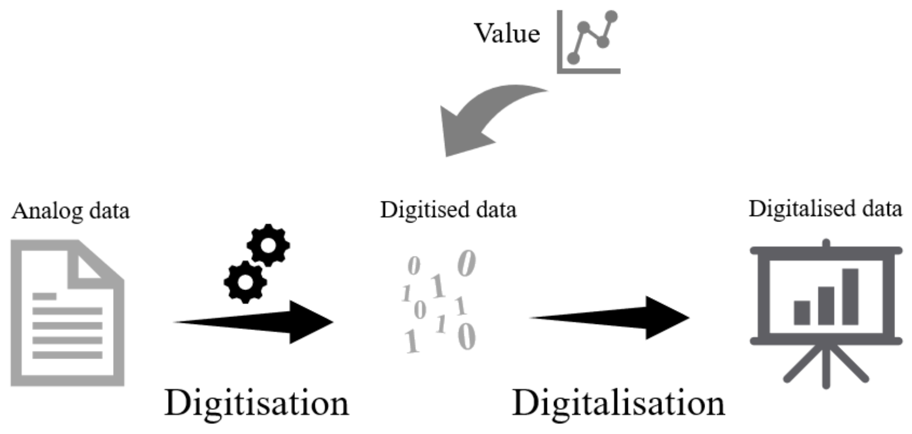

Figure i: Process from analog data to digitalised data

Highest-paid person's opinion (HiPPO)
The opinion of the highest paid person, often hieratically higher.

First piece inspection (FPI)
The measurement made when a new product or batch is released after changeover.

Process measurement (PM)
The continuous measurement in the process, measured according to the control plan. To monitor that the process stays within specification.

Product audit (PA)
The measurement to verify that the control plan for PM is working. Could be seen as the “customers eyes” in the factory.

Quality data management software
A software to organize, analyse and visualise quality data in an Industry 4.0 environment that can bridge the gap between digitisation and digitalisation.

Quality data management system
The whole system around the software, including measurement collection, measurement equipment, data storage, operational guidelines, IT security and IT infrastructure.

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1 Introduction

This chapter introduces the master's thesis by presenting a background to the problem, followed by the purpose, delimitations and the research questions the thesis aims to answer. The chapter ends by illustrating the outline of the report.

1.1 Background

The manufacturing industry have in the last decade been digitalised through a data-driven revolution where traditional production facilities have been transformed into smart ones (O'Donovan, et al., 2015). These facilities make it possible to access real-time data from production processes, which supports the decision-making that can give benefits to the whole organisation. As a central part of the Industry 4.0 concept, Internet of Things is a system where units are connected and can exchange data (Schönsleben, et al., 2017). The Internet of Things technology is the foundation for processing machines, measurement tools and all other production facility equipment to talk to each other. This creates completely new possibilities for companies to collect live-data from their factories (O'Donovan, et al., 2015). To make use of the opportunities this creates, it is not enough to only collect data, you must know how to handle the data in the right context to take advantage of it. The smart manufacturing facilities generates enormous amounts of data that organisations must learn to extract meaning from by using appropriate analytical techniques (O'Donovan, et al., 2015).

The case company selected is a leading global supplier of the products, solutions and services they provide. In 2017, the case company introduced a new production unit that is the first of its kind within the company group. This new channel is a fully-automated and digital production process adapted for manufacturing the case company's products. The investment cost for the channel was SEK 190 million and was among other intended to develop long-term statistical evaluations of diagnostic data. Through the use of previously mentioned technologies, the entire value chain from inflow of material to delivery of final product is connected. In this channel, every single product that passes by gets measured automatically and the values are uploaded to a database.

Two central words regarding Industry 4.0 are digitisation and digitalisation. Digitisation is the process when converting analog data into a digital format (Machado, et al., 2019). The latter, digitalisation, is on the other hand the process where the digitised data is used to add value to the business. At the moment, the measurements from the case company's new production unit are digitised, which means the values are converted into a digital format and stored in a database. However, the data just gets piled up in the database and as there are lots of measurements it is basically impossible to interpret the data and even harder to analyse, straight from the database.

To make the data useful for decision-making, it must be transformed into information (Theriault, 2014). This could be made by using a quality data management software (Carl Zeiss, n.d.). This software can be used to view and analyse measurement data in an easy and understandable way. Today, there is no established central software for handling measurement data at the case company and the company faces challenges in general when it comes to organising and defining data sets. Though, the case company's parent company has recently decided to use a specific quality data management software as a global standard and this software is now about to be implemented at the case company. With this system implemented, all the measurement data will be accessible in a user-friendly environment and could be used to make accurate analyses based on the actual production processes. This would also make today's process evolve into a digitalised one as the data can be used to improve the business. Conclusions can be drawn based on the data when it is viewable in the software and therefore it becomes value-adding. Now, the case company would like to explore and evaluate the benefits such system would give the factory when it is implemented.

1.2 Purpose

This study aims to investigate the effects and advantages the case company will achieve by digitalising their measurement data by using a quality data management software in their daily operations. This will explain how the software supports the company to keep track of their production processes. It will also help managers to realise what they can achieve if they understand how to use the data in an efficient way. Finally, this will hopefully lead to more decision-making based on facts, in order to avoid decision-making based on intuition, speculation and single observations.

1.3 Delimitations

The thesis will focus on what is possible to achieve by using data that is in a digital format today or data that is currently planned to be digital in the future. Hence, a specified implementation plan to describe what the case company must do in the nearest future will not be given. As the purpose says, the study will explore how managers can make use of such program to extract information, which build process-knowledge that supports decision-making. Therefore, operators will not be involved in the interview study in this thesis.

1.4 Research questions

To fulfil the purpose of this study, three research questions have been formulated:

RQ1: What needs does the stakeholders at the case company have on a quality data management software?

RQ2: How does the usage of a quality data management system affect the case company? What benefits and value-adding comes by using such system?

RQ3: When having a quality data management software, what makes it a natural part of the daily routines?

1.5 Outline

To simplify for the reader, the following subchapter illustrates the structure of the report. The thesis consists of six chapters, and the main points of each chapter are described in Table 1-1.

Table 1-1: Outline of the thesis.

Chapter	**Content**
1. Introduction	The chapter describes the background of the project, followed by the purpose and the delimitations. The chapter ends by presenting the research questions.
2. Theoretical framework	The literature study of the thesis is presented in this chapter. Both literature regarding the subject and the methodology concepts used, are presented.
3. Methodology	This chapter explains the methodology used in this thesis, covering how the literature, interview and benchmarking study was planned, executed and analysed.
4. Empirical findings	In this chapter the empirical findings from the study are presented. It consists of the interview study held at the case company as well as the performed benchmarking study.
5. Discussion	The empirical findings are analysed by the studied literature and further discussed. Also, a discussion regarding the methodology and future research are presented.
6. Conclusion	The conclusions of this thesis where the research questions are answered to fulfill the purpose.

2 Theoretical framework

This chapter provides an overview of the relevant theoretical framework used in this thesis. Central concepts regarding the topic as well as methodology concepts are presented.

2.1 Digitisation and digitalisation

To fully understand what digitalisation is, it is important to be familiar with the word digitisation. Machado, et al. (2019) states that the concept of digitisation means that analog data is transformed into to a digital format. Further, Finch (2018) describes digitisation as "*doing the same things, differently*" and points out how often people misunderstand the buzzword. Digitisation uses technology to improve operational efficiency, without adding value to the business model. If you go one step further from here, digitalisation status can be reached. Machado, et al. (2019) defines the process as "*digitalisation is connected with the use of technologies and data to improve and transform business processes*". This means that by using the digitised data in a manner to add value to your business model, you have digitalised your process. This provides new opportunities to optimise products and processes in a way that was not known before (Büttner & Müller, 2018).

Digitalisation is a megatrend that affects the whole society, according to Büttner and Müller (2018). Within the manufacturing industry, it is currently seen as one of the biggest uncertainties. Though, both Maffei, et al. (2019) and the Swedish Ministry of Enterprise and Innovation (2016) are convinced that digitalisation gives enormous opportunities to develop smarter and more sustainable manufacturing. One challenge regarding digitalisation is that it requires a higher level of IT security (Ministry of Enterprise and Innovation, 2016; Büttner & Müller, 2018). Another frequently mentioned challenge in literature is that it might require a change of competence. The possibility to handle, as well as to perform fast and effective data analysis, will be crucial for companies to capture the potential values (Ministry of Enterprise and Innovation, 2016). Therefore, it will be important to invest in training and professional development early in the digitalisation phase in order to make it a successful transition (Agostini & Filippini, 2019).

2.2 Industry 4.0

The most prominent use of digitalisation in industry is the fourth industrial revolution which is known as Industry 4.0 (Schumacher, et al., 2019). It was first introduced by the German government in 2011 with the name *Industrie 4.0* as a part of the "High-Tech Strategy 2020 Action Plan" (Wang, et al., 2016). What made this revolution stand out from the previous was that it used new and smart technologies, that was lacking before (Crandall, 2017). This made programs developed during the third revolution, reach its full potential where programs as manufacturing execution systems and shop floor control could be connected. Two of the concepts often used within Industry 4.0 are Internet of Things and big data (Agostini & Filippini, 2019) which are further explained in the following subchapters 2.2.1 and 2.2.2.

Manufacturing companies expects the new possibilities created through Industry 4.0 to contribute to company's net profit in the end, especially for production locations in high-wage countries (Schönsleben, et al., 2017). Industry 4.0 also supports employees in operating with new technology to make manufacturing service performance smarter and more streamlined (Gradeck, et al., 2019). But even though intelligent technologies play a dominant role in Industry 4.0 (Závadská & Závadský, 2018), it is much more than that.

Agostini and Filippini (2019) means that you must focus on developing a well working organisation and management to be able to implement it successfully. Managerial factors as highly skilled employees regarding innovation and digital technologies, as well as knowledge of lean methods has shown to be important during the introduction. Especially important is the lean philosophy part as you do not want to digitalise any unnecessary waste, see subchapter 2.4.1. Another risk associated with personnel and Industry 4.0 is that companies may lack necessary talent (McKinsey Digital, 2016). One frequent role mentioned regarding this is for example data scientists. Machado, et al. (2019) also argues that a challenge in Industry 4.0 is to identify a common language. Apart from certain skills that is needed for a good Industry 4.0 environment, it is of high weight to build a strong internal team with an agile mindset (McKinsey Digital, 2016). It is a must to remove traditional barriers between internal functions to not have a silo-based organisation. Collaboration is a must, and expert input from operators, IT and business must all work together to capture the values from Industry 4.0.

According to a McKinsey Digital (2016) report, a good way to capture values from Industry 4.0 is to use a digital quality management. A good application could result in benefits such as higher efficiency, improved traceability and cost reductions from customer complaints. All this is possible due to using a program that record and store quality and production data. The stored data can be used for quality control, advanced algorithms and big data for quality analyses, that can help the process of identifying root causes of errors. Another suggested area for capturing value is predictive maintenance. Also here, the foundation is to collect and interpret your production data. McKinsey Digital (2016) defines three specific components for having a successful predictive maintenance; deep maintenance knowledge, strong advanced analytics know-how and a good change management strategy.

2.2.1 Internet of Things

One of the main pillars in the new digitalised era is what is known as the Internet of Things (IoT). The IoT is the trend of connecting more and more devices, or "things", to each other via the Internet (Mohn, 2018). These connected devices could be practically anything with an on/off switch that can exchange data, such as smartphones, vehicles, home security systems or manufacturing machines. As the devices reveals, IoT could affect every industry in the world. Though, Mohn (2018) sees three fields where the potential is biggest; manufacturing, health and transportation.

In the manufacturing and production area, IoT moves the border of what is possible (Mohn, 2018). Everything from all-automatic inventory systems to connected machines that signals operators when they need to be repaired, something mentioned as predictive maintenance earlier. Increased efficiency, higher production uptime and better product quality are all results that can be achieved by IoT, which leads to lowering costs and energy use. But to connect everything and exchange data does not only come with benefits, there is also a risk of industrial espionage, data theft and attacks by hackers. In a study by Deloitte (2015) made on Swiss manufacturing industry, 84% of the respondents believed that the level of cyber risk could increase considerably or very considerably as an outcome of Industry 4.0 and IoT.

2.2.2 Data-driven decisions

Big data is a term that is becoming more and more popular in digital environments lately. As the name can tell, big data are large data sets that are too hard to handle for traditional processing applications (Schönsleben, et al., 2017). It is used as a method for evaluating complex data and its primary goal is to support companies in making better business decisions (Zhong, et al., 2017). Big data enables managers to measure, hence know more about their business (McAfee & Brynjolfsson, 2012). This gives a better foundation for better predictions and smarter decisions, that previously was made by gut and intuition rather than data.

There are technical challenges with big data, as for example how to store the data as efficient as possible (Behdad, et al., 2018), but the managerial challenges are even greater according to McAfee and Brynjolfsson (2012). When you for example do not have digital data, it makes sense to let people and managers with experience make the decisions. These decisions are probably made based on their experience they have collected over time, which could make them biased. And historically, important decisions have been made by HiPPOs. This have made the transition towards data-driven decisions harder.

Specifically in many manufacturing companies, decision-making is based on historical experiences, which could affect the decision-making by taking decisions based on subjective consciousness (Zhong, et al., 2017). This results in inaccurate, untimely and incomplete consequences. Big data can help manufacturing managers to early identify errors through trend analysis of production processes (Deloitte, 2015). Though, the data collected in an Industry 4.0 environment is according to O'Donovan, et al. (2015) considered as "*low-level granular*" data. Therefore, the data must be processed by analytics and modelling applications to translate the data to manufacturers to get a better understanding of current activities in order to improve future operations.

As Industry 4.0 has changed the way data is collected, the areas of use are almost infinite. One area Behdad, et al. (2018) mentions is quality control. With a connected system, the time interval between collection can be much shorter than with traditional collection and it also enables real-time analysis. This makes the data collection cost lower, but it comes with higher cost for data storage. The authors further explain that, as the manufacturing resources have been moving towards a big data environment, the corresponding quality monitoring techniques should adapt accordingly.

2.3 Quality management

Quality is defined by Bergman and Klefsjö (2010) as "*the quality of a product is its ability to satisfy, or preferably exceed, the needs and expectations of the customers*". As the definitions says, quality is not only to match the customers' expectations, it is important to aim for even better to make the customer surprised, delighted and fascinated. The quality of goods could be categorised in eight dimensions, illustrated in Table 2-1 below.

Table 2-1: Eight dimensions for quality of goods (Bergman & Klefsjö, 2010).

Dimension	**Description**
Reliability	Measure of how often problems occur and the seriousness of these.
Performance	How well the goods are performing in the intended market.
Maintainability	Measure of how easy it is to detect a problem.
Environmental impact	How big impact the product has on the environment.
Appearance	Measure of how well the product is design wise.
Flawlessness	E.g. if the goods are marred by defects when sold.
Safety	That the goods do not cause personal injury.
Durability	A measure of that the goods can be used as intended without being damaged.

2.3.1 Process capability

Process capability is a way to measure how well a manufacturing process performs within the tolerances (Thornton, 2004). Hence, an early step in all quality improvement programs is to quantify its capability (Saha & Maiti, 2015). This can be done by doing a process capability study. It is important for managers to understand this concept as a major challenge in today's industry is to produce high quality products at minimum costs. It is a good tool to use capability index for successful quality improvement activities and quality program implementation. The process capability can be measured in different ways, for example by the process capability index C_{pk} (Thornton, 2004). If the C_{pk} value is greater than 1.33 it is considered as acceptable with a low risk. However, a value below 1.0 corresponds to high risk. Process capability can be used to express short-term, long-term and special causes of variation that makes the process instable and disturbs the predictability. Saha and Maiti (2015) states that every process has inherent statistical variability that can be identified, evaluated and reduced using statistical methods.

2.3.2 Quality data management software

Manufacturing companies must act quickly to troubleshoot production problems when characteristics does not meet tolerances, which could be hard if outdated tools are used. A program that helps doing this is a quality data management software, where all data can be stored in the same program (Probst, 2017). By using a quality data management software, measurement outliers could be seen immediately as the last measurements can continuously be visualised. This makes it easy to tell if the measurement is part of a trend or an outlier and therefore it is possible to react more quickly to fluctuations (Deloitte, 2015; Probst, 2017). The software can even give specific instructions for what production machine parameter that must be adjusted when a particular characteristic have been out of tolerance (Probst, 2017).

The software makes the creation of detailed measurement plans possible (Probst, 2017). The plans can also be connected with CAD-drawings of the workpiece, which excludes the risk of misinterpretation from an operator. Hence, operators are always using up-to-date plans and drawings, instead of using old printed versions that might change. The updated plans increase process reliability and reduces workload for inspection engineers. There have also been cases where the time for changing measurement plans have been massively reduced due to the program.

A software of this kind can also help to reduce machine set-up time, up to half the time according to Probst (2017). By analysing data from set-up changes, it is possible to identify a few key characteristics that could be enough to measure after a set-up. This makes the process much faster than if all potential characteristics had to be measured. In production environment where companies produce in small batches the reduced set-up time could also lead to reduced inventory costs, which would increase competitiveness.

2.4 Lean production

Lean production is a production philosophy with its origin from the Japanese car manufacturer Toyota and its well-known Toyota Production System (Liker & Hoseus, 2008). The concept focuses on eliminating unnecessary waste and to establish a culture that builds on continuous improvements, to improve customer value. Lean production consists of 11 important principles to learn the philosophy (Gao & Low, 2014):

1. Reduce the share of non-value-adding activities (waste)
2. Increase output value through systematic consideration of customer requirements
3. Reduce variability
4. Reduce cycle time
5. Simplify by minimizing the number of steps, parts and linkages
6. Increase output flexibility
7. Increase process transparency
8. Focus control on the complete process
9. Building continuous improvement into the process

10. Balance flow improvement with conversion improvement
11. Benchmark

Lean production and Industry 4.0 share common features according to Agostini and Filippini (2019) as companies must be agile and be able to adapt their production processes and continuously improve these. Furthermore, the authors say that lean production could be a prerequisite for digital technologies in the production.

2.4.1 Waste

As mentioned in the section above, eliminating waste is a fundamental part of lean production. At first point, there were seven wastes which was identified by Ohno in 1988, but an eighth waste was added by Liker in 2004 (Gao & Low, 2014). The initial seven wastes were overproduction, waiting, transportation, over processing, inventory, movement and defect products, and the latest addition by Liker was the waste of unused employee creativity. All eight wastes are further explained in Table 2-2 below.

Table 2-2: The eight wastes defined by Liker (2004).

Waste	**Description**
Overproduction	Producing items for which there are no orders.
Waiting	Operators waiting for an automated machine or waiting for the next processing step.
Transportation	Unnecessary transportation of material, parts or finished goods.
Over processing	Taking unneeded steps to process the parts.
Inventory	Excess inventory of raw material, work in process or finished goods.
Movement	Any wasted motion the operators are performing during their work.
Defect products	Production of defective parts.
Unused employee creativity	Losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to your employees.

2.5 Theory of methodology concepts

In this section, a theoretical description is given of the methods used in this thesis. First, two research approaches are explained, followed by a clarification of two data collection methods. Lastly, the terms reliability and validity are explained.

2.5.1 Research approach

This subsection gives a brief explanation of two types of research methods. First, the concept of qualitative research is described, and the second part defines an abductive research approach.

2.5.1.1 Qualitative research

A qualitative research study aims to investigate of what character a phenomenon is, and how to identify it (Wallén, 1996). In this type of study, the data collection focuses on what Patel and Davidson (2019) describes as "*soft*" data, which can be obtained through interviews. The purpose of a qualitative study is to get deeper knowledge than what a quantitative method gives. Bryman and Bell (2015) has summarised the work procedure of a qualitative study in six steps, which are listed in Table 2-3.

Table 2-3: The main steps in qualitative research (Bryman & Bell, 2015).

Step
1. General research question
2. Selecting relevant site and subjects
3. Collection of relevant data
4. Interpretation of data
5. Conceptual and theoretical work
6. Writing up findings/conclusions

2.5.1.2 Abductive approach

An abductive research approach is an outcome of the combination of inductive and deductive research strategies (Patel & Davidson, 2019). The abductive strategy has evolved as a way to overcome the limitations associated with inductive and deductive approaches (Bryman & Bell, 2015). A research with an inductive approach means that the researcher starts by exploring the empirics before studying any from the theoretical perspective (Patel & Davidson, 2019). In this research strategy the data collection is supposed to be made completely unconditionally (Wallén, 1996). A deductive approach starts the other way around, where the literature is studied initially and based on this, a hypothesis is created. The hypothesis is then tested empirically to either confirm or reject it (Bryman & Bell, 2015).

The combined approach based on inductive and deductive strategy is called abduction. The abductive approach is an iterative process that goes back and forth between empirical and theoretical data (Dubois & Gadde, 2002). The first step of the method is according to Patel and Davidson (2019) of inductive kind, where a specific case forms a hypothesis. The following step is deductive where the hypothesis is tested on a theory. An advantage when using an abductive approach is that the researcher is not as restricted compared with the two conventional methods. Even though that the abductive research approach was developed to overcome the limitations of inductive and deductive strategy, it has its own weaknesses. The greatest risk by using an abductive strategy is according to Patel and Davidson (2019) that the researcher unconsciously selects a study based on past experience, which may exclude different interpretations.

2.5.2 Data collection methods

The following subsection gives a brief explanation of two types of method for collecting data. First, the concept of semi-structured interviews is described, and the second subchapter defines benchmarking.

2.5.2.1 Semi-structured interviews

Semi-structured interview is a commonly used interview technique within qualitative research (Patel & Davidson, 2019). The interviews are characterised by covering pre-defined areas, but where the sequence of question may vary (Bryman & Bell, 2015). The questions are also more of general kind, which enables sessions to focus more on certain areas depending of the interviewees' answer. These focus areas give the interviewer the possibility to ask follow-up questions when more relevant answers are given.

2.5.2.2 Benchmarking

Camp (1989) defines benchmarking as "*the continuous process of measuring products, services, and practices against the toughest competitors or those companies recognized as industry leaders*". Benchmarking is about comparing performance levels against the best ones, in matter of whole companies as well as specific functions (Pettersen, 1995). This comparison can be an important contribution to both motivate and convince your own organisation where an improvement is possible. Benchmarking can be performed at an external company but can also be made internally (Hansen & Riis, 1993). Camp (1989) has divided the benchmarking process into four steps, as presented in Table 2-4.

Table 2-4: The benchmarking process as described by Camp (1989).

Step	**Description**
Planning	Identify what and who to benchmark, determine data collection method and collect data.
Analysis	Determine current performance gap.
Integration	Inform benchmarking findings and establish goals.
Action	Develop action plans, implement them and monitor progress.

2.5.3 Reliability and validity

When conducting a study, it is important to ensure that a high quality of the research is achieved. This can be evaluated by the study's reliability and validity. Bryman and Bell (2015) defines reliability as "*the consistency of a measure of a concept*". The idea is to tell how stable a process or method is if it would be repeated over time. The concept of reliability aims to minimise the biases and errors in a study (Yin, 2014). By documenting every step that is made during the research, a higher reliability is ensured. Though, reliability is normally a greater threat within quantitative research.

Validity refers to how well you investigate what you really were intended to investigate (Bryman & Bell, 2015). The validity can for example be affected by the number of interviews held, where an undesirable situation could be where a few people's subjective views becomes representative for a whole company. The validity can be increased by different actions, where respondent validation is an example. That is a process where the researcher provides the people whom given input to the study, the possibility to read the findings.

3 Methodology

This chapter presents the methodology used to perform the thesis. It starts by describing what research approach has been used and followed by the procedure of the planning phase, data collection and how the data was processed. The chapter ends by discussing the reliability and validity of the study.

3.1 Research approach

The study has been conducted of a qualitative nature, see section 2.5.1.1. That means that the data collection has focused on words and human factors rather than numbers and hard data (Bryman & Bell, 2015; Blomkvist & Hallin, 2015). The project has also had an abductive research approach, which is described in section 2.5.1.2. The abductive approach was used due to its combination of inductive and deductive kind which gives more flexibility to move between theory and empirics. The iterative process that characterises the abductive strategy suited the project well as the literature was studied continuously, while performing the interview and benchmarking studies. This made it possible to find new interesting topics to read about in between interviews. The abductive approach is also well suited when carrying out a qualitative study (Bryman & Bell, 2015).

The work procedure of the study started out with a planning phase, which was followed by the iterative data collection phase. After the collection of data, it was analysed and further discussed resulting in the study's conclusion, as is illustrated in Figure 3-1.

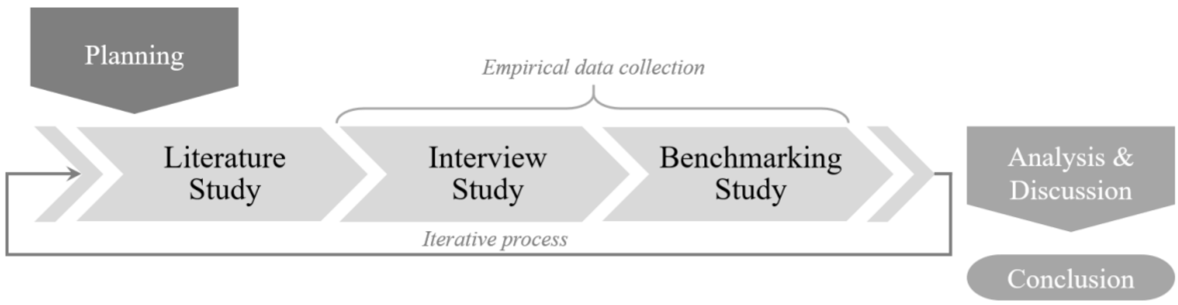

Figure 3-1: Work procedure of the study.

3.2 Planning phase

The first step of the project was to initially plan what the study should include, how it should be performed and when things would need to be done to be able to finish the thesis on time. Therefore, a planning report was written. The report consisted of a brief background description of the case as well as the current situation at the case company and a preliminary purpose to present the intended outcome of the thesis. Following this, the delimitations for the project was stated, before the preliminary research questions ended the first part of the report.

The second part of the planning report answered the question of "how" by giving a short methodology description. This consisted of what type as well as how the data was planned to be collected. Finally, a Gantt chart was created to illustrate the time plan of the project. Once the planning report was approved by the supervisors at both Chalmers and the case company, a brief presentation of the planning report was held at the case company to introduce the thesis for relevant stakeholders.

3.3 Literature study

To make the study possible, a literature review of the topic was made. Bryman and Bell (2015) claims that a literature review is necessary to avoid a situation where you "*reinvent the wheel*". As mentioned in the first section of this chapter, the literature study was performed continuously throughout the project. The objective of the literature study was to obtain knowledge on the topic of the thesis. This knowledge was later used as a foundation when the interview guides were created for both the interview and benchmarking studies.

The literature review consisted of theory from scientific papers, reports and books covering relevant areas. The major part of the collected literature came from scientific papers, to ensure a high reliability. The collection of these papers has been made through databases provided by Chalmers Library. Keywords used when searching for theoretical material was for example *digitalisation, big data, Industry 4.0, quality management* and *manufacturing*. Based on these results, other relevant articles were found in their reference lists. This is a search method called snowballing, which is used to identifying high quality sources in obscure locations (Greenhalgh & Peacock, 2005).

3.4 Collection of empirical data

The collection of empirical data consisted of two parts, one interview study and one benchmarking study. Below, each part is further described.

3.4.1 Interview study

The major part of the data collection of empirics was obtained through interviews at the case company. The purpose of doing interviews was to get an understanding for what perception the affected employees at the case company had regarding digitalising their measurement data by using a quality data management software. The interviews were designed in a semi-structured manner, see section 2.5.2.1. This made it possible to deepen in areas where the interviewee had more knowledge, in accordance to how Bryman and Bell (2015) describe one of the characteristics of a semi-structured interview.

The interview guide used, see Appendix A, consisted of an introduction question, followed by four areas; *Current state*, *Areas of use*, *Effects* and *Implementation*. All areas were broken down into several questions, to access relevant data. The areas and questions were developed from what was found in the literature study as well as the thesis' research questions. Something that is suggested by Bryman and Bell (2015). The questions were also shaped to be as general as possible, to not steer the interviewees answer in any direction. All interviews were held with the same interview guide which made it possible to compare the answers afterwards in an adequate way. Some questions evolved from one session to another to reduce misunderstanding, without changing the meaning.

3.4.1.1 Selection of interviewees

The selection of interviewees was made together with the company supervisor. To make sure that the selected respondents would mirror the overall perception within production at the case company, they were chosen strategically from different departments to represent the whole population. This is considered suitable in a qualitative study (Ekengren & Hinnfors, 2012). The aim was to interview at least two form each role, to minimise the event of getting biased answers. One more factor that was considered was the fact that the case company consists of three different manufacturing factories. These factories have a wide spread in technical development with varying conditions. Therefore, it was desirable to involve people from all factories. In total, ten interviews were held with people of the roles stated in Table 3-1. Three more interviews were planned but got cancelled for various reasons. Of these ten, four represented the A factory, four represented the C factory and the last two represented the B factory.

Table 3-1: Interviewees' roles and distribution.

Role	**Number of interviewees**
Business Excellence	3
Quality Management	3
Industrial Engineering	2
Metrology Development	1
Production Manager	1

3.4.1.2 Performing interviews

All interviews were held in Swedish due to the interviewee's native language and was made individually in-person at the case company's facilities. To continuously improve the interviewing technique from session to session, the time period from first to last interview was scheduled as short as possible, which ended up being three weeks. In the beginning of every interview session, a brief presentation of the interviewer as well as a short description of the project scope was given. The interviews lasted in averaged for 40 minutes.

In agreement with the interviewees, all sessions were audio recorded to not bypass any details. Recording of interviews is a way to increase the reliability of the obtained data (Bryman & Bell, 2015). As a last step before the interviews started, the respondents were informed that they will remain anonymous in the study, except that their work role will be used if approved. As everyone accepted these terms, the respondents' department are listed in Table 3-1 above.

A phenomenon described by Bryman and Bell (2015) occurred at a few interviews. When the last question was answered, and the recording was switched off, some interviewees started to tell more interesting things than what was mentioned during the interview. This information was noted in the greatest extent to not miss out on anything. This phenomenon is relatively common when performing semi-structured interviews according to Bryman and Bell (2015).

3.4.1.3 Summarising the interviews

When the interviews were finished, they got transcribed. To a large extent, the transcription was made the same day or the day after the interview. Wallén (1996) means that if the after work is not done as soon as possible after the interview, essential parts could quickly be missed out. The transcription also allows a more thorough examination of what people say and facilitates it to repeatedly read through the answers (Bryman & Bell, 2015).

When an interview had been transcribed, the next step was to highlight answers, or part of answers that were more relevant to the thesis. This was necessary as the questions were formed to be as general as possible, which led to that the interviewees also spoke about things outside the scope of this study. The highlighting made it easy go back to the interviews at a later stage and quickly finding the interesting details, without having to read through all again. The last phase of the summarising was to compile the interviews in an Excel spreadsheet. In the spreadsheet, a short version of all answers from all interviewees where lined up next to each other to easy get an overview for comparison. This made a good foundation for the further analysis.

3.4.2 Benchmarking study

Parallel to the interview study, a benchmarking study was performed by following the process described by Camp (1989), see Table 2-4. As the benchmarking study was a sub-part of this thesis, the last step *Action* was excluded as it was considered irrelevant. The benchmarking study was made as the case company had no prior experience about using a quality data management software. In accordance to Camp's (1989) definition, an industry leader within quality data analysis was identified. The company was asked if they could contribute to this study as a benchmarking object, which they accepted. Thereof, the benchmarking made in this study was of external type. The benchmarking company is among the biggest Swedish industrial manufacturers, with a long history of collection and analysing quality data.

The benchmarking took form as a study visit at the company, including a tour in their production facility where a few of their measurement equipment was used. Apart from the tour, a semi-structured interview was also held with the manager for the dimension control department. The interview guide used for this, see Appendix B, was made on the basis of the interview guide used in the interview study. The biggest difference between the two guides was that the *Current state* area was substituted for an area called *Background*. The questions in each area was of course changed to get a more historical perspective, rather than the hypothetical kind which was used in the first guide. After the study visit the interview was transcribed and highlighted in the same manner as described in section 3.4.1.3.

3.5 Data analysis

The analysis was made by studying the Excel spreadsheet to find similarities and differences in the interviewee's answers. Many respondents answered more than one question in the same answer, therefore the analysis was not made separately on each question. Instead, the analysis was made based on the four areas from the interview guide; *Current state*, *Areas of use*, *Effects* and *Implementation*. The benchmarking study was analysed in the same manner, where the answers were grouped to the different areas. Further, the results of the empirical studies were compared to the findings from the literature study. Here, similarities and differences were also identified and further discussed before coming up to the thesis' conclusions.

3.6 Reliability and validity

The quality of this research has been ensured through evaluating its reliability and validity. As this study is of qualitative nature, a big focus has been put on achieving a high reliability. To do so, every step performed has been well documented to make it possible for another researcher to use the same method and come up with a similar result in accordance to how Yin (2014) describes it. Regarding the data collection, all interviews in the interview study as well as the benchmarking study has been recorded and further transcribed. This has made it possible to listen to them several times, which according to Patel and Davidson (2019) increases the reliability. All interviewed are also considered as experts in their area, which ensures that reliable answers were given. The theory that was reviewed during the literature study was mostly scientific papers and established books on the topic. Hence, this has guaranteed that both the empirical data as well as the literature are reliable, which makes them a good foundation for further analysis.

The validity of the study has also been ensured through several methods. After every step was performed and documented, a review was made to ensure that it had a connection to the thesis' purpose and research questions. Bryman and Bell (2015) argues that the validity can be decreased if not enough interviewees are involved. This has not been something affecting this study as there have been many similarities in the answers given by people from different departments. Finally, to verify that the interviewees felt that the result represented their view, respondent validation was used to ensure the validity in accordance with Bryman and Bell (2015).

4 Empirical findings

This chapter consists of the collected empirical data. First, the findings from the interview study at the case company are presented. They are divided into the same subsections as the interview guide. The chapter ends by presenting the findings from the benchmarking study.

4.1 Interview study

The result from the interview study is presented in this section. Everything described below are things that employees of the case company said during the held interview sessions.

4.1.1 Current state

The current situation regarding collection, handling, visualisation and analysing of measurement data at the case company varies depending on which factory studied. The range goes from completely automatic measuring of almost all parameters specified on the products produced in the modern A factory, to fully manually collected data by operators in the C factory. The B factory can be seen as a mixture of the first two, where there are manual as well as automatic collection of measurement data. However, regardless of the current technical level in the factories, all interviewees agree on that the measurement data is not used to improve the business systematically.

4.1.1.1 Types of measurements

In general, there are three types of measurements that are made in all factories; first piece inspection (FPI), product audit (PA) and process measurement (PM). The FPI is required every time a new product or batch is released. Here, extensive control and adjustments are done repeatedly until all parameters are within the limits. To exemplify how extensive the FPI is, one interviewee said that the cycle time for FPI in one of the manufacturing channels in the A factory is about seven times longer than an average one. When accomplished, the operator manually notes the values and signs a protocol to confirm that the process resetting is within specifications and it has been released and then the protocol paper is archived for many years. Therefore, the FPI is a sort of go/no-go measurement and it is hard to make any analysis of the data as it is mostly stored in binders or boxes.

The PA is made by the staff from the measurement rooms located in each factory. In this type of measurement, products are collected from the manufacturing channel and brought to the measurement room for further inspection. The frequency and the number of products involved in the PA is specified in the control plan for PA. The purpose of a PA is to verify that the PM has a high reliability. If the reliability is low, an action could be to increase the frequency of PMs. The PA data is documented digitally in an Excel sheet. As the PA is made according to a schedule in the control plan, for example a few times a week in the C factory, some product types might not be in production when the PA is performed. Therefore, the reliability of the PMs for these types will not be tested. This could make the distribution of products covered by the PA incomplete.

The PMs are measurements that are made continuously during production and used to help the operators to control the process, so it stays within tolerance. This happens according to the control plan for PM, which could be that certain critical parameters should be measured every 10th or 20th minute for example. These time intervals in the control plans are very static today and are set by gut feeling to some extent, which is not preferable. The PM is not noted or documented except in places where the PM is made automatically (mostly in the A factory). It works more like a momentary status check without memory where the operator must act and change the process if a PM parameter is out of limit, otherwise the production keeps going.

Apart from the three main measurements, there are also sometimes extra measurements made for a specific reason. One example of this type of measurement is the machine capability studies that the industrial engineering department is responsible for. Though, to make a capability study trustworthy, it must consist of data over a long time. This is currently hard to do as it requires a big effort to collect and gather this data in a structured way. Therefore, the capability studies are not made in the desired extent today. In general, the extra measurements made are of reactive type where data is collected with a pre-defined purpose for a certain project. During several interviews, it was clearly stated that it would be preferred to do it the other way around, to have all data accessible from the start. In that case the desired data could just be selected, and the analysis could be made straight away without extra collection, in a more proactive manner.

4.1.1.2 Conditions of the factories

During the interviews it was explained that in many channels in the A factory, almost all product parameters are measured automatically by CMMs, which in this case represents the PM data. The data is either stored locally in the CMM or uploaded to a connected server. Here, the conditions for automatic quality control are very good as the IT infrastructure already is well-developed and the data is collected and stored. But even though huge amount of data is collected, there is no tool for visualisation and analysis. One interviewee means that there are good conditions in the A factory, but they have not utilised the full potential of it yet.

Contrary to the A factory, the C factory is not as technically developed. Almost all measuring is made manually by operators. As in the other factories, the FPI is signed manually by the operator and then archived, and the PA is performed by the metrology team. Though, the PM is only a momentary status check to see if the process is running within limits and the interviewees said that basically no PMs are noted in the C factory. The B factory is a mixture of the A and C factories. A few manufacturing channels have measurement equipment which can collect digital data, but as the B factory has no online network, it is hard to transfer the data. One of the interviewed employees from the B factory meant that the digital data is not sufficient for basing conclusions and compares the small amount to "*a fish in the sea*". The manual measurements made in the B factory can be compared to the corresponding ones in the C factory.

4.1.1.3 Usage and decision-making with current data

All interviewees agreed on that sufficient amount of measurements are conducted today. Some did even think that it was measured too much in some cases. For example, due to the static control plans, a parameter that is inside tolerance every single time, will continue to be measured over and over again at the pre-defined time interval, regardless of the result.

The interviewees think that there is too little documented data available for making accurate decisions, especially as it is currently not possible to visualise the data. Today there are still gut feeling and speculation in the decision-makings. For example, some parameters are being monitored due to people's historical experience that they once were associated with problems, even if they have become stable. Though, it is worth saying that most of the employees interviewed thinks it is moving towards more fact-based decisions and that there is no resistance by going in that direction.

During the interviews it was explained that the intention of the data collection is for it to be used as input for improvements. But, if we ignore the purpose of the specifically collected data through the extra measurements, the measurement data is mostly used to monitor the process, rather than control and improve it. The operator uses the FPI to control the process when it is released and the PM when it is continuously running. The results from the PA, which is saved in Excel files, is used in some extent to identify problem parameters but it is too time consuming to gather the data according to the respondents.

4.1.2 Areas of use

During the interviews, several areas where the quality data management software could be used as input were exemplified. One area that almost all interviewees said was to visualise the quality data, which is something that is lacking today. Especially in the A factory where the data already is digitally stored, but without the possibility of using it. To involve the digital quality data in the daily management was also something that many asked for. As of today, the daily management is divided into three different levels where level 1 is on channel level and level 3 is on factory level. So, the forums are already there where improvement activities could be driven.

To use the software for doing capability studies was an area many respondents mentioned, for machines and measurement equipment, as well as for processes. The interviewees believed that if the measurements could be stored in the program, the effort of making capability studies would be significantly lower. Another area was to use it for making dynamic control plans. The program could use the collected data and automatically update the frequencies in the control plans, based on the last measurements. The full list of all areas of use that was brought up during the interviews are listed in Table 4-1.

Table 4-1: Summary of the areas of use mentioned by the interviewees.

Area of use	**Frequency**
Visualise and analyse quality data	9
Capability studies	7
Daily management	6
Dynamic control plans	5
Input for problem solving	3
Statistical process control	3
Support for investments/exchange of machines	3
Improve traceability	1
Support when introducing new measurement equipment	1

The interviewees believed that the range of users that will be affected by the program is big. Almost all roles with a connection to the production were thought to benefit from such program and the following roles and departments were mentioned; operators, technicians, managers as well as the departments for quality, industrial engineering, maintenance and process development.

4.1.3 Effects

During the interviews, all respondents made it clear that they believe that a program of this kind is needed and will be value-adding in many ways. A few interviewees also said that there have been talks about implementing something like this for a long time, without anything to happen. But now, especially when the A factory has invested a lot in new machine technology, it is time to take the next step regarding quality data as well.

4.1.3.1 Improved base of data and visualisation

When a quality data management system is up and running, and data is continuously captured and stored in the associated database, the conditions for visualisation and analyses are significantly improved. Instead of investing much time in collecting data, the corresponding time can be used to identify improvement areas. The respondent who said that the digital data in the B factory is currently only "*a fish in the sea*" meant that this will change when documenting data more frequent. It creates completely new possibilities for analysing quality data when all data is gathered in one place. Also, if for example the PMs are documented every time they are measured, it will be easy to see if measurements have been skipped by an operator. A few respondents believed even, that if the PMs were continuously logged, there might not be as important to do the PA.

Further, the data can be visualised, and the visualisation can be adapted to the user in every case. This is one of the reasons why so many different roles are believed to be users according to the interviewees. The general awareness of the current situation will increase and this could make people ask more questions that could start improvement activities. There will also be a more transparent environment where for example measurement errors comes to the surface faster when the data is visualised on screens. This makes it possible to easier learn from mistakes in order to personally develop.

It is not only the employee’s awareness that will be improved, many respondents are confident that it will lead to more communication between operators and managers as well as different departments. With a more open dialog among stakeholders, the knowledge gap between operators and decision-makers will diminish. The interviewees were also sure that this will support more decision-making based on facts due to the possibility to see results and trends in a way that is not possible today. Though, some respondents, who believed that the data base would be improved by using a quality data management system, were also afraid that there is a risk that it could be too much data. Therefore, they meant that it is important to have a strategy in an early stage for how to handle the data, as well as how to make the analyses value-adding.

4.1.3.2 New equipment required and improved capability tracking

In the areas where data collection is manual today, the interviewees meant that investments in new measurement equipment is a prerequisite. The main reason is that most of the equipment in the B and C factories are very old and cannot register any type of digital data files. Some respondents added that it is only a matter of time before the equipment must be replaced anyway as some gauges’ spare parts are not even produced any longer.

During the interviews, some drawbacks were mentioned regarding the investments of new equipment. The operators who currently are working in the B and C factories must accept the new equipment as well as learn how to use it. As the operators might not document all measurements today, it is important that they can adapt to the new requirements needed for the system to work. The respondents did point extra on that it is important to get everyone on board from the start, especially the operators. Investing in new equipment is also expensive, which might affect how the measurement stations should be located. It could be too expensive to just replace every old station with a new as there are many stations in most channels today. Therefore, fewer, but bigger stations might be a solution for the future.

Of course, there are also benefits when investing in new equipment. Apart from that digital data can be stored and documented, operators could be motivated by the investment. The new way of collecting data would probably also spare administrative work. Errors such as writing errors would be eliminated if the manual work is removed. This also increases the reliability of the data as the operator cannot embellish the result, which some interviewees are suspecting might be happening today.

More documented data will also play an important role when it comes to the process capability studies. As data from long time periods are available in the database, the capability studies will both be easier to perform and more trustworthy. Apart from historical data, it is also possible to follow the machine capability by real-time data. This could be used as a tool to help managers to be proactive in their work around capability. One respondent said that it would be preferable if an email could be sent automatically to the responsible if a capability value is decreasing somewhere. This proactive way of working is believed to improve product quality and in the long run reduce customer complaints.

In the same way, the data could be used for predictive maintenance. This would ease the process of prioritising which area that are concerned as the most critical one. The machine capability studies could also be broken down in many steps to identify the root cause of the problems. Finally, to illustrate how important the simplification of the capability study process would be, one respondent said that if the quality data management system only improved one thing, and that was the capability study, it would be a reason good enough for the whole implementation.

4.1.3.3 Knowing the data better makes decision-making faster

With data visualised and better track of the process capability, it is easier to see how the production processes are going. By knowing the data better, users could learn to see patterns in the data. One interviewee believed that if synergies between parameters could be identified, for example when parameter X is unstable, parameter Y and Z are also unstable, lead times could be massively reduced in the problem-solving phase. But to understand the data good enough for these types of analyses, some respondents thought that it would be necessary to have data analyst experts making them.

The awareness that has been mentioned in previous sections, will also cut lead times as people will understand each other in an earlier stage if sharing the same view of the problem. This will speed up the decision-making in order to take action faster. It also reduces the waste in the decisions-making process which would hopefully lead to finding solutions faster than what is possible today.

Regarding the cycle times for measuring, it is not for sure that they will be shorter when using a quality data management system. But by using dynamic control plans, the calculated cycle times are believed to be closer to reality as some parameters might be measured more often and other more seldom depending on how stable they are. Hence, it will maybe not decrease the number of measurements that are currently made, but it is a way of learning how to measure right. Also, extra measurement data that previously was collected for specific projects are already stored in the database, which saves much time that can be used for analysis instead.

4.1.4 Implementation

To be sure that the quality data management software will be used in the daily activity, it is important that the implementation is performed strategically. Parameters such as preparing the employees with knowledge, what technical obstacles to avoid and which forums that could ease the integration are presented in the section below.

4.1.4.1 Important to generate a shared understanding

One of the things that most interviewees said was important for a successful launch of a system of this kind was that users must have the right understanding. From the first moment, all users should feel that they see the purpose for using it and what it can bring. If people see the big picture and understand why it is implemented, how it is used and what it brings, it is much easier for people to accept it. It is about making all stakeholders from operators to managers to think “we need this” instead of thinking “not one more system”. Managers must also see it as more than just a monitoring and reporting tool, they must see it as a tool to support improvement activities.

Something the respondents have learnt to be crucial from past unsuccessful implementations is how important it is to support users initially. Therefore, it is suggested to have a smaller group that is running the implementation and the development. This makes it clear who people can turn to when facing problems. To have an in-house education program could also be useful for more frequent users to maintain the competence for a longer time. But it will not only be important to educate software specific knowledge, education among operators regarding capability and statistical process control might also be necessary.

It is believed that some organisational changes must be made in order to capture more value. Today many of the different production units are built as silos and focuses mainly on their own business. One of the interviewed meant that the communication between different functions must be improved as they all in fact are working towards a common goal. The interviewee said that quality, maintenance and industrial engineering must start to care about more than their own parameters and work more cross-functionally. It was also said during the interviews that people have to be prepared that this system might require that some work tasks are rearrange between departments. For example, it is possibly more efficient that the quality department took over the responsibility of machine capability studies so that industrial engineering could focus more on problem-solving.

4.1.4.2 Technical obstacles to be aware of

When implementing new technical solutions, there are always obstacles that must be considered. A concern that was brought up during several interviews was the question of licences. There have been previous cases where software implementations have been struggling due to expensive and complicated licenses. The interviewees meant that it is crucial to investigate what alternatives that are available in an early stage, so the software can be used in the manner it was planned to be.

As the current IT infrastructure differs severely between factories, local adaptions must be made. For instance, the A factory is well equipped for such software already meanwhile the B and C factories requires network solutions as well as digital measurement equipment for example. In places where investments must be made, it was said during one interview that it is important not to scrimp with equipment that makes the usage better. Therefore, screens and dashboards to visualise data in the channels and at meetings, should also be prioritised.

To have a program with a user-friendly interface was something that almost all respondents agreed on to be important. It must be easy to use it and one interviewee used the word “*self-*

instructing” to describe it. As there is expected to be a wide range of users, it is important that the content visualised is relevant to the user. If this could be managed, the respondents believed that the program would promote itself. It must also be user-friendly in a way that it is simple to understand. Operators that only are going to use the system briefly must easily understand what is visualised without having to take several courses. The same goes for managers who wants to make simple analyses. To select and filter data to see what you are looking for cannot be too time consuming, otherwise it will not be used in the daily work.

4.1.4.3 Daily management a forum to use

To make sure that the software is not becoming a side-project after implementation, a well-suited forum to present and discuss the quality data is at the daily management meetings. It could be part of the meetings at all three levels. Especially, the respondents think that it would make a big impact to include it in level 1 meetings, as it is not involved there today. The three-level structure of the daily management is perfect for dynamically escalating bigger issues to a higher level. This is also a way to spread the knowledge gained from the system as well as exchange experiences from previous events. Finally, when problems are reaching the highest level, one respondent is sure that it will help to identify black sheep in the factory.

4.2 Benchmarking study

The result from the benchmarking study is presented in this section. Everything described below is data that was obtained from the interview and the study visit at the benchmarking company.

4.2.1 Background of their system and usage

The benchmarking company have a long history of analysing processes in their production based on measurement data. The first efforts were made back in 1989, when data was documented with pen and paper. This analog data was used as a base when manually drawing diagrams which was used for analyses. Since then, quality evaluation has always been important at the company. In the mid-90s, the first digital software for handling quality data was introduced and for about 15 years ago the current software was launched.

The main argument for starting to collect and analyse measurement data was that the company wanted to have underlying data to base their improvement decisions on. They had experienced decision-making based on speculation and understood the risk it came with. With a continuous collection of the data, it is possible to steer and control processes in a more precise way as well as improve it. It also generates a better understanding of why errors occur. For example, when output has been bad and started to become better again, it is possible to learn from the actions taken that lead to stabilising the results.

The quality data management software the benchmarking company is using store all different measurement data in the same database. This database also includes data from their other factories as well as their subcontractors' data. The data is mostly automatically collected, but there are also manually collected data in the same database. The manual collected data is registered by hand straight into the program. Though, the company is trying to minimise this type of data collection as there is a risk for human errors. In total, almost all measured data is stored in the database. This means that it is a huge amount of data and therefore it is important to look for trends where parameters are moving closer to the limits.

4.2.2 Areas of use

The collected data is of course used for metrology documentation of the products, but it is also used to monitor their processes. This makes it a powerful tool to track process capability as well as maintenance needs. The company has learnt that if they can ensure that the process is performing well, it will also lead to high quality products. Therefore, they can use the software to adapt the time interval between measurements depending on how parameters are variating.

The company have three specific roles that are focused on the measurement area; metrology technicians who are responsible for the measurement machines, geometry technicians who are responsible for the process equipment and geometry engineers who are responsible for finding connections between product and process. The interviewee said that in this factory they use the measurement data mostly for analyses and not as much to visualise data for operators but added that it was more common in other factories. One example of analyses they are doing is to identify synergies. This means that they can use one parameter to represents more and surrounding parameters. Therefore, less measurements can be made but still maintain a high reliability.

During the daily management meeting every morning, there is always a review of the quality data from the day before. In these meetings, focus is on parameters that are getting closer to a limit. When that happens, an action list is generated which could include things that can be corrected directly, but also more complicated improvements. The quality data is also analysed on weekly and monthly basis, to see variations that cannot be found when only evaluating the last 24 hours.

4.2.3 Effects

Since the benchmarking company started to work with their measurement data with a quality data management software, all decisions are fact-based. This has not only improved performance, but also been important to be able to stand up against more hierarchically powerful wills that used to have a big impact on decisions. The interviewee also said that a big advantage with measurement data is that it is neutral. It is easy to talk about it with both internal and external stakeholders, without getting feelings involved. The company also feel that it gives a faster decision-making process as you can be more confident in your actions. Though, the interviewee said that they must always be aware of the risk that some data could be corrupt, even if that is not something that often occur.

The interviewee described their program as easy to use and that no advanced user-skill is needed to handle or filter data. To filter data is important as there is huge amount of data stored in the database. This helps the company to track and trace problems and solutions. From the data, they can tell when a problem started as well as when the problem was solved. This is important for the future as they can use this information to estimate how severe a problem is in an early stage.

The software also helps the company to be more proactive in their actions. As trends are studied, they do not need to wait for limits to be exceeded. When for example capability values are starting to decrease, they can start to look for the root cause of the problem before it actually causes damage. The program also has a function that notifies a geometry technician when certain events occurs in order to act quickly. Before, they worked much with trial and error, but the respondent said that they would never have time for that nowadays. Also, the way they are working with synergies is a good way to cut lead times.

One area that the respondent thought was challenging was when it came to investments. As with any kind of quality assurance, it is hard to prove that it will generate any financial profit. This makes it tough to create business cases to show the importance of the investments, especially when the equipment is expensive. Therefore, the respondent said that the deciding people must be convinced every time an investment is about to be made.

4.2.4 Implementation

The respondent described any implementation phase as the best phase, because it is not until then you can prove how much it will improve. Though, to implement a new software could be hard as it is not always received with open arms. It is therefore important to spread the purpose to give employees an understanding for why the implementation is made. To have an organisation prepared for it is also something that should not be underestimated. The company has worked hard to remove silos in their organisation structure and this has helped them to reach a more shared understanding. Finally, the benchmarking company has also put much effort in coaching new users with internal education. This has also been important to maintain the competence within the company.

5 Discussion

This chapter provides a case specific discussion based on the empirical findings presented in the previous chapter to give a foundation for further conclusions. The chapter also consists of a discussion of the used method as well as gives a recommendation for future research.

5.1 Current state

It is evident that the current situation of evaluating measurements at the case company has not reached its potential. There are so many measurements performed that lose value due to the lack of documentation. Of course, the measurements made are important and used for controlling the processes whilst running. But it could be used for much more, especially when themselves said that the main argument for collecting data is to use it as input for improvements.

In places where there is manual collection of measurement, too little data gets documented. However, if this data was documented more frequently today, it would still require lots of administrative work to get something out of it. But even in places where the data is automatically collected and documented, for example in the A factory, the data is not used. A reason why the situation is like this could be as there is no software to use for this type of evaluation.

The bad circumstances of this has clearly affected parts, and the capability studies is one area that has suffered. Due to the major efforts that currently is needed to collect the data, this important study has nearly been excluded. As the vision is to use the measurements data for improvements, it should be a prerequisite to quantify the process capability. This is something that Saha and Maiti (2015) points out as an important early step in any quality improvement program.

In regard to the current differences in technical development of the factories, they face different challenges. In the A factory, the collection process could be described as digitised (see Figure 5-1) according to the definition by Machado, et al. (2019). Here, the challenge is to digitalise the collected data in order to use it in a value-adding manner to improve the business. And as the factory already is equipped with the requisite needed for IoT usage, a quality data management software could help to take the last step. In the other two factories, the conditions are not as Industry 4.0-prepared as the A factory, which also can be seen in Figure 5-1. Here, the process has not even reached a digitised level yet as most measurements are still analog. Therefore, new equipment is a must to later be able to digitalise the measurement handling here as well.

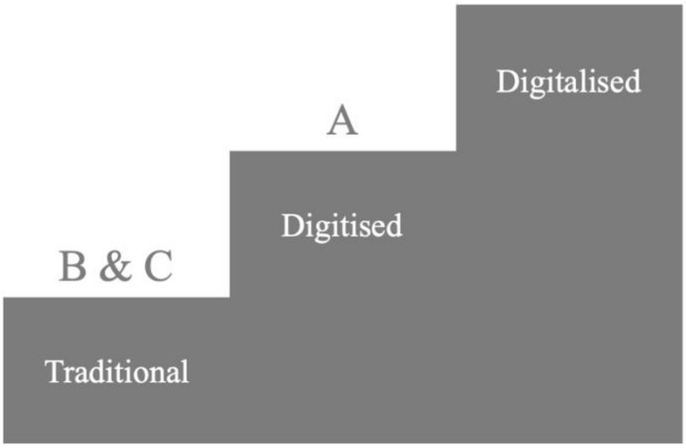

Figure 5-1: Illustration of current data collection process.

5.2 Effects

By having a quality data management software, the documented data can simply be visualised according to Probst (2017). This is one of the functions that most respondents were asking for during the interviews. They believed that communication will be improved as operators as well as managers will be more aware about how the processes are going. Though, the benchmarking company did not use its software to visualise so much data. They used it more in their work of being proactive by analysing trends to foresee errors. But as the benchmarking representative said, their company used the visualisation as a useful tool in other factories.

All interviewed agreed on that a better base of data will help them to make more correct decisions. Today, there are still subjective opinions that affects for example which parameters to study more often. This is something that Zhong et al. (2017) describes as common in many manufacturing companies. The benchmarking company has managed to overcome this issue, as since they launched its quality data management software, all decisions are fact-based. This has also helped them to tackle the problem that decisions are affected by HiPPOs, explained by McAfee and Brynjolfsson (2012). When people at the case company start to use the software, they will learn more about their business. This will give a better foundation for better predictions and smarter decisions (McAfee & Brynjolfsson, 2012).

The case company interviewees believed that lead times also can be shortened due to the possibility to study trends and patterns, which Deloitte (2015) and Probst (2017) confirms. One thing that was interesting regarding reduced lead times was that one respondent at the case company was speculating about that it would be very useful if synergies could be identified. And as this is currently being made at the benchmarking company, it is obvious that the software could help with this. The benchmarking company did also use their quality data management software in a way that can be compared to what the case company respondents referred to as dynamic control plans. This means that the software will help the case company to update the time interval between measurements according to the current situation. This, together with a better general awareness gives a faster decision-making process which would eliminate wastes such as waiting and over processing.

To use the quality data management system for making the capability studies was one of the most frequently mentioned application areas during the interviews. The reason for that the studies are not made today is because of the big effort needed to collect the data. Especially as the respondents meant that so much data is needed for the study to actually say something. With the new system the whole collection process is removed and the data is easy to access in the database. This makes it possible to use the time for value-adding activities instead. If the capability studies are made on a more regular basis in the future, maybe they also can fill the purpose of the current PA. This would in that case also remove the waste transportation as the products do not have to be moved from the channel to the measurement room for the PA.

The way that the benchmarking company's software notifies people when a limit is crossed is also a function that a case company respondent asked for. This is a good tool for handling a situation before it starts to cause damage. This is also a way to use the system to support maintenance in their work to become proactive. If machine errors or other things that affect product quality can be identified early, waste could be eliminated by reducing the number of defected products (Liker, 2004). It will also increase the durability and maintainability, which are two of the dimensions that Bergman and Klefsjö (2010) defines as quality. This will lead to happier customers as complaints will decrease if the case company can assure a higher quality.

There were three employees of the case company that thought the quality data management software would be a useful tool for motivating new investments. They meant that machine capability values could be used to find machines that is in need of replacement. But what is interesting here is that the biggest challenge according to the benchmarking company was specifically to motivate investments, even though they already have such software. This shows that it is maybe not as easy to motivate investments regardless if you have lots of data backing your investment. Though, the software could probably help to identify machines that needs maintenance or replacement. But the investment itself is still hard to get through as it is difficult to make business cases when it comes to quality assurance, according to the benchmarking company. However, investments are a must for the case company if this software should be used in the B and C factories.

A challenge that none of the interviewed at the case company seemed to be aware of was the question regarding IT security. In the studied theory, Deloitte (2015), Ministry of Enterprise and Innovation (2016), and Büttner and Müller (2018) all writes about the cyber risks that companies are exposed to when digitalising or using Industry 4.0 technologies. Therefore, it was expected that at least someone would mention something about it during the interviews. It might be just a coincidence that none of the interviewed people was aware of these threats, but as no one was, it could reflect that the general awareness of these threats is low at the case company. A reason for people to miss out on this could be that they are so desperate to sort out the measurement situation, that they only see the benefits and positive outcomes. Another scenario could be that this is a question that only the IT department is working with. If so, that would explain why the benchmarking company did not either mention anything about this challenge. Nevertheless, the case company should not forget to prepare for this threat before implementing the system.

5.3 Implementation

When it came to important factors for a successful implementation, it seemed like the respondents had valuable experience from past implementations. One area where they had learned the hard way was to give extra support initially. This is something important for a successful transition (Agostini & Filippini, 2019). If people find it hard to see the benefits the program generates, it could be smart to use the data at the daily management meetings. This would force employees to use the data every day which eventually leads to a better understanding, which has worked at the benchmarking company. The three levels are also creating a possibility for more detailed and area-specific analyses, which probably makes the once present feel that the data is more relevant.

The importance of a prepared organisation was something the benchmarking company said had benefited their system, which is a theory supported by Agostini and Filippini (2019). For years, the benchmarking company shaped their organisation into a more agile and cross-functional working one. Several of the interviewees of the case company were also on to that and said that some changes to the current organisation are needed. Traditional organisations are often silo-structured and to capture the values from Industry 4.0 applications, the internal barriers must be removed (McKinsey Digital, 2016). To support the collaboration initially, a work group consisting of people from each of the involved departments could be created. This group could be used as a forum to exchange experience they have gained during the implementation in order to learn how to use the software better.

A few of the interviewed people at the case company believed that good analyses would require that special analysts made them. This is a role that they do not have at the moment and a role that McKinsey Digital (2016) says is often lacking when companies enter the Industry 4.0 environment. It is therefore an advantage that the case company see the need of this before starting the implementation. One way that the benchmarking company has solved this is to have an own department that is responsible for dimension control. The department works as experts in this area and are supporting the rest of the organisation in these questions. As the benchmarking company has a central function for this unit, the dimension control department becomes a knowledge bank that collects experience from all types of issues. It makes it also easy for other departments to know where to turn when these types of error occur.

Due to the differences in the factories, the implementation must be planned according to each factory's current condition. It will be important to be humble depending of the prevailing situation, to be able to take the right next step. The implementation of the quality data management software will make the measurement data in the A factory digitalised, which make this factory an option for piloting the software here. This pilot could then be used as a success story for the remaining factories. For the B and C factories to become digitalised, new measurement equipment and IT infrastructure must be installed to make the software value-adding. If the conditions in those two currently undeveloped factories are upgraded, another alternative would be to start the implementation there. If this implementation would turn out as a success, with those circumstances to start with, it would prove that it is possible to implement the system anywhere. With new conditions in the B and C factories, and with the software implemented, all three factories could be considered as digitalised, as illustrated in Figure 5-2.

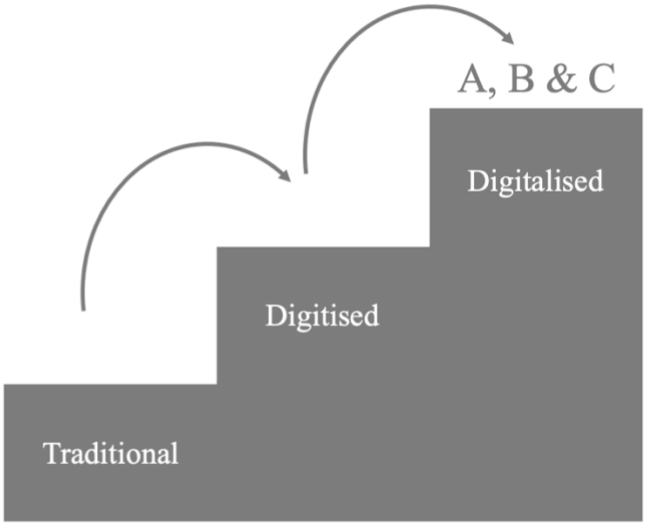

Figure 5-2: Illustration of future data collection process.

5.4 Methodology discussion

The research methodology used in this thesis, which is described in chapter 3, was of qualitative and abductive approach. The iterative process that characterises the abductive approach made it possible to study literature between interview sessions when new terms and concepts were mentioned. This was not utilised as much as believed in forehand as there were many similarities in the interviewee's answers. Still, some new literature was studied during the empirical data collection which made the method closer to an abductive approach rather than a deductive or inductive.

Regarding the interviews, the study could have been broader if more roles such as operators and technicians were included. As the result show, many believed that the operators would be important users of the software which indicates that it maybe would have been beneficial to interview them as well. Though, as the study had a time restriction, a prioritising was made together with the supervisor at the case company and focus was aimed to interview more managerial roles. Three more interviews were also planned but got cancelled of different reasons. This is not believed to have affected the results of the study as their areas were covered by other interviewees. What maybe would have been beneficial was if one more production manager was involved, as only one was interviewed. Regarding that only one respondent from metrology development was involved was due to that the size of the department is very small.

Some critics could be aimed at the interview questions. When the literature was studied prior to the interviews, it became clear that the cyber risks was a big threat in Industry 4.0 environments. Still, it was decided not to ask a specific question regarding this as it was considered as a leading question. Therefore, the questions regarding risks and challenges were kept very open to not impact the answers. Considering the fact that no one mentioned this risk, it could have been interesting to have asked more specifically about this to see what their answers would have been.

Initially the plan was to involve two or three companies in the benchmarking study. Many companies were contacted but only one agreed to participate in the study. Therefore, it could be argued whether or not the benchmarking company could be classified as an industry leader within this area, before the visit. Though, the study visit at the benchmarking company made it clear that, if they are not classified as an industry leader, they are however far more experienced on the area than the case company, which made the company a good benchmarking object. Also, as many of the requested functions that interviewees of the case company asked for was used at the benchmarking company is something that proves that the benchmarking study provided useful information to this thesis.

5.5 Future research

This thesis has clearly showed that the employees at the case company would like to introduce a system of this kind. The thesis has briefly covered the implementation part, but not enough to use it as a step-by-step description. Therefore, it would be interesting to further investigate how a detailed implementation plan could look like. This would guide the case company how to introduce the system as efficient as possible. It would work as a bridge between the current state without a solution and the improved future state which this thesis has proven. A future study could also focus more on what technical investments in form of IT infrastructure and measurement equipment to make in order to reach maximum utility.

6 Conclusion

The purpose of this thesis was to investigate what effects a quality data management software brings when measurement data is digitalised. The study was intended to show how the software supports managers to keep track of their production processes, but also showed that it is a useful tool for many more roles. By using the software and understanding the advantages, more decision can be fact-based to avoid decision-making based on speculation.

RQ1: What needs does the stakeholders at the case company have on a quality data management software?

The study has shown that the stakeholders at the case company want to use their measurement data as input to drive improvement activities. This is not made currently as they do not have a tool for analysing or visualising the data. Therefore, such software must help the case company to store and access this type of data and support stakeholders through real-time data to steer, control and improve production processes. This is a must to be able to be confident in future decision-making.

RQ2: How does the usage of a quality data management system affect the case company? What benefits and value-adding comes by using such system?

By using a quality data management system, the measurement data becomes visible to more stakeholders which will generate a better shared understanding for how the production is running. This will cut lead times in several activities as wastes will be eliminated compared to the current situation. As more people will be involved regarding the measurement data, it will also lead to better communication between every stakeholder. The system will also help the case company to continue their road towards more fact-based decisions. When data is used as a basis for making decisions, the decisions will become more accurate when trends and patterns could be identified.

In places where the system transforms the process into a digitalised process, the system makes the use of measurement data value-adding. In those places, the capability studies will be possible to perform with a fraction of the current effort. This will be an important application in the work for driving improvement activities with the use of the data. Though, when the measurement data is digitalised with the quality data management software, the data could be exposed to the IT security risks that are connected with Industry 4.0 applications.

RQ3: When having a quality data management software, how do you make it a natural part of the daily routines?

To make the integration as smooth as possible, it will be important to clarify the purpose to affected stakeholders early in the process. They must understand why it is implemented, how it is used and what it brings to them before they will include it in their daily work. A requirement will also be that the organisation must start to work more cross-functionally towards a common goal for the integration to be successful.

To include the measurement data analysis in already existing forums will be important to integrate it in the daily activities. This thesis suggests that one of these forums should be the daily management meetings. Here, as well as in the environment close to the operators, it is essential that there are screens and dashboards available to visualise and analyse the data. This will help to further utilise the full potential of the software.

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Appendix A

Interview guide

Introduction

1. Could you give a short description of yourself, what role you have, main work tasks as well as how long you have been working at the company?

Current state

2. How do you feel that the collection of measurement data works today?

3. What different types of measurements are you doing?

4. Could you estimate how big part of all performed measurements that are documented?

5. Do you think it is enough documented data to make reliable monitoring?

6. What is the measurement data used for? (both documented and not documented)

7. What do you feel is driving the decision-making today, in regard to measurement/quality data?

8. Do you miss the possibility to use data when taking decisions?

Areas of use

9. What areas of use do you see for this software?

10. What would you need from the software in order to take “better” decisions?

Effects

11. Is this a software that you are requesting?

12. How do you think that the organisation would be affected if this software is introduced?

13. How do you think that such system affects the analyses/monitoring in the future?

14. Do you think that this software would replace something that is used today?

15. Do you think the case company could achieve value by using this type of software in the future?

Implementation

16. What is important for you to actually use this type of software in your work in the future?

17. Do you see any obstacles with this system?

18. What do you think is the hardest challenge by implementing such system?

Appendix B

Interview guide benchmarking study

Introduction

1. Could you give a short description of yourself, what role you have, main work tasks as well as how long you have been working at the company?

Background

2. Could you tell me about your system for handling and analysing measurement data?
3. For how long have you been using it?
4. What was the reason for implementing it?
5. How did it work prior to the implementation? How was the monitoring made then?

Areas of use

6. What are you using the system for?
7. What parameters are you analysing?
8. Who are the users of the system?

Effects

9. How do you feel that this system has affected your work?
10. Does it lead to more fact-based decisions? Do you use more data as a base for decision-making today?
11. By using this system, have other work tasks been replaced?
12. Do you know if there are any numbers to prove any “results” of the system?
13. Have you been forced to educate staff to be able to use it?
14. What are the biggest challenges that you have faced when using this system?

Implementation

15. How do you feel that the implementation worked out?

16. Is it something you would have made different if you were about to implement it again?

17. What was the most important lesson learnt from the implementation?

18. How important is the usability?

19. How does the software work together with other systems you are using?

20. How do you make sure to involve this is the daily operations?