Exploring the Enablement of a Digitized Bakery

A case study

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This Master Thesis finalizes our five years studying Industrial Engineering and Management in Lund. During the course of the program we have learned a lot of things, and this thesis has given us the opportunity to both pursue our interests and specialities, in Software Intensive Systems and in Supply Chain Management. Furthermore, the five years in Lund have made us richer in experiences and let us grow as persons, and for this we want to thank our friends.

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Abstract

Title: Exploring the Enablement of a Digitized Bakery

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Background: The concept of Industry 4.0 is widely discussed among scholars and business leaders alike. Being able to adapt to this fourth industrial revolution is argued by many as necessary to stay competitive and to be profitable. Many companies today, however, have production lines built on legacy systems, as well as their own unique product challenges. This study aims to overcome these challenges by exploring the enablement of a digitized bread bakery.

Purpose: The purpose of this thesis project is to propose how and where Pågen should establish measuring points in its bakery lines in order to achieve productivity improvements, minimize manual input, and improve continuous monitoring.

Method: Multi-method qualitative single case study

Conclusions: The thesis found that there is an opportunity for the case company to combine the installment of new sensors with capturing signals from existing MES and PLC systems to extract information from the production lines. This information can be used in multiple areas of the company, and can generate a multitude of benefits regarding decision-making, reporting, machine availability, and more. To achieve the benefits, twelve projects were proposed, as well as general details on sensor placement and conceptual visualization of dashboards. A recommended order of implementation of the projects was presented.

Contribution: This thesis has been a complete elaboration between the two authors. Each author has been involved in every part of the process and contributed equally.

Keywords: Industrial baking, Bread industry, Digitization, Digitalization, Industry 4.0

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List of Abbreviations

BDA - Big Data Analytics
CO - Carbon monoxide
CO_2 - Carbon dioxide
CFD - Computational fluid dynamics
CPU - Central Processing Unit
ERP - Enterprise Resource Planning
ESI - Enterprise System Integration
FIFO - First In First Out
IoT - Internet of Things
IIoT - Industrial Internet of Things
IP - Internet Protocol
IT - Information Technology
LAN - Local Area Network
MES - Manufacturing Execution System
MOVT - Multiple Versions of the Truth
MRI - Magnetic Resonance Imaging
OEE - Overall Equipment Effectiveness
PLC - Programmable Logic Controller
PM - Predictive Maintenance
RFID - Radio Frequency Identification
SCADA- Supervisory Control And Data Acquisition
SMO - Smart Manufacturing Objects
SSoT - Single Source of Truth
WAN - Wide Area Network

1 Introduction

This chapter introduces the background to the thesis as well as a brief description of the object of study. It explains the problem statement and presents the purpose and research questions. Lastly, it presents the scope and delimitations of the study.

1.1 Background

The manufacturing industry has gone through multiple paradigm shifts. First when the steam engine was introduced, secondly when mass production became standard, and thirdly when technology made it possible to automate the industry. Today the rise of smart technology and big data computing has lead to the rise of the fourth industrial revolution, Industry 4.0 (Galati & Bigliardi, 2019). Industry 4.0 is expected to bring great opportunities and benefits, but research into Industry 4.0 is still in its infancy. For example, few articles focus on its risks and barriers (Galati & Bigliardi, 2019), and there is a lack of articles with a supply chain perspective (Hahn, 2020). With Industry 4.0 comes immense pressure on companies to adapt and transform to stay relevant throughout this period in time.

One of the driving factors for Industry 4.0 is the cost reduction of smart industrial sensors, defined by EY (2019) as “the combination of a sensor, microprocessor, and communication technology used to convert environmental inputs [...] into readable data and transmit it onward”. An increasing availability of sensors leads to an abundance of data which facilitate companies to make informed and automated decisions throughout their processes (Mourtzis et al., 2019). Capturing this opportunity is important for companies to stay competitive.

The Swedish Ministry of Enterprise and Innovation have stated the importance of industrial digitization to maintain competitiveness and develop national competences. This is reflected in the initiative “Smart industri - Sveriges nyindustrialiseringsstrategi” that The Swedish Agency for Economic and Regional Growth has been tasked to pursue (Tillväxtverket, 2020). The initiative show the importance of this subject on a national level and with this thesis the authors want to contribute to the understanding of digitization as a phenomenon in the industrial baking sector.

1.2 The case company

Pågen was founded in 1878 with the name *A. Påhlssons bageri*, making bread and rusk from the family home. As the business expanded, Påhlssons became a professional bakery, separating the family home and bakery in 1903. When packaged food became mainstream by 1950, Påhlssons were able to leverage this trend and distribute their products nationally. By 1965, Påhlssons bakery needed a name which was easier to relate to, and consequently changed their name to Pågen, the Scanian dialectal word for ‘boy’. (Pågen AB, 2020)

Pågen has ownership of a large number of companies, including its own wheat and yeast suppliers. It is the leading bread manufacturer in Sweden, and had a revenue of 3.3 billion SEK in 2018, with 2.7 billion coming from the production company. They have two manufacturing plants, in Gothenburg and Malmö. In Malmö, bread and rusk is produced, while the Gothenburg plant produces bread and confectionery. The Pågen bakeries in Malmö and Gothenburg together consume approximately 380 tonnes of flour daily and deliver to around 5000 stores in Sweden. (Pågen AB, 2020)

The vision of Pågen is to be “a naturally integrated part of every occasion”, and their mission is to “bake for future generations - we want to be able to give what we bake to our children”. (Pågen AB, 2020)

1.3 Problem statement

Pågen has a wide variety of IT-systems and applications. This is the result of many years of adding and altering the applications to match the current needs and operational demands. As a consequence there is a lack of unity and integration between the different applications and there is no one system that can control and observe the entire value chain.

In similarity, the production lines and machines at Pågen are of varying age and have great differences in possibilities of capturing data as well as analysis and control. The possibilities of detailed strategic, tactical and operational production control are therefore limited.

To tackle these two problems, Pågen has initiated a project to map and increase the digitization from sensors to Enterprise Resource Planning (ERP). The IT-levels are illustrated in Figure 1.1, the automation pyramid (Körner et al., 2019).

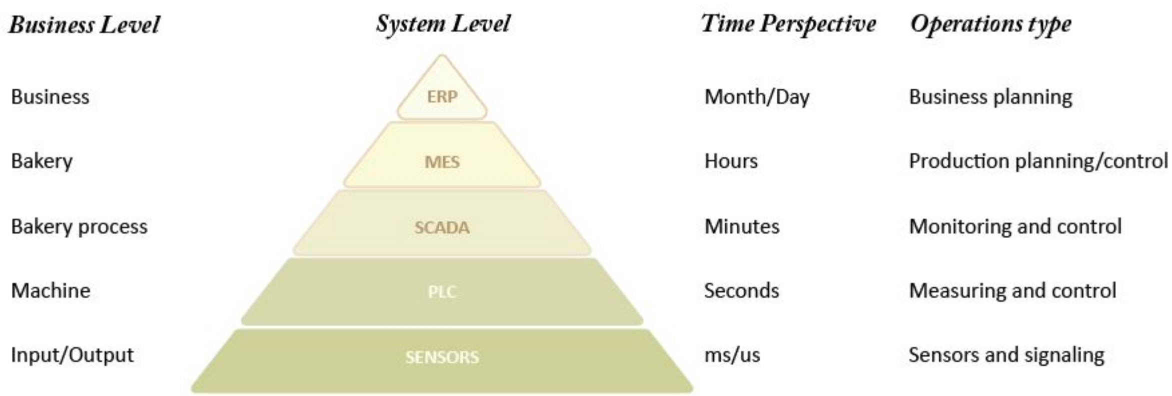

***Figure 1.1**: The automation pyramid. Source: Körner et al. (2019)*

1.4 Purpose

The purpose of this thesis is to propose how and where Pågen should establish measuring points in its bakery lines in order to achieve productivity improvements, minimize manual input, and improve continuous monitoring.

1.5 Research questions

RQ1: What benefits could be generated from a more digitized bread production?
RQ2: How can the identified benefits be realized in a bread bakery line?
RQ3: Where should measurement points be placed in the production?

1.6 Scope and delimitation

Pågen has multiple production lines in both Malmö and Gothenburg. To focus the thesis, delimitations were made to study two bakery lines in Malmö with typical characteristics for the organization to be able to make generalizable recommendations. The first, line LOAF, produces three similar products with multiple batches made per scheduled shift. The second, line LONG, continually produces one product, with scheduled cleanings. Further, the study will focus on the baking and packaging areas of the production.

Moreover, focus will be on the system levels PLC and Sensors which are defined in Figure 1.1. There will not be enough time for implementation the proposed solutions, therefore the project will focus on giving recommendations to Pågen for future development in digitalization.

2 Methodology

The following chapter will describe and highlight research strategies and methods. This is performed to be able to make an informed and balanced decision on the methodology for this specific master thesis.

2.1 The Research Onion

Introduced by Saunders et al. (2007), the research onion describes each layer or stage in the development of a research strategy, see Figure 2.1. It begins describing what choices to make at a high level, constructing research philosophies and approaches, and works down to the final core of how to conduct data collection and analysis. (Saunders et al., 2007)

In this master thesis, the design of the method strategy was based on the layers of the research onion, beginning at the philosophy level. As describing every aspect of every layer will be both tedious for the readers as the authors, the chosen strategy for each layer will be presented and if more in-depth knowledge is sought after the authors refer the reader to Saunders et al. (2007).

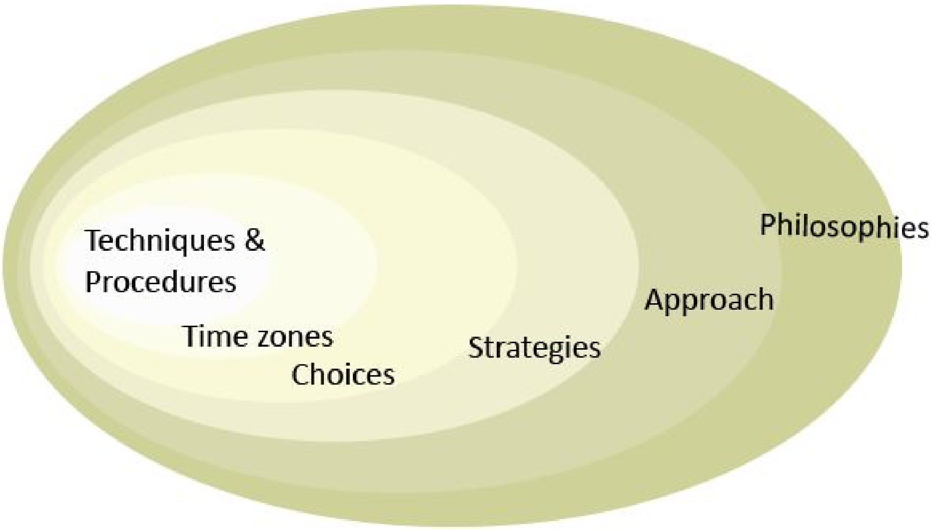

Figure 2.1: *The research onion. Source: Saunders et al. (2007)*

2.2 Research philosophy

The research philosophy is the general view of how knowledge is obtained and how it is developed. In short it reflects the way the researchers view the world. This master thesis is of an epistemological nature, which concerns the knowledge of a field of study and is often used by scientific research. When taking an epistemological approach to research the study can either be of a positivistic, realistic, or interpretivist nature (Saunders et al., 2007).

This thesis is of interpretivist nature, as it is largely focused on the experiences of individuals, which cannot yet be confirmed by data. The thesis is therefore mostly based on qualitative data, such as experiences and opinions of employees, to be able to capture the complexity of the business case.

2.3 Research approaches

The research approach is the second layer of the research onion and concerns the decision between inductive or deductive research approach.

This master thesis aimed to gather data and intelligence about the production lines at Pågen, and based on this information draw conclusions and form theories as to how and where measurement point should be implemented. No formal hypothesis was formulated and there was no testing of pre-existing theories. Because of this, the master thesis is of inductive nature and can be described as moving from the specific to the general. Based on the conclusions drawn from production lines LOAF and LONG, the authors aimed to formulate a theory that generally applied to all of Pågen's bread production lines.

2.4 Research strategies

The third layer of the research onion decides which research strategy to employ. When conducting social science research there are five distinguishable methods to choose from. These different methods are *experiments*, *surveys*, *archival analysis*, *history*, and *case study.* The most suitable type of method is determined by the form of research question the study is intended to answer if behavioral events can be controlled, and if the study focuses on contemporary or historical events, see Table 2.1. (Yin, 2018)

Table 2.1: *Relevant situations for different research methods. Source: Yin (2018)*

Method	Form of research question	Require control over behavioral events?	Focuses on contemporary events?
Experiment	how, why?	yes	yes
Survey	who, what, where, how many, how much?	no	yes
Archival Analysis	who, what, where, how many, how much?	no	yes/no
History	how, why?	no	no
Case Study	how, why?	no	yes

The purpose of this master thesis was to study and formulate a hypothesis of *how* and *where* measuring points should be established in the production. To be able to argue and discuss the presented hypothesis the motivational question *why* needs answering. With the research question focusing on *how* and *why*, without control over behavioral events and with contemporary focus, the chosen method of study was a case study.

A case study is the empirical investigation of a contemporary phenomenon in its natural context, where there may not be a clear divide between what is the phenomenon and what is the context. A case study is therefore a way to understand real-world scenarios and how the environment affect these cases. Case studies are not limited to either quantitative or qualitative data collection, but is more than often defined as being based on a multitude of different sources of evidence. (Yin, 2018)

A case study can be categorized into single-case or multiple-case, with their respective advantages and disadvantages. A single-case study can provide a greater depth when looking into the object of study. However, it might not be generalizable and there is a risk of assigning too much weight to single events. A multiple-case study can instead help augment validity and guard against observer bias. However, to be able to perform a multiple-case study more resources need to be assigned to the research effort and it will not be possible to go into the same depth as a single-case study. (Yin, 2018)

This case study is a single-case study focusing on the digitization efforts of Pågen. This increases the vulnerability of the project, making the research dependent on the local conditions. Therefore, the authors need to be able to adapt to changing circumstances, for example, if Pågen decides to implement a new network of measuring points before the conclusion of the thesis or if the coronavirus impacts the food production system, the authors may need to adjust and alter the study to stay relevant. However, the adaptability should not affect the rigor of the case study if the planned procedures are followed (Yin, 2018).

2.5 Research choices

The fourth layer of the research onion describes the choice between quantitative or qualitative methodology to perform data collection and analysis, and whether it is suitable to use a combination of both. The possible choices are illustrated in Figure 2.2.

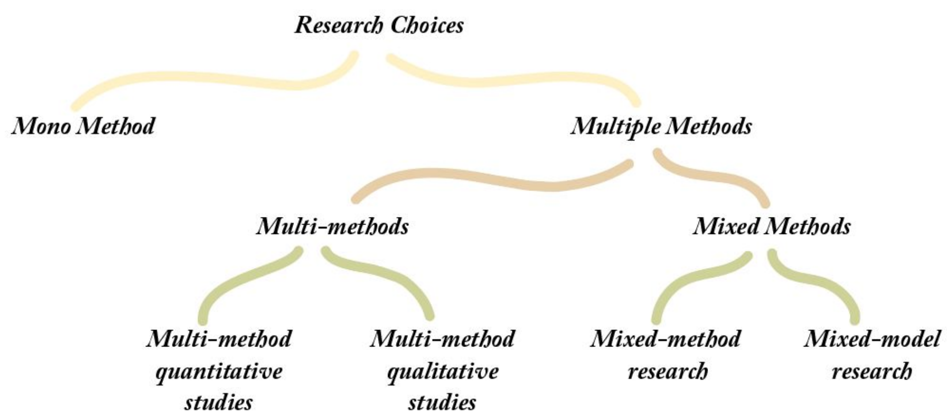

***Figure 2.2**: Research choices. Source: Saunders et al. (2007)*

For this master thesis, data was collected through observations, focus group, document study, and interviews. These are qualitative approaches to data collection and the collected data was analyzed in a qualitative way. Since the thesis used four qualitative methods of data collection and this data was qualitatively analyzed, the thesis is a multi-method qualitative study.

2.6 Time horizons

This layer of the onion describes the time dependency of the research project. The question answered with this layer is whether the research should be a snapshot of the phenomenon or have a diary-like perspective of time.

The study considered the production at Pågen as static and did not take account for the effect of time passing during the research. Even though the data collection was conducted over the course of approximately two months, this was not considered in the analysis. Therefore, the study can be seen as a snapshot of the production and is called a cross-sectional study.

2.7 Techniques and procedures

2.7.1 Literature review

The literature review was of the conceptual and scoping style defined by Jesson et al. (2011). Both reviewing methods are considered as a traditional or narrative review. The purpose of a conceptual review is to summarize the current knowledge in the area and add to the conceptual understanding of the topic. The scoping review looks at the current research in a specified area and determines the gaps in knowledge that can be used for further research. In general all traditional review methods are good for developing ideas, exploring issues, and identifying gaps in knowledge. (Jesson et al., 2011)

Despite the stated pros of these review methods, there are drawbacks, which the authors need to be vigilant toward. Traditional reviews have the risk of delivering one-sided review results because of the authors bias and objectives when doing the review. It is also less transparent than the popular systematic review. (Jesson et al., 2011)

2.7.2 Data collection

Empirical studies are based on observation and the collection of different information. There are many ways to collect information and it is important that the chosen method of data collection correlates and matches with the research questions. Table 2.2 illustrates the choices of different methods of data collection. (Säfsten & Gustavsson, 2019) This master thesis collected data through interviews, observations, focus group, and document studies.

Table 2.2: *Types of data and how they are accessed/collected. Source: Säfsten & Gustavsson (2019)*

Naturally occurring data		Artificial data		
		Real-world occurrences	Human perception of reality	Reconstructions of reality
Data access	Primary data	Observations, measurements	Interview, survey, workshop, focus group	Simulation data
	Secondary data		Document study, source criticism	

2.7.3 Interviews

Conducting interviews are a qualitative approach to doing research. Qualitative research is used to understand and analyze the “real world” by either explaining, describing, or understanding social phenomenons. An interview can be either unstructured, semi-structured, or structured. The structured interview can be compared to a survey which is performed orally. There are a pre-decided set of questions and clear ways to answer them. In contrast, an unstructured interview generally discuss topics in an open and free way and the interviewer has the freedom to follow up on statements with new questions, and the respondents can answer as they please. The semi-structured interview is a mix of the two aforementioned methods and most commonly used among engineers. The semi-structured interview has prepared questions and topics but the respondent can answer freely and the interviewer can ask follow-up questions. (Säfsten & Gustavsson, 2019)

When constructing the interview guide there are multiple aspects to consider. According to Kvale (2007) the first step of conducting a interview inquiry is to thematize, in other words defining the purpose of the interview and what knowledge that is wished to be attained. When a clear purpose have been formulated, the design of the interview guide should be finalized. The purpose of an interview guide is to act as a memory aid, ensuring all planned topics and subjects are discussed under the interview. (Kvale, 2007).

This master thesis conducted semi-structured interviews to have the freedom of following up on topics of interest but having a structure of the interview guide which can aid un-experienced interviewers through memory support and focus on the purpose. In *Appendix 1* the interview guide used is presented. The interview subjects ranged from a board member, members of IT-administration, process managers, and production operators. The main goals and knowledge obtained from these interviews are presented in Table 2.3.

Table 2.3. *Interviewees and the intended purpose of the interview. Source: Authors*

Interviewee	Purpose and information that should be obtained
Executive board member, IT & Controlling	Vision and goal of IT and Controller unit, as well as company goals
IT operations manager	Technical capabilities, IT-infrastructure, manual input
Process manager	Production overview, technical production capabilities, improvement potential
Production operators	Manual input, quality-determining factors, improvement potential
Product owner	Improvement potential
Supply chain controller	Improvement potential, basic data
Innovation manager	Improvement potential, quality control implications
Process/Product developer	Improvement potential, usage of quality measures
Automation responsible	Technical capabilities in production, current solutions, goals of automation
Automation engineer	Technical capabilities in production, technical infrastructure

2.7.4 Observations

In this master thesis, observations were used to understand the operations of the manufacturing plant. In Table 2.4, a thorough account of what was observed is presented along with the purpose of the observation. When conducting observations there are multiple aspects that should be taken into account by the researcher (Säfsten & Gustavsson, 2019).

Firstly, the researcher needs to make a decision on what role the observer wants to take in relation to the object of observation, ie. whether to be an active participant in what is being observed (insider) or passively observe (outsider) (Säfsten & Gustavsson, 2019). For purposes in this thesis, the choice was to act as an outsider. This necessitated that the authors were aware of the impact our presence made and that our interactions were limited, in order to not influence the credibility of the observations.

Secondly, observations can be of indirect or direct nature. Indirect referring to observations being done by, for example, measurement equipment. Direct refers to the use of the observers own senses to gather information (Säfsten & Gustavsson, 2019). This thesis used direct observations to evaluate and understand the production as well as the operators' work processes.

Thirdly, the observations can be structured or unstructured in how they are conducted. (Säfsten & Gustavsson, 2019) This thesis used unstructured observations. This was because the observations acted both as a learning experience and as information gathering. Therefore it would not be possible to beforehand make a detailed plan of what information was to be collected. However, thorough documentation of the observations was made through note-keeping.

Table 2.4. *Subjects of observations and the purpose of observing them. Source: Authors*

Subject of observation	Purpose of observation
Manual routines	Find areas of improvement and understand needs
Occurrence of scrap	Understand the characteristics of scrap
Baking and packaging processes	Find areas of improvement
Digital monitors in production	Understanding available data and what data is considered valuable for production

2.7.5 Focus group

Using a focus group, a method where several participants discuss a mutual interest together, is a useful tool to complement other data collection techniques (Morgan & Spanish, 1984). Focus group research can also effectively generate new ideas as well as exploring and verifying hypotheses. It can effectively formulate what is common knowledge. However, as the focus group can be biased according to each individual's unique knowledge and skill, the information obtained from focus groups need to be handled critically. (Fern, 2001)

This master thesis utilized a focus group to prioritize and evaluate the potential impact and the level of difficulty to implement the solutions. The focus group participants are presented in Table 2.5 and were chosen to represent a wide selection of company functions, as well as for their knowledge in either the production processes, the IT processes, organizational needs, or implementation.

Table 2.5: *Focus group participants and purpose for involvement. Source: Authors*

Participant	Specific knowledge
Production manager	Production processes, production needs
Quality Assurance/Innovation manager	Production processes, organizational needs
Director of IT & Controlling	Organizational needs, implementation, IT processes
Automation responsible	Production processes and implementation
Supply Chain Controller	Organizational needs and production processes
IT operations manager	Implementation, IT processes

The focus group discussions were executed in a late stage of the thesis work and were performed over Microsoft Teams as a result of the corona crisis. The discussions were recorded. The focus group was presented with a selection of possible projects which were connected to the digitization of the production processes. Thereafter they were split into two smaller groups for discussion of the project's impacts and value for the organization. The smaller groups were also asked to rank the projects in relation to their potential impact. The procedure was repeated regarding different aspects of implementation, ranking the feasibility of different solutions.

2.8 Quality of research design

According to Yin (2018), the quality of research design is judged on four tests. The first, *Construct validity*, means the correct measures related to the concepts being studied are taken, without being influenced by the researchers' bias. The second test, *Internal validity*, where a chain of consequence cannot be validated or proven. This is mainly a concern for explanatory case studies. The third test is *External validity*. This deals with the generalizability of the study, and can be in risk in a single case study. To improve external validity, it can be helpful to improve the case study research with study questions. The last test is *Reliability.* This is connected to replicability, where a case study should be able to be repeated, albeit the exact same conditions rarely appear. The procedures should be approached as explicit as possible, and according to Yin (2018), research should be conducted "as if someone were looking over your shoulder". (Yin, 2018)

3 Literature review

This chapter presents literature relevant and applicable to the case study. Firstly, an explanation of the bread baking process is presented in order to give an understanding of the production process and important factors which influence it. Secondly, literature regarding the digitized supply chain is presented with emphasis on the impact digitizing can have on the supply chain performance. Thirdly, the IoT concept is expanded and the tools and methods utilized by the digitized supply chain are presented. Thereafter, project management techniques are briefly introduced to adress change management factors of digitization. Lastly, case studies on previous digitizations are presented to add practical real-world insights to the thesis study.

3.1 The baking process of bread

The first bread was baked around 10 000 years ago. The Egyptians perfected the craft and with their influence bread became an important dietary product worldwide. Since then bread has become a basic commodity for many. (Mondal & Datta, 2008) The process of baking bread saw an industrialization from 1858, when the first mechanical bakery was introduced in Philadelphia, USA (Unknown author, 1858).

When industrially producing bread the processes begin with the mixing of ingredients and preparation of the dough. The dough is thereafter divided and molded into loaves. These loaves are leavened and baked. (Yousefi et al., 2018)

The two most important ingredients in bread are flour and water. Depending on the bread, these two ingredients stand for the bulk of the dough and they have a large impact on the texture and crumb of the finished product. For yeast bread, the amount of water correlates to the amount of CO_2 bubbles produced during leavening. Bread with high amount of CO_2 bubbles will be less dense and have a coarser crumb. During the leavening, the dough is fermented by yeast converting starch to sugars. The sugar is in turn converted into moisture and CO_2. To kickstart the fermentation process, sugar, as well as salt, is often added to the dough, which strengthens the gluten and stabilizes the expansion of the bread. During baking, the high temperature results in the gas bubbles expanding in the bread. These bubbles act as an insulator to protect the crumb from high rising temperatures and bind the moisture to the bread. Because of this process the core temperature tends to stabilize under 100°C and bread is often considered done when the core reaches 98°C. (Mondal & Datta, 2008)

3.1.1 Controlling and monitoring the baking process

Kondakci & Zhou (2017) describe baking as a dynamic process that is highly dependent on the relationship between dough properties and baking parameters. This leads to the need for suitable control strategies to be able to consistently produce high-quality products and optimize energy consumption. Advanced control strategies have been developed to control various parts of the baking process. Many are related to food extrusion cooking, which is not applicable for leavened bread, but a few approaches addresses other methods of bread production.

Paquet-Durand et al. (2012) developed an optical control system from inside the ovens to observe characteristics as color saturation, shape, and height of the bread. This insight resulted in the possibility to forecast lightness of crumb and color of the finished bread, increasing the possibility to automate the control of the baking process.

Computational Fluid Dynamics (CFD) modeling is another approach to estimate the browning of the bread, with addition to being able to forecast optimal oven temperatures, airflow, and core temperature of bread, according to Chhanwal et al. (2012). CFD modeling is a numerical computational method that can predict transfer of heat in masses, flow of fluids, and chemical processes by using large computational power. Even though there are multiple opportunities with this method of modeling there are limitations concerning prediction of the baking process. These pertain to the prediction of mass transport and volume expansion which needs to be addressed by further research. However, Chhanwal et al. (2012) claim CFD modeling to be a valuable tool for optimizing the bread baking ovens and estimate temperature, browning, and other properties of the bread during baking.

Moreover, the leavening process is one of the steps that define the quality of the finished bread (Yousefi et al. 2018). Both the texture and the flavor of the bread is impacted by this stage in the process and the addition of yeast may lead to altered resting times and changed flavor. The research by Yousefi et al. (2018) presents an automated control system based on machine vision to closely monitor the leavening process, decreasing human interference, and improving productivity.

Another approach to control and monitor process parameters is to install a wireless sensor network as shown by Baire et al. (2019). By monitoring CO_2 and CO levels, air temperature, and humidity in the leavening and kneading process the authors claim it is possible to reach improved processing parameters, reduced scrap, increased quality of product, and decreased production stops. Through the measurement of these parameters during real production Baire et al. (2019) concluded that the measurements taken could differ from target levels significantly, up to 64% from the desired value.

There are multiple measures to be taken into account when monitoring the quality of produced bread. According to Curic et al. (2008), the bread attributes that are vital to the consumers perception of the quality of the bread are appearance, crust, crumb, texture, and flavor. The evaluation of appearance and crust can be done through visual inspection (Wipotec, 2020; Sightline Process Control Inc, 2020; EyePro Systems, 2020). Noninvasive methods to examine the crumb of the dough include magnetic resonance imaging (MRI), microscopy, ultrasound, and X-ray microtomography. According to Koksel & Scanlon (2016), the insights gained from these assessments can be used to improve quality assurance, evaluate the functionality of ingredients, and optimize operations and products. However, all mentioned non-invasive methods are time-consuming (Koksel & Scanlon, 2016). An invasive approach to assessing the crumb of the bread is through the software C-Cell, which bases the analysis of the crumb quality of an image of a slice of the bread (C-Cell, 2020).

To evaluate if a bread is thoroughly cooked, the core temperature is regularly used as a good indicator. However, the temperature of the core of the bread does not have a linear correlation to the temperature of the crust (Ureta et al., 2019). A different approach to assessing the readiness of bread is, according to Chimenti & Faeth (2000) to subject the bread to ultrasonic vibrations. In addition, analysis of color can be used as a method to indicate the end of baking (Mondal & Datta, 2008).

3.1.2 Energy consumption

According to Mukherjee et al. (2018), industrial baking ovens account for 4-10% of a baking factory's energy consumption and are often designed with focus on effectiveness rather than efficiency. Therefore, energy management in ovens is valuable to decrease costs as well as CO_2 emissions. Through thermal measurements connected to variables such as fan frequency and CFD modeling, Mukherjee et al. (2018) claim there are significant cost reductions possible. Similarly, Bech et al. (2019) decreased CO_2 consumption significantly, by installing sensors to highlight possibilities to adjust the process without affecting its effectiveness.

3.2 The digital supply chain

There is a common understanding among supply chain managers that a digital revolution is overtaking supply chain management. However, there is high variance in what the term "digital supply chain" means. Sanders & Swink (2019) defines the digital supply chain as:

"A digital supply chain makes maximal use of "digital" technologies to plan and execute transactions, communications and actions".

A digital supply chain has four core attributes. It is *digitized*, meaning it is able to produce and capture data at the source, be it structured or unstructured. It is *connected* and can convert data into information. This involves combining, filtering, and organizing the data in useful ways. It is *intelligent,* meaning the information creates insights through for example visualizing, predicting or diagnosing capabilities. Lastly, it is *adaptive* and can convert insights into actions, improving the processes. (Sanders & Swink, 2019)

3.2.1 Industry 4.0

Industry 4.0 is a concept introduced in 2011 to signify the development of a digitally integrated industry. The term highlights its potentially revolutionary impacts by the term "4.0", deriving from the three previous industrial revolutions that it follows. Industry 1.0 introduced mechanical production plants through water and steam power. Industry 2.0 introduced mass labor production based on electrical energy, and industry 3.0 introduced automatic production based on electronics and Internet. (Galati & Bigliardi, 2019)

The projected impact of Industry 4.0 is extensive. The German Ministry for Economic Affairs and Energy predicts that by 2020 German companies will invest €40 billion annually in

Industry 4.0, and that it will have created €150 billion of additional growth in the German economy. (Federal Ministry for Economic Affairs and Energy, 2020)

3.2.2 Improvement potential of Industry 4.0

Through a survey of 300 manufacturing companies, McKinsey & Co. listed the top five impactful application areas of Industry 4.0. The list can serve as a pointer for where Industry 4.0 project efforts could start for high returns on investment. (McKinsey & Co, 2016)

1. Digital performance management

Digital performance management can through low resource requirements and simple solutions serve as a gateway to more advanced measures. Performance management tools such as digital dashboards can give rapid improvements of OEE through employee involvement, and normalized calculations and reporting can be created. Digital performance management can also work to lower silo barriers and create a more data-driven mindset.

2. Predictive maintenance

Through predictive maintenance, machine availability can increase by 10-15% according to McKinsey & Co. To be able to introduce predictive maintenance, the organization needs to have a deep expertise and knowledge about the assets involved, strong analytics capabilities, and appropriate change management expertise.

3. Yield, energy, and throughput optimization

Integrating process data with cost data can, according to McKinsey & Co., make a company able to optimize yield, energy, and throughput. To be able to do this, it is important to be able to create the right algorithms, as well as being able to both create a pilot and a scalable solution.

4. Next-level automation

Industry 3.0 brought a high level of automation, however the automation of jobs is still an improvement potential according to McKinsey & Co. (2016). As prices of industrial robots and sensors are falling, many blue-collar jobs can still be eliminated. However, also automating white-collar jobs such as demand planning and order management is possible, and can produce better results.

5. Digital quality management

Through digitization of documentation systems, companies can receive benefits such as higher efficiency, improved ability to trace errors, and cost reductions from recalls. Further advanced efforts, such as big data analysis can improve root cause analyses (identifying the root causes to solve problems), and drive improvements. (McKinsey & Co., 2016)

According to Schuh et al. (2017), Industry 4.0 brings benefits related to time needed to adapt to events in manufacturing. When an unforeseen event occurs, there are barriers in data collection, analysis, decision making, and implementation that needs to be overcome to be able to respond with a countermeasure as soon as possible. These barriers all take time, during which the value of the countermeasure decreases. As Industry 4.0 aids companies to swiftly adapt to an event, the benefits of adapting also increase, illustrated in Figure 3.1.

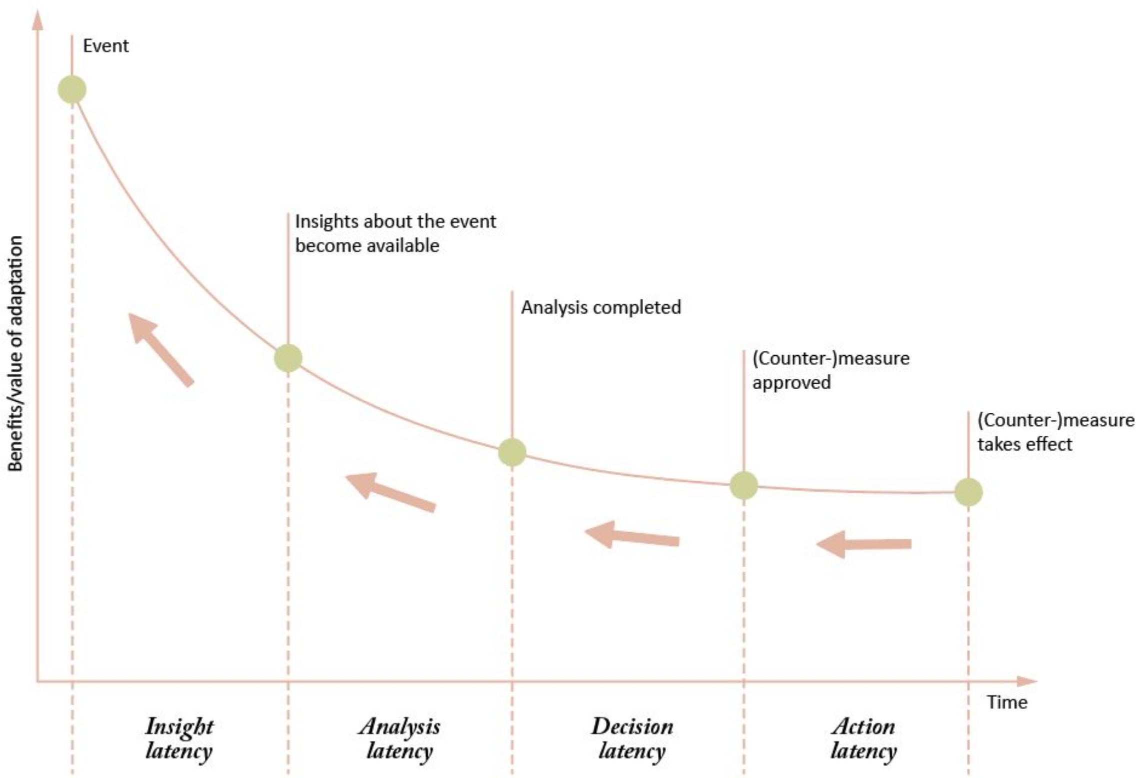

Figure 3.1*: Decision making latency implications Source: Schuh et al. (2017)*

3.2.3 The process of digitalization

According to Sanders & Swink (2019), many companies' work toward a digital supply chain is currently in its infancy and has no well-established roadmap or strategy. The goals of the transformation may be quantified in financial terms, or they can be more strategic, such as moving functional silos closer together or gaining end-to-end visibility. During the transformation project, Sanders & Swink (2019) argue that it is important to keep the goal perspective in mind, as a balance needs to be struck between solving specific problems and creating a more integrated, strategic solution. Similarly, McKinsey & Co. (2016) argue that many digitization efforts fail because of a lack of pragmatism.

According to Schuh et al. (2017) and adapted by Li et al. (2019), there are multiple stages in the implementation and development of Industry 4.0. These stages are illustrated in Figure 3.2 and show the different Industry 4.0 maturity levels a company can be in. *Pre-digital* companies rely on 'Word of mouth' and 'pen and paper' to collect and act on data. Further developed companies are *digitized*, and have computers which control processes, but collect information in silos independent of each other. Companies in stage two are connected through Internet Protocols. When a company has reached Industry 4.0, it can be labeled in four stages. In the *visibility stage* industries use sensors to collect data with the possibility of creating a 'shadow factory', a simulation that can visualize ongoing processes. The fourth level, *transparency*, involves utilizing the shadow to understand the causes of events. When the company has a capability of *predictability*, it can simulate future scenarios and assign possibilities, while *adaptability* can allocate real-time decision-making to IT-systems, making the processes more adaptable. (Li et al., 2019) (Schuh et al., 2017)

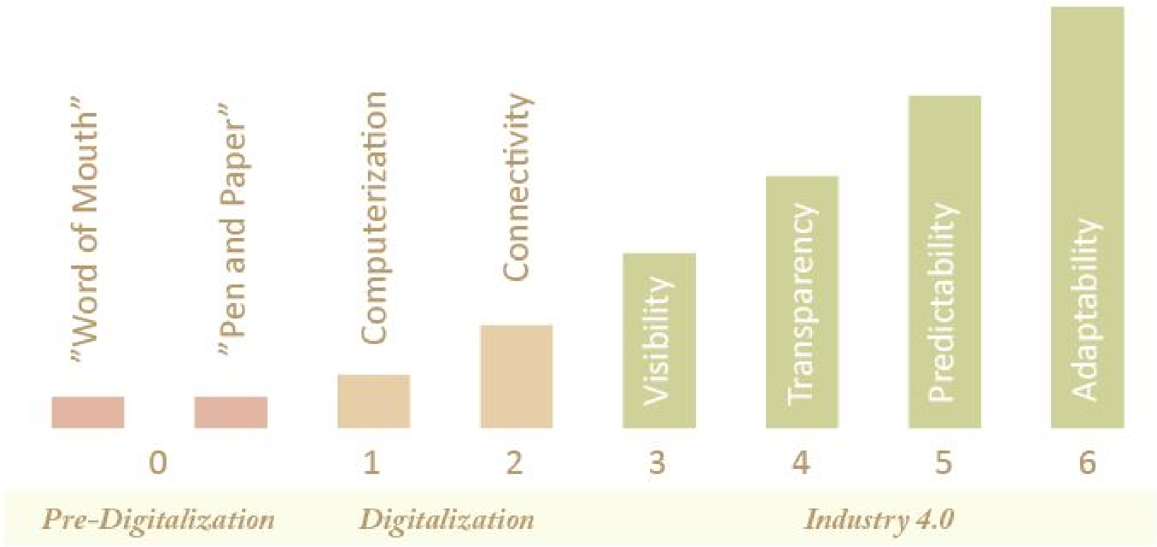

Figure 3.2: *The maturity stages of Industry 4.0 Source: Li et al. (2019), adapted from Schuh et al. (2017)*

Sanders & Swink (2019) suggest four main challenges to overcome to create a digital supply chain.

1. Getting the right data in the right form at the right time.
2. Communicating data as useful information to the right stakeholders.
3. Deriving actionable insights from the information.
4. Adjusting operations quickly enough to capitalize on the insights.

To achieve development in Industry 4.0 capabilities, there are four main structural areas which are needed to be developed: resources, information systems, organizational structure, and culture. Each of the four structural areas are connected to two guiding principles, see Table 3.1. The guiding principles outline the capabilities needed to be developed to support further maturity in Figure 3.2. (Schuh et al., 2017)

Table 3.1*: Structural areas for industry 4.0 development and their guiding principles. Source:* Schuh et al. (2017)

Structural area	Guiding principle
Resources	Digital capability Structured communication
Information systems	Self-learning information processing Information system integration
Organizational structure	Organic internal organization Dynamic collaboration within the value network
Culture	Willingness to change Social collaboration

The guiding principles needed to develop the structural area of ***resources*** are *digital capability* and *structured communication*. Digital capability encompasses that all resources such as personnel, machinery, tools, materials, and products need to be upgraded with the relevant technology. This would enable the personnel to be able to process data, data acquisition to be automated, and data to be processed decentrally. Structured communication stresses the need for efficient communication where data is available for those needing it, for example by a Single Source of Truth (SSoT) system. (Schuh et al., 2017)

Developing the structural area concerning ***information systems*** is guided by the principles of *self-learning information processing* and *information system integration*. Self-learning information processing involves transforming data into information automatically to analyze known and unknown cause and effect relationships. This should make it possible to predict issues with a high degree of confidence. The information then needs to be delivered in a suitable medium to support decision-making. An integrated information system should ensure that common data is available to be used throughout the value chain, facilitating access by standardizing data interfaces, integrating information systems, implementing data governance, and upgrading cybersecurity standards. (Schuh et al., 2017)

The structural area regarding ***organizational structure's*** guiding principles is *organic internal organization* and *dynamic collaboration within the value network*. In an organic internal organization, employees are not bound by their location on the organizational chart, but instead work across the organization in a task or goal-focused project groups, giving larger flexibility. The decision rights should be allocated as close to the origin of the information as possible. However, decisions which need high level of coordination should remain centrally decided. Incentive systems need to be reworked to also allow for occasional mistakes, and management should be agile, for example using scrum methods. Dynamic collaboration within the value network is achieved by having a focus on customer benefits, and larger levels of cooperation within the network. (Schuh et al., 2017)

The ***cultural*** structural area is similar to organizational structure, and the two need to support each other. The guiding principles of the cultural structural area are *willingness to change* and *social collaboration*. To accomplish the first, it is imperative to recognize the value of mistakes, being open to innovation, being committed to data-based learning and decision-making, offering continuous professional development, and making employees understand that they are responsible for shaping change. The second principle, social collaboration, is accomplished by a democratic leadership style, open communication,and being confident in the processes and information systems. (Schuh et al., 2017)

3.2.4 Analytical decision making

Being analytical is defined by Davenport et al. (2010) as using analysis, data, and systematic reasoning to make decisions. It can be done at any area of business. However, it has traditionally been more developed downstream, toward the customer.

Analytics can answer questions in two dimensions: time frame and type of information, i.e. are insights or information generated. The questions answered are illustrated in Figure 3.3. In its decision making, these questions encompass what a company needs to know about itself. (Davenport et al., 2010)

	Past	Present	Future
Information	What happened? (Reporting)	What is happening now? (Alerts)	What will happen? (Extrapolation)
Insight	How and why did it happen? (Modeling, experimental design)	What is the next best action? (Recommendation)	What is the best/worst that can happen? (Prediction, optimization, simulation)

Figure 3.3: *Questions answered by analytics categorized by time horizon and type of information. Source: Davenport et al. (2010)*

There are a number of situations when analytical evidence can be misleading. These are categorized into two types of errors. *Logic errors* concern the usage of the analysis, and whether the right conclusion can be drawn from the data. This can be the case when the analyses does not answer the right questions, using analytics to justify a course of action instead of being guided by facts, or not understanding the data correctly. *Process errors* are related to the process of doing analytics, such as making careless mistakes, failing to consider alternatives seriously, or using incorrect of insufficient decision-making criteria. (Davenport et al., 2010)

3.2.5 OEE

Overall equipment effectiveness (OEE) is a quantitative metric for measuring productivity of individual equipment in a factory, launched by Nakajima (1992). The metric identifies and measures losses in three important aspects of manufacturing: availability, performance, and quality rate. The concept of OEE is widely used as a tool essential for measurement of productivity and is also used to improve asset utilization. (Muchiri & Pintelon, 2008)

There are six large losses which are mainly measured by OEE. The full scheduled hours of the machine, the loading time, is shortened into operating time by its downtime losses. The downtime losses are mainly due to equipment failure or setup and adjustment time. The operating time is in turn shortened by speed losses through idling & minor stoppages and reduced speed. This results in a net operating time, which is only valuable when it produces products of appropriate quality. The defect losses consist of defects in processes or reduced yield. The whole system is illustrated in Figure 3.4. (Muchiri & Pintelon, 2008)

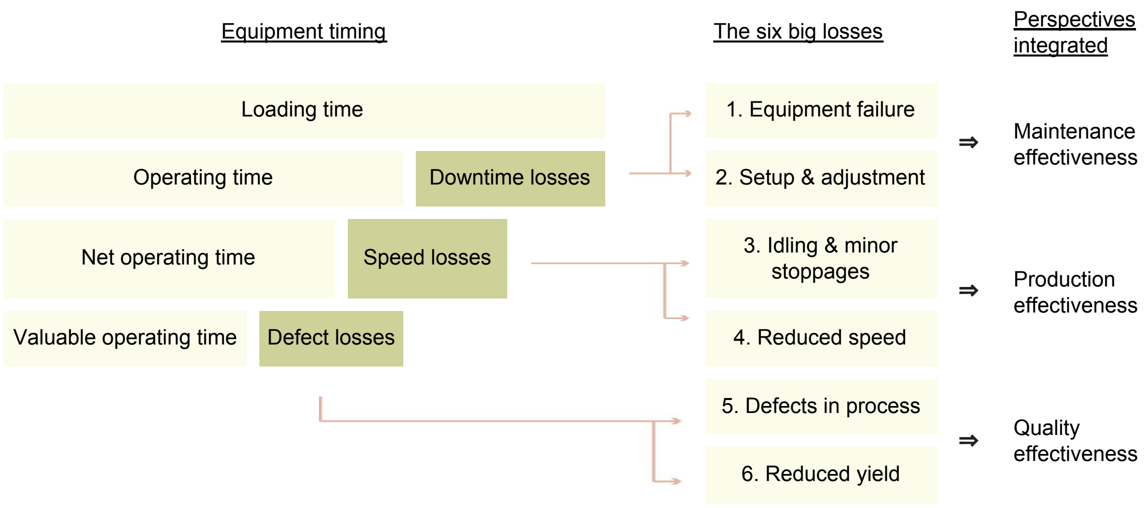

Figure 3.4: *Efficiency losses in equipment. Source: Muchiri & Pintelon (2008)*

OEE is a function of availability (A), Performance (P), and quality rate (Q).

$$OEE = A * P * Q$$

$$Availability\ rate\ (A) = \frac{Operating\ time\ (h)}{Loading\ time\ (h)}$$

$$Performance\ efficiency\ (P) = \frac{Theoretical\ cycle\ time\ (h) * Actual\ output\ (units)}{Operating\ time\ (h)}$$

$$Quality\ rate\ (Q) = \frac{Total\ production - Defect\ amount}{Total\ production\ (units)}$$

Data collection for calculating OEE can either be manual or automatic, and needs to be done on an appropriate level to be able to fulfill its objective without being unnecessarily demanding. Manual data collection has a low cost, but has a low accuracy. This might lead to minor events being forgotten and reporting risks demotivating employees. To collect data automatically can instead have a considerable cost, but is also very accurate and makes real-time data possible. (Muchiri & Pintelon, 2008)

When collecting data for OEE, there are two units which can be used: production time and output. Availability is calculated using the downtime, while quality and performance are calculated using the output. (Muchiri & Pintelon, 2008)

It is not unusual to have a low OEE level in a company. In a study of 25 machines by Ljungberg (1998), the OEE levels ranged between 30-93% with an average of 55%. The availability ranged 38-100%, performance ranged 30-100% averaging 68%, and quality ranged 97-100%, averaging 99%.

Criticism of OEE point out that the measure is limited to individual pieces of equipment, while most production chains are more complex than this. In the process industry, however, the full system can be considered as one machine. (Muchiri & Pintelon, 2008) It is also necessary to point out that OEE is not a performance measure, as such that it does not fit the definition of productivity being the result of output divided by input. As exemplified by Andersson & Bellgran (2011), a performance improvement caused by a decrease in cycle time would in effect lower the performance efficiency for the same number of customer orders fulfilled. Therefore, the OEE measure needs to be complemented by measures capturing changes in equipment constraints.

Sohal et al. (2010) found that motivation to implement OEE is often based on creating a basic reference measure for analyzing utilization of plant resources. However, through data analysis, the measurement often transforms into a tool to identify waste. It was critical for the success of implementing OEE to first make collection, storing, displaying, and benchmarking the OEE data as simple (or automatic) as possible and secondly to transition the management support to ensure the continuity of the system. This could be done be connecting the OEE data to company objectives. The main barrier to implementing OEE was found to be resistive cultures.

3.3 Technologies driving Industry 4.0

There are multiple technologies driving the Industry 4.0 industrial revolution. According to Noor Hasnan and Yusoff (2018), these technologies are described as the pillars of Industry 4.0 and include the following areas: Big data and analytics, autonomous robots, simulation, horizontal and vertical integration, cybersecurity, the Industrial Internet of Things (IIoT), the cloud, augmented reality and additive manufacturing. (Noor Hasnan & Yusoff, 2018)

Big Data and analytics refers to the analysis of large datasets to forecast, determine, control, find solutions and opportunities, and prevent issues.

Autonomous robots are entities that with flexibility, intelligence, safety and versatile collaboration can solve desired tasks.

With *simulation*, Noor Hasnan and Yusoff (2018) refer to the software that models the industrial process which makes it possible to analyze and optimize production parameters in a virtual setting before launching them to production.

Horizontal and vertical integration refers to standardized data networks which make it possible to integrate and link the value chain both inhouse and with other companies to ease cooperation and automate processes.

Cybersecurity is the response to cyber threats which has lead to the development of secure control of identity and accesses, as well as the protection of data and communications.

Industrial Internet of Things (IIoT) refers to the possibility for devices to collaborate and share data through a common network. This enables centralized control of the system but also facilitate the decentralization of analytics and possibility for the single devices to take real-time action.

The Cloud makes sharing of data between devices in a large and scalable way possible with up to no delay times.

Additive manufacturing is the manufacturing technology that benefits from 3D modeling to produce a product through 3D printing and similar methods.(Noor Hasnan & Yusoff, 2018)

Sanders & Swink (2019) propose four enabling technologies leading to the digital supply chain: analytics/decision technologies, processing technologies, communications technologies, and integrative/platform technologies. Analytics/decision technologies provide computing, information, and data management to enable higher quality decision-making. Processing technologies automate transactions and material processing for higher real-time visibility. Communications technologies create a richer flow of information, gathering from a multitude of sources. Integrative/platform technologies combine data management, communications etc.

3.3.1 Internet of Things

The Association for Supply Chain Management defines internet of things (IoT) as “the network of physical objects connected through the internet, as well as the intelligent communication that occurs between them”. They classify IoT as emerging practices, meaning it has potential to “redefine the playing field” within an industry. Through insights generated by IoT, companies can improve customer feedback, run production diagnostics, as well as drive process performance improvements. (Association for Supply Chain Management, 2017)

The applicability of IoT stretches from healthcare and transportation to smart homes and industries. As such, IIoT focuses the term to the industrial landscape. Jeschke et al. (2017)

argue that IIoT and Industry 4.0 are similar but not the same. IIoT is, according to them, a technology movement, while Industry 4.0 adds to the concept by addressing the impact the technology movement has on its stakeholders. That is to say, IIoT leads to Industry 4.0.(Jeschke et al., 2017)

IIoT is not a specific theory, but rather an interdisciplinary trend, which combines production, computer science, communication technology, mechatronics, and ergonomics. It is also related to general models of systems thinking and modeling, which in its turn goes into design theory, see Figure 3.5. (Jeschke et al., 2017)

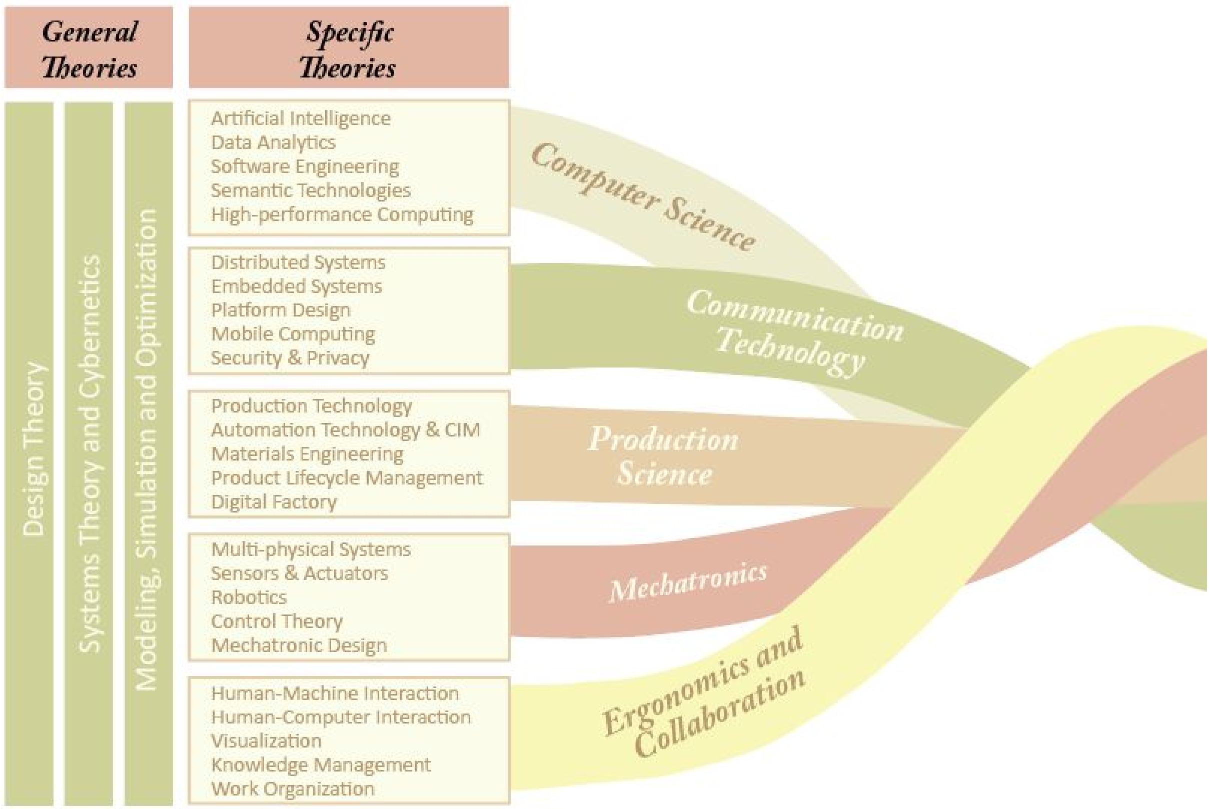

Figure 3.5: *The disciplines of Industrial Internet of Things. Source: Jeschke et al. (2017)*

3.3.1.1 Architecture of IoT systems

When IoT devices are connected and used for a set of specific applications, the related IoT devices are a part of the same *IoT system*. An example of an IoT systems architecture is illustrated in Figure 3.6. This architecture is composed of five main components. The *plant* is the physical system the IoT system aims to interact with. The *devices* are the leaf nodes of the system and can include sensors, actuators, processors, and/or memory. These devices have the ability to connect to a *hub* through a network (not necessarily with Internet Protocol (IP)). The hubs normally run IP and are the IoT-devices link to the network. The *fog processors* are not always a part of IoT systems. The fog processor connects to local devices and hubs and has process power to compute critical functions that need is dependent on low latencies. In general, the majority of computing takes place on the *cloud servers* which stores data and computational results on a database. (Serpanos & Wolf, 2018)

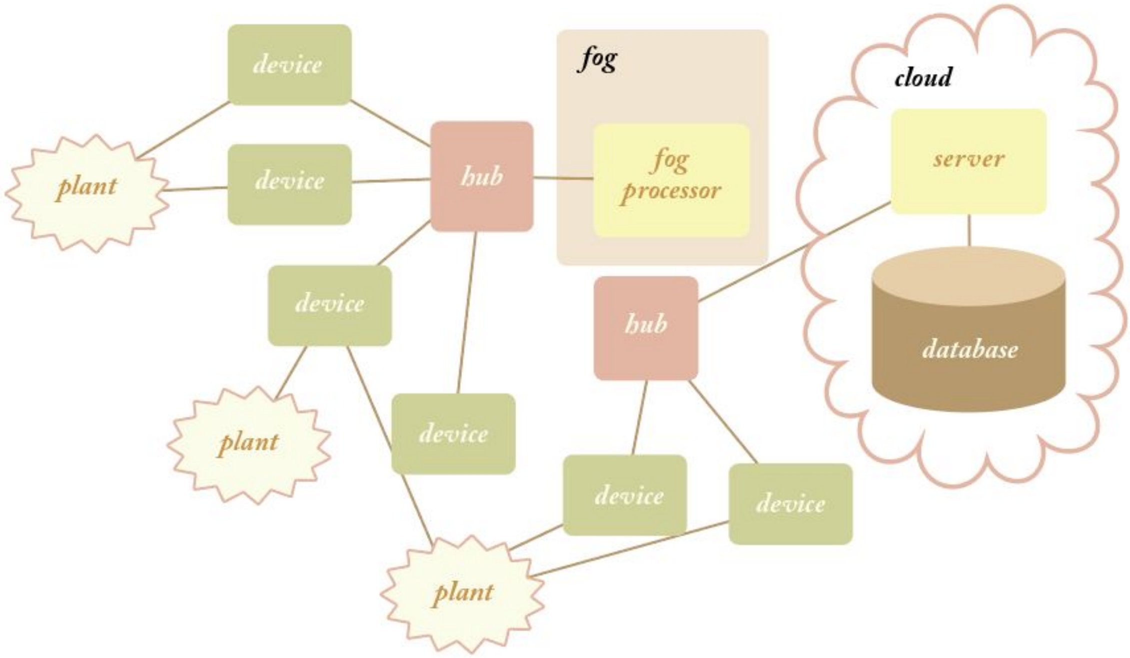

Figure 3.6. *Architecture of an IoT system. Source: Serpanos & Wolf (2018)*

3.3.2 IoT Devices

IoT devices are systems that can, on a single chip, combine processing, memory, communication, and sensing. These devices normally consume a low amount of power and do not run continuously. According to Serpanos & Wolf (2018) the cost of ownership of IoT devices is directly correlated to the power consumption. However, installation cost and purchase price are also a substantial cost.

When addressing installation costs, solving power supply (either by wiring, energy harvesting methods, or batteries) needs to be considered. In cases, the cost of hardwiring power supply can exceed the cost of hardware, making it an unattractive method. On the other hand, energy harvesting methods such as solar panels can impose restrictions on the devices and batteries leads to increased cost of maintenance. (Serpanos & Wolf, 2018)

3.3.2.1 Programmable logic controller

In industrial application the IoT device is often composed of a programmable logic controller (PLC) (Serpanos & Wolf, 2018). A PLC is a small processor that produces output signals according to the input and a stored program logic. PLCs were first developed in 1968 to satisfy the need for easily programmable controllers in manufacturing environments and are the replacement for hard-wired relays. There are four main components of a PLC, the central processing unit (CPU), the input unit, the output unit, and the power supply. Typical input devices for a PLC are different kinds of sensors, but buttons and control panels are also common ways of collecting information that the PLC will act upon. The output can be directed to multiple devices such as visual displays, lights, to control a motor, and more. (Ridley, 2003)

Challenges pertaining to the integration of PLC to ERP software are connected to the way they have been developed. PLC and the often connected supervisory control and data acquisition systems (SCADA) have been developed independently from IT technology because of specific requirements at the physical shop floor. Examples of these requirements that needs to be addressed by the PLC and SCADA systems are safety (operating as expected), continuous operation, and real-time operation. There are difficulties correlated with integrating these systems with the ERP systems because of the different requirements that have driven the development of the different systems. For example, operational technology systems have historically had a large focus on safety while IT systems (i.e. ERP) have focused on security and to integrate these pose a challenge. (Serpanos & Wolf, 2018)

3.3.2.2 Sensors

A sensor is a device that "responds to a physical stimulus [...] and transmits a resulting impulse" (Merriam-Webster, 2020). In the model for IoT systems by Serpanos & Wolf (2018), the sensor is a part of the IoT device. Currently, the availability of sensors has increased due to cost reductions (Mourtzis et al., 2019).

There is a myriad of different types of sensors on the market today that utilizes different technologies to convert environmental conditions into electrical charges. For example, to measure the position and displacement of objects, Fraden (2016) introduces eight different methods to do so and each method has multiple ways of implementation. In short, there are a multitude of options and it is important to have the intended use in mind when choosing and designing the sensor. Some of the more common applications of sensors and detectors are listed below. (Fraden, 2016)

- Occupancy and motion detectors
- Position, displacement, and level detectors
- Velocity and acceleration detectors
- Force, strain, and tactile sensors
- Pressure sensors
- Flow sensors
- Acoustic sensor
- Humidity and moisture sensors
- Light detectors
- Radiation detectors
- Temperature sensors
- Chemical sensors

When installing sensors in a baking line, Baire et al. (2019) defined requirements for the wireless sensor network to be taken into account when choosing a supplier. These include the following criterias:

- Be composed of small sensor nodes for high-density deployment;

- Present a robust radio technology in order to ensure variable-link capacity with a suitable packet error rate to guarantee a continuous flow of elaborated data;
- Have a flexible I/O for various sensors, in order to ensure high modularity;
- Be resistant to harsh environments; e.g., to dirt, dust, and humidity;
- Use a flexible, open-source development platform for portability;
- Ensure a high quality-of-service; e.g., through an accurate and reliable time synchronization between nodes;
- Have an energy-efficient processor to ensure long-lifetime;
- Have an easy to use graphical user interface;
- Be scalable or allow dynamic reconfiguration of network topology;
- Be safe and secure; i.e., guarantee the integrity and the authentication of messages.

3.3.4 Big Data Analytics

Big data has been widely discussed since 2011. In general, it applies to a large amount of data that has been created from a myriad of sources. A common definition is based on “the four V:s”: *volume, variety, velocity,* and *value.* Big data consists of large volumes of data with high variety. This demands high velocity or a high frequency of data delivery. Value highlights the need to convert big data into useful information. (Fosso Wamba et al., 2015)

In a connected supply chain there are many units that create and share data. This creates an opportunity for companies, but also requirements to handle this large amount of data in a valuable and effective way. The main difficulty with this is that the data collected from the production is often of different types, sizes, formats, meaning, and from a variety of sources. This creates a problem for many existing data handling systems, which cannot effectively handle the large quantity of data and the variation of data types, leading to the need for big data analytics (BDA) platforms. There are a multitude of BDA platforms accessible on the market, S4, Apache Hadoop, and Google’s Dremel being three of the more common software platforms (Fahmideh & Beydoun, 2019).

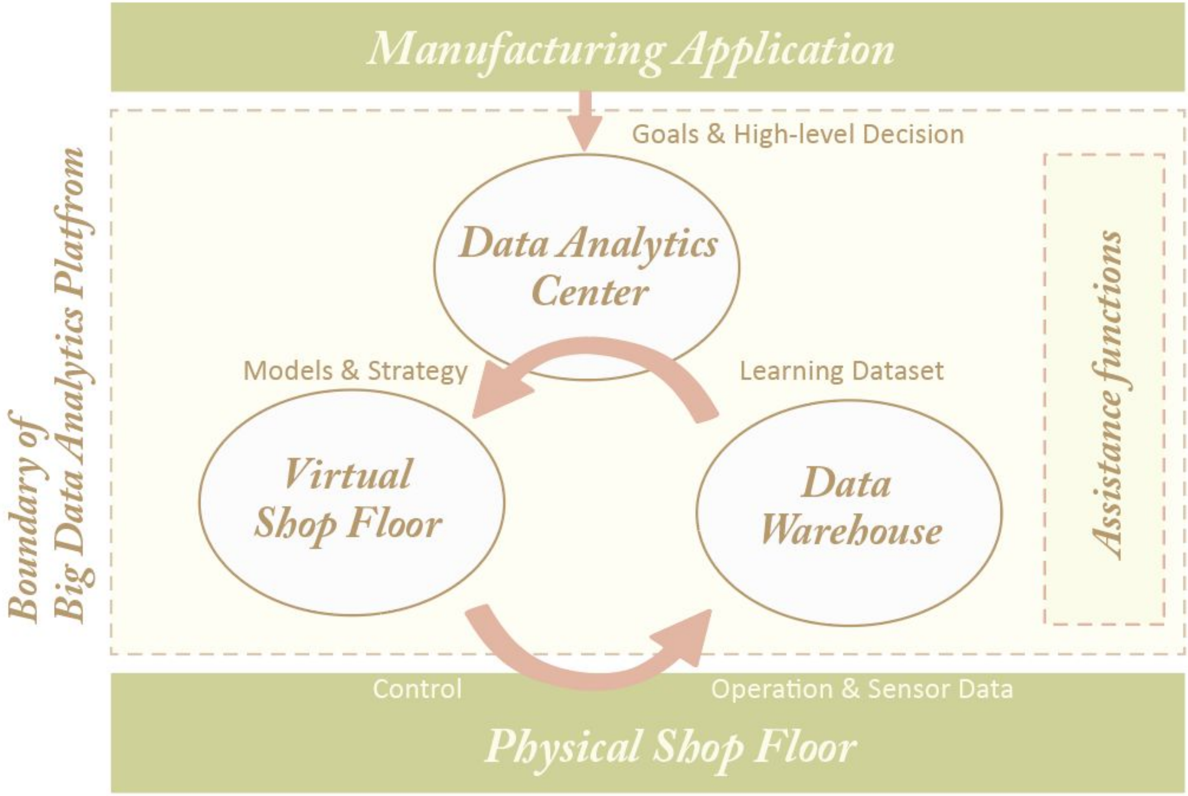

Figure 3.7. *Visualization of big data platforms. Source: Jungyub Woo et al. (2018)*

To utilize the capabilities and possible advantages that comes with big data computing, it is important to have an architecture that supports it. Jungyub Woo et al., (2018) proposes an architecture to leverage these capabilities and integrate them with the manufacturing system. Figure 3.7 visualizes how this system could be arranged at a high level. This architecture is based on three main components. The *virtual shop floor* is a representation of the physical shop floor, composed of agents that represent physical objects. It is responsible for planning and controlling the real shop floor and surveil the accuracy of the data-model. The *data warehouse* standardize and process raw data from the physical shop floor and store this data to distribute to the analytics center. The *data analytics center* creates data-models and strategies for individual agents, and manage the life-cycle of the models. (Jungyub Woo et al., 2018)

Fahmideh and Beydoun (2019) address the difficulties in integrating existing systems with big data analytics. Compared to industries such as health care, telecommunication, and financial trading, the manufacturing industry is slower to adopt BDA into their businesses. There are numbers of possible reasons for this, the high capital cost of manufacturing systems being one of them. Moreover, it is reported that 60% of big data adoption projects fail, making companies reluctant to try. These failures can often be associated with a lack of IT capabilities, contrasting legacy systems (systems which are not up to modern standards), and an inability to understand the different needs within the company for using BDA. Because of these difficulties it is important to approach data analytics integration by carefully evaluating the goals of the organization and the obstacles that stand in the way, to avoid cost surges in implementation. (Fahmideh & Beydoun, 2019)

The use of big data analytics and having flexible IT systems have proven to contribute to more agile operations of an organization. More specifically, the operational improvements which the use of BDA can lead to are mainly connected to improved forecasting of previously hard to predict scenarios, and improved performance of processes. In turn these affect the following areas positively: operations planning, inventory levels, scrap, customer service, and overall costs. However, adopting more advanced IT capabilities do not automatically generate improved performance, but the success of implementation is dependent on the readiness of the organization to utilize new IT functions. The relation between BDA capabilities and organizational readiness is visualized in Figure 3.8, showing how they interact to create improved manufacturing performance. (Fosso Wamba et al., 2015)

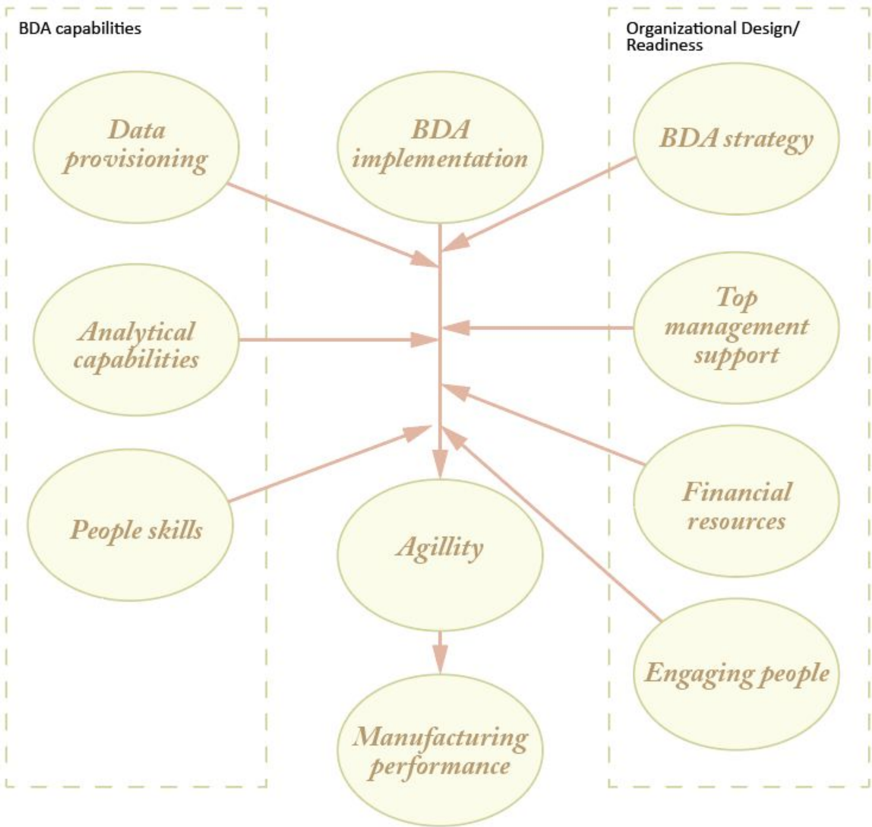

Figure 3.8. *Relation between BDA capabilities and organizational readiness to enable BDA. Source: Fosso Wamba et al. (2015)*

3.3.5 Visualization

Visualizing data can be described as representing data in some structured, systematic form including attributes and variables. Visualization is used in big data analytics to get a complete view of the data and discover the value of data. There are multiple benefits to visualization, including improved decision-making, better ad-hoc data analysis, and improved information sharing/collaboration. (Wang et al., 2015)

According to Wang et al. (2015), there are three main points of advice when visualizing data. First, do not ignore the metadata, which can be revealing. Secondly, visualization tools should be interactive and promote user engagement. Lastly, encourage interactivity. Meanwhile, there are four main myths concerning how to use visualization techniques. They are that (1) all data must be visualized, (2) that only good data should be visualized, (3) that visualization will manifest the correct decision, and (4) that visualization will lead to certainty. In fact, some messages can be conveyed without visualization, errors in data can be found by visualizing, critical thinking is still essential, and visualization can be manipulated or biased. (Wang et al., 2015)

According to Wang et al. (2015), the main obstacles needed to overcome when visualizing are the four V:s. Large volumes of data from a variety of sources are needed to be well structured, and the software needs to be robust enough to handle the high velocity. Lastly, visualizing the data needs to be done with value in mind. (Wang et al., 2015)

According to Berinato (2016), the key to succeed with visualisation of data is to focus on the purpose of the collection of data, not the data itself. When presenting ideas and information with visual aids there are two questions that should be answered before commencing with designing the display of it. The questions are:

Is the information conceptual or data-driven?
Am I declaring something or exploring something?

The first question relates to whether the visualization illustrates an idea or collected data. The second question defines whether the visualization is used to create insights or communicate a message. Combined, the questions create the visualization matrix, see Figure 3.9. (Berinato, 2016)

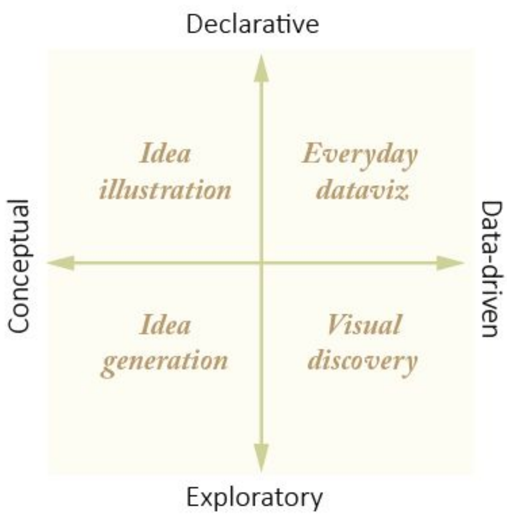

Figure 3.9. *The visualization matrix. Source: Berinato (2016)*

3.3.6 Single source of truth

A Single Source of Truth (SSoT) is defined as a data management strategy, consisting of a logical repository that contains one authoritative copy of all crucial data. (DalleMule & Davenport, 2017) With an SSoT setup, each business entity is the single source of its data, and offers this data to other entities. It does not allow replicating data, which could cause inconsistencies, as the data might be out-of-sync. (Pang & Szafron, 2014)

Establishing an SSoT is the first step identified by Ross et al. (2013) toward becoming a company of evidence-based decision making. It focuses efforts and counters the sub-optimization of isolated metrics. However, it demands an adjustment from employees to be able to utilize the information flow to its highest potential.

The SSoT service model is also beneficial to improve the data handling across an organization. In particular, it can according to Pang & Szafron (2014) be used to "*eliminate data replication, enforce data autonomy, advocate data self-containment, ease data maintenance, and enhance data protection*". Additionally, it would increase business adaptability.

DalleMule and Davenport (2017) argue that SSoT emphasizes "defensive" data, meaning it is used for control and minimizing downside risk, instead of "offensive" data, used to create value for business. According to them, offensive data needs flexibility which SSoT can not provide, that it is necessary to strike a balance between SSoT and multiple versions of the truth (MVOT). The optimal balance is determined by the core objectives of the business. (DalleMule & Davenport, 2017)

3.3.7 Predictive Maintenance

Preventative maintenance is one of the most popular maintenance policies. The core of the policy is that maintenance should be carried out before the condition of a machine can negatively affect production significantly. In traditional preventative maintenance, maintenance is done periodically at time intervals, based on the analysis of historical data on machine failures (Kaiser & Gebraeel, 2009). According to Hashemian & Bean (2011), time-based maintenance is however considered an imprudent way of doing maintenance, since it ignores the actual condition of the machine. Modern preventative maintenance is predictive and enabled by IoT. This type is commonly referred to as predictive maintenance (PM). With PM, it is possible to save on routine maintenance and avoid the noticeable problems that come with equipment failure. (Hashemian & Bean, 2011)

According to Hashemian & Bean (2011) there are three main techniques to utilize when employing online predictive maintenance. The first technique utilizes process measurements such as temperature, pressure, energy consumption, etc. to identify anomalies in the machines. The second technique uses test sensors to measure for characteristics of failure, such as vibration and acoustics. The third technique injects signals into the equipment to actively test them for cracks, corrosion, etc. (Hashemian & Bean 2011)

According to Åkerman et al. (2020), the main challenge for implementing predictive maintenance is the knowledge gap across different domains.Therefore, they suggest that implementation of PM is done incrementally, in cycles of data acquisition, analysis, and utilization. It is also necessary to know the machines well, and know what parts are critical to the production. The data should also be connected to metadata, such as what products or machine the data is related to, and the manufacturing process experts need to be guiding the experimentation of data. (Åkerman et al. 2020)

3.3.8 Enterprise System Integration

According to Govindarajan et al. (2016) legacy systems are the systems in use today that are not up to modern technological standards, considering hardware as well as software. In manufacturing companies these legacies are often critical to the value-adding processes and expensive or almost impossible to replace. Therefore, initiatives that strive to digitize manufacturing need to adapt to and work with these legacy systems to be successful. One way to approach this problem is to modernize the existing systems to be able to integrate them with the overall framework of data handling in the organization. This is referred to as Enterprise System Integration (ESI) and is crucial to create a smooth integration of systems and data within the organization. (Govindarajan et al., 2016)

There are multiple ways to approach ESI. Below are some methods that can be used to reach this goal either with help from management architectures, IoT adaptors, gateways, and integration measures.

Agent-based wrapper mechanism maps the legacy interfaces to an agent interface which then can be used in large Multi-Agent System to control and observe the real processes. This bridges the gap between the legacies and creates a stable platform (Zhao et al., 2008).

Business Process Reengineering is a methodology for examining and redesigning business processes and can be utilized to update current systems to meet the demands of the new technology. (Govindarajan et al., 2016)

A *12 step incremental framework* presented by Langer (2012) describes the process of integrating legacy systems into the current system. These steps of action come with many challenges, with migration of databases and applications being some of the most prominent.

Modoni et al. (2017) present an *ontology approach* to improve and handle system integration. The model leverages the possibility to convert the semantics of legacy models and reuse the existing data models to develop a new ontology. This ontology is then simple to further extend and support.

3.3.9 Technology in the food industry

According to Bech et al. (2019), the manufacturing setup of the food industry has been designed and operated with tacit knowledge, and with a long service life of the production equipment. The industry also has a low rate of investment in manufacturing technology, commissioning only 8,200 robots worldwide in 2016. Bech et al. argue that the consequence of this is that the food industry is prone to improving existing production lines instead of installing new lines.

To successfully improve processes through sensor data, there are, according to Bech et al. (2019) several challenges to overcome.

- The in house competencies need to be able to do big data analysis with millions of data points.
- The analysis process need to become anchored within the company.
- To be able to involve operators, the data need to become relatable to specific challenges in the production, leading to change management challenges.
- Decision making needs to overcome a paradigm shift, from being intuition driven to being data-driven.

3.4 Project management

One of the most popular models for change management is the 8 step change model proposed by Kotter (1996). The model consist of eight steps which need to be fulfilled in order to lead a project into a successful conclusion.

1. *Step 1: Create urgency* and make employees willing to challenge the status quo. An understanding needs to be developed organizationally that change is needed to remain able to compete.
2. *Step 2: Create a guiding coalition,* which has the capability to drive change. The coalition should have four main characteristics: positional power, expertise, leadership, and credibility.
3. *Step 3: Create a vision for change* is the first task of the guiding coalition. The importance of a well-defined vision is well established (Appelbaum et al., 2012), as it is easier for employees to understand and act on.
4. *Step 4: Communicate the vision* is critical to reduce uncertainty, ambiguity, and negative reactions to the change. More communication makes employees see more personal opportunities, therefore increases support.
5. *Step 5: Empower action,* includes giving employees structure, skills, systems, and supervisory support to be able to get rid of obstacles to the change vision.
6. *Step 6: Generate short-term wins* motivates employees by proving the value of change, and creating cause for celebration, reassuring stakeholders that the progress is on the right track.
7. *Step 7: Consolidate gains and produce more change* leverages the short-term wins and utilizes their momentum to tackle more issues which are not aligned with the change process, instead of declaring victory.
8. *Step 8: Anchor new approaches in the corporate culture* makes the change rooted in social norms and values of the company. This can be done by proving value, as well as making sure management is dedicated to upholding the change.

Appelbaum et al. (2012) reviewed the 8-step model and found each step significant for a core business change. However, criticism of the model argue that most companies enact changes stemming from their company culture instead of applying step 8, trying to change it. There are also examples of projects where steps should be omitted, for example irreversible or secret projects. In conclusion, however, they argue that following the 8-step model should increase the chances of success.

3.5 Case study examples of digitization

Single case studies of digitization can give valuable insights into the process of digitizing a manufacturing plant and provide learning opportunities from in-depth experiences. The two case studies showcase the process of using sensor data for experimental improvement, as well as decisions that need to be made.

3.5.1 A Danish bakery

To add sensors to existing production systems is inexpensive compared to new more digitized production systems, according to Bech et al. (2019). The challenge is instead to make the data valuable. As it is difficult and time-consuming to determine the outcome of installing sensors beforehand, they argue for an iterative six-step method to install sensors, see Figure 3.10.(Bech et al., 2019)

The method proposed by Bech et al. (2019) starts by formulating a hypothesis of improvement by involving different experts in the company. Secondly, the sensors are installed, with the location and type of sensor carefully considered. Thirdly, the sensor data is collected and stored in one common database before being analyzed to address the hypotheses formed in the first step. If the hypotheses can be answered, the project can conclude. Otherwise, new hypotheses can be formulated and evaluated. (Bech et al., 2019)

When implementing this framework at a danish bakery, Bech et al (2019) could significantly lower the CO_2 consumption, resulting in a low payback time and high return on investment.

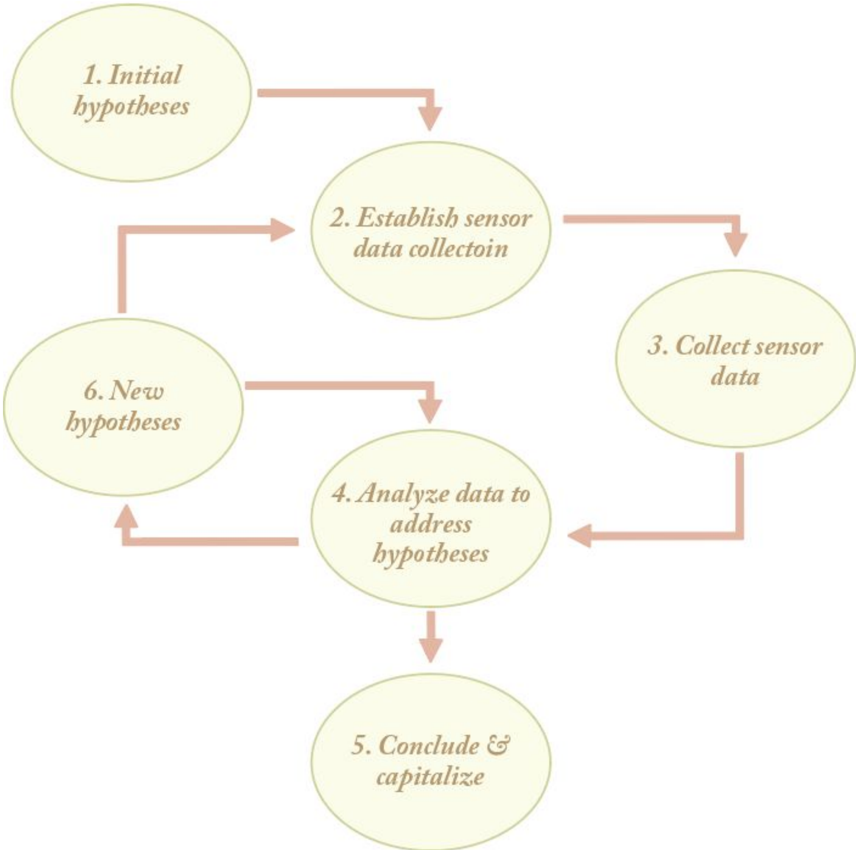

Figure 3.10: *Sensor installation method. Source: Bech et al. (2019)*

3.5.2 Transformation of the digital sawmill

In a case study by Lycken & Luomala (2019), a transformation project toward “the digital sawmill” was conducted in four steps.

Firstly, an as-is analysis was made.The goals of the project were to improve the OEE by 15%, increase product value by 10%, and reduce energy consumption by 10%. Therefore, the base level of key metrics needed to be benchmarked to be able to pinpoint processes to improve. (Lycken & Luomala, 2019)

Secondly, an analysis of installation requirements was made as well as a mapping of the current infrastructure inventory, laying the ground for an installation plan. The installation plan connected the production to the internal company network and drew cables, before installing sensors and related software. Thereafter, an integration platform was installed as well as a platform for big data analysis. Many choices were made regarding what sensors to install, where to install them, what software should be used, and how data should be stored. (Lycken & Luomala, 2019)

Thirdly, a number of analyses were made with the data collected. The analyses were developed from promising hypotheses, “known truths”, and/or gut feelings. Before the installation of sensors, many of the analyses had been possible to make isolated. After the installation, correlations and connections can be analyzed holistically. To be able to connect a product to multiple measuring points, time measurement was used. (Lycken & Luomala, 2019)

Finally, the project intended to implement process improvements based on the results of the analysis. However, due to unexpected events, Lycken & Luomala (2019) could not finish this step in time.

3.6 Summary

The literature review has been presented in five sections beginning with *the baking process of the bread*, followed by *the digital supply chain*, *the possibilities of technology, project management,* ending with *case study examples of digitization*. The relation of the addressed subjects and how they interact to build the foundation of knowledge required for increasing the level of digitalization in a bread bakery production is visualized in Figure 3.11.

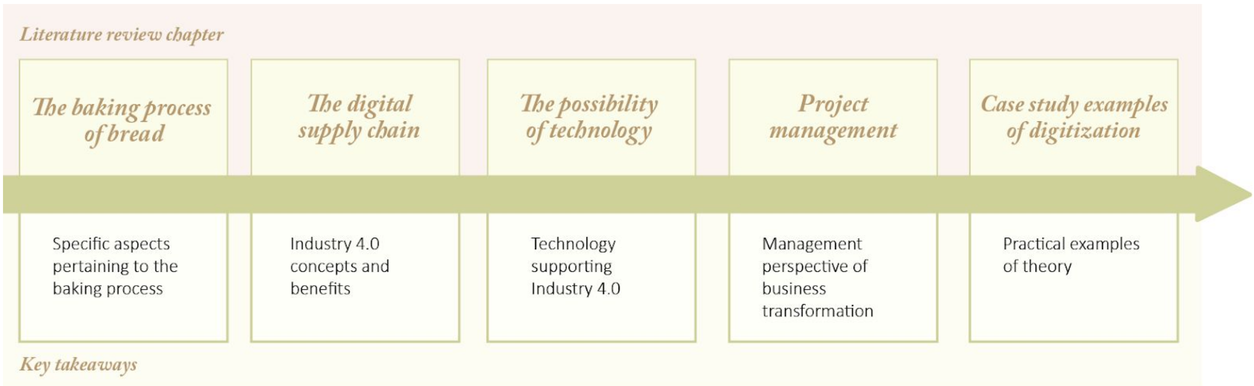

Figure 3.11. *Visualization of how the chapters build the foundation of knowledge needed to increase digitalization of a bakery. Source: Authors*

The baking process of bread introduces the importance of bread as a dietary product throughout the years and gives the reader an overview of the techniques to monitor the baking process. The section highlights the possibilities associated with a digitized bakery and what techniques are required to achieve them.

The digital supply chain present the reader to the concept of *Industry 4.0*, the process of reaching a higher level of digitization, and key benefits gained by embarking on the journey of digitization. Lastly, the section introduces the reader to OEE as a KPI to control and optimize production efficiencies. This section emphasize the high level aspects of digitization projects.

The possibility of technology gives the reader a balanced description of the technologies and competencies that are the foundation for the majority of digitization projects. The section presents frameworks and knowledge to be able to perform digitization projects.

Project management presents Kotter's model for change management and introduces eight steps to reach successful project conclusion.

Lastly, the information presented in the literature review is tied together by *case study examples of digitization*, which gives real-life examples of digitization projects and example on how the theory is put into practice.

4 Empirics

This chapter presents the production process and routines at Pågen, as well as the information technology employed today.

4.1 Production

The factory in Malmö was established 1965, becoming “Europe’s most modern bakery”, according to Pågen. The production department is the largest employer at Pågen, baking more than 40 bread products. Historically, the production department has had a high degree of autonomy, and the transparency towards other departments of Pågen has generally been low. Their offices are separated from the other departments at the company.

In general for the production at Pågen, the baking of bread starts with ingredients being mixed and made into dough according to a recipe provided by the ERP system. These doughs are thereafter left in large cauldrons to leaven before being portioned into smaller pieces. The pieces of dough are left to rise, before being baked in the oven. After baking, the bread is left for cooling before being sliced and packed into plastic bags. However, there are some differences between the two production lines.

4.1.1 Production line LOAF

Line LOAF produces three different types of bread, and between each batch a cleaning is required. On line LOAF, the bread is cut into loaves and placed into oven forms before entering the oven. After the oven, a robot arm ejects the loaf from the oven form. In Figure 4.1 the mapped process from inbound to outbound is visualized. The parts of the process that are marked green in the Figure 4.1 represent the processes that are covered by this thesis. Below, in Figure 4.2, a simplified map of the production line is shown.

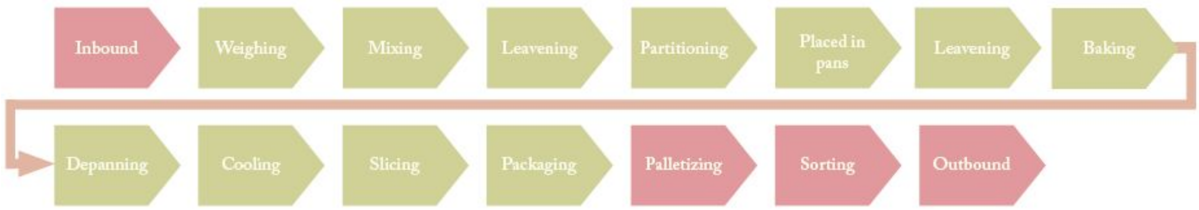

Figure 4.1. *Production process, line LOAF. Source: Authors*

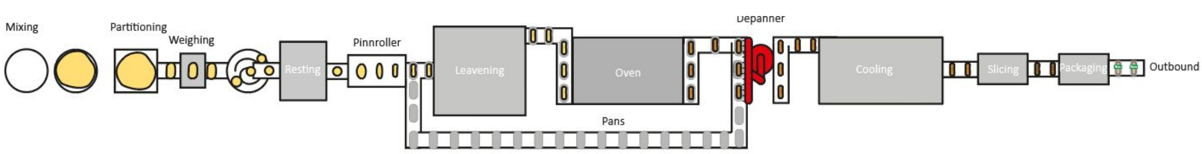

***Figure 4.2**. Simplified map over the line LOAF. Source: Authors*

Line LOAF produces three main types of bread. These breads have similar production speed. The bread that is produced in the largest volume has a relatively long changeover time (the time it takes to switch production from one bread to another) of 100 minutes when changing from the other two bread types. In relation the changeover time is only 15 minutes to switch to the other two types, irrespective of its predecessor. In total it takes a minimum of three to four hours depending on the bread to be processed, from weighing to packaging. It is necessary for it to spend at least one hour cooling down.

This production line is considered one of the more stable lines in the production, with low downtime and technical issues. The line has also been subjected to a pilot project within digitization with the installation of the Axxos-system that monitors selected variables in the production. This system has made it possible to automatically alert production supervisor and if there is a longer stop (ca >5min) the supervisors will be called to visit the line to investigate. Moreover, the line is also considered one of the more clean and automated lines in the factory because there are few or no ingredients that are added manually in the mixing process.

4.1.2 Production line LONG

Line LONG produces one type of bread with high demand. The side pieces of the bread are cut off before packaging. Therefore, to reduce waste, the bread is apportioned into long horizontal loaves during the production process. On loaf during production weigh around 15kg. The production process is visualized in Figure 4.3 and 4.4.

Line LONG produces bread twice a day. One shift starts in the morning and run to afternoon when the cooling racks are full. The bread on the cooling racks are pushed out to packaging at 21 and a new batch is started to run during the night. This results in two natural stops in the production where cleaning is performed.

Line LONG has a long lead time, taking a minimum of six hours for the bread to be processed from weighing to packaging. It spends at least 180 minutes in cooling.

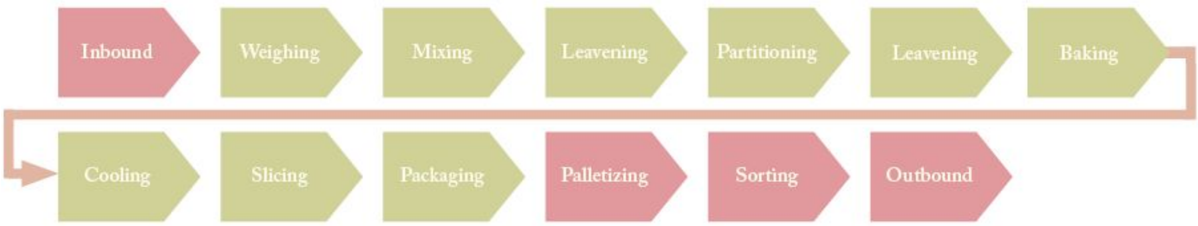

Figure 4.3. *Production process, line LONG. Source: Authors*

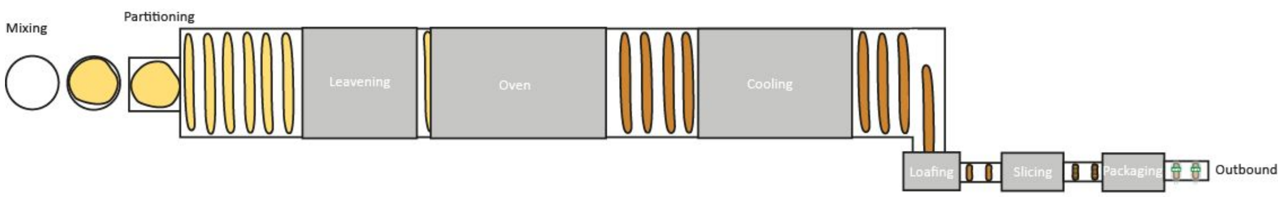

Figure 4.4. *Simplified map of line LONG. Source: Authors*

Line LONG has been subjected to a pilot project in quality assurance. After the oven, a visual system has been installed to control the shape of bread passing. This systems display if the bread should be scrapped or not. However, the system is wrongly calibrated, falsely reporting that a majority of bread does not meet the quality standards.

4.1.3 Existing sensors

Many machines and processes currently contain sensors which track the progress and status of the production. Some of these sensors are connected to a SCADA system that collects data and visualizes this on displays. The sensors function for many purposes, such as timing the drop when a piece of dough is put into pans, controlling that the conveyor is running, or removing bread which is underweight or heavily overweight. There are also sensors reporting the status of the oven, such as oven temperature and steam levels. The sensors communicate with the PLC level, as described in Figure 1.1.

4.1.4 Alarm central

At all production lines there is an alarm central connected to the conveyor belt. This central visualizes stoppages along the conveyor, ranging from where breads are placed in pans (line LOAF) or at the start of the leavening process of single loaves (line LONG) to when loaves are exiting the cooling racks. When there is a stop, the conveyor stops and the location of the problem is highlighted in red on the monitor to guide the operators. After the problem is fixed, the alarm central is used to restart the conveyor belt.

As a terminal used to aggregate and control multiple PLCs, the alarm central can be classified as being on the SCADA level defined in Figure 1.1. It is not connected to any network at Pågen, and has limited capabilities in becoming so. It is however possible to connect the individual PLCs directly to the network, without configuring the alarm central. In Table 4.1, the different alarms that are visualized on the display are summarized.

Table 4.1. *Displayed alarms on the alarm central. Source: Authors*

Along the pan conveyor	Cooling conveyor
Dough releaser	Depanner
Oven depusher	Elevator in
Conveyor pusher	Cooling rack
Bread-in-pan detector	Elevator out
Pan cleaner	Conveyor separator
Pan stacker	
Pan magazine	
Pan destacker	

4.1.5 Scheduling

The consumers demand fresh bread, which makes Pågen adapt its production by scheduling the production to the night and late evening. The production is maximized during “day 0 production”, from 9pm to 6am. Batches that are required to be transported far distances are processed earlier, and being able to swiftly ship the first trucks is therefore correlated to the company’s geographical reach.

To be able to support swift shipments, the packaging has a higher throughput capacity than the oven, and a queue is formed in the cooling lanes in front of the packaging machines before 21.00.

Operations planning is done in two steps, with a preliminary plan being followed before a final plan for the night is set at a later stage. The production orders are distributed by paper and the operators see a potential in digitizing this process.

4.1.6 Scrap

Today, the reported scrap is an estimation based on the difference between the expected yield of the number of mixed cauldrons and the number of bread put on pallets to outbound. The location of the scrap is not recorded, and it is therefore not possible to follow the resource consumption exactly, for example knowing how many plastic bags that are thrown away as a result of unsatisfactory bread.

Scrap can arise throughout the entire bread production process, from the overflowing of a cauldron at weighing to the rejection of an underweight bread at packaging. The areas with highest probability of scrap occuring are detailed in Figure 4.5.

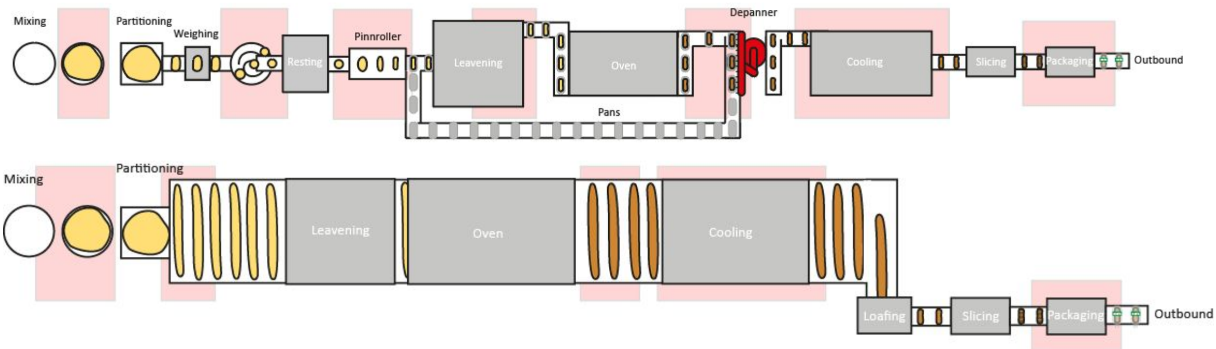

Figure 4.5: *Areas with higher probability of scrap. Top: line LOAF, bottom: line LONG. Source: Authors*

There are two main reasons for scrap to occur. Firstly, it can be caused by technical issues, for example if worn oven pans make the depanner unable to pick up a loaf of bread and a stoppage occurs. Secondly, they can be related to the baking process, for example by baking in too low temperatures, which would result in an unbaked bread.

Technical issues can cause scrap in multiple ways. As the process line is long, a stop in the production would at an earlier point make the bread or dough pushed into the system unable to fit. Therefore operators need to remove product from the conveyor or they will overflow. Generally, technical issues resulting in stops can occur along the entire line, however, some create scrap more frequently. If packaging is not working faster or as fast as the bakery, the cooling lanes can become full, and newly baked bread is dropped on the ground. The risk of this is larger at the beginning of a night, as a consequence of the pre-baked queue which has formed. Additionally, if a stoppage in the oven takes more than 3 minutes, the bread would be burned and needs to be removed. This is done partly directly after the oven, but as the bread is too hot to handle for a longer time period, it is also done in the packaging area.

It is also possible for technical issues to influence the quality of the product. For example, if the wrong proportions of ingredients are administered by the weighing system. Often, the quality issues become apparent during slicing and packaging, where the bread is then scrapped.

Discrepancies in the baking process can result in scrap in multiple ways. The dough is a living organism and as such it will be affected by the conditions its is subjected to. In general, if settings are off the desired target (for example, ovens too hot, resting times too short, flour to glutinous) the resulting product will be affected in some way and possibly lead to quality issues. Quality issues are often noticed in the packaging area, thereby scraped there. Additionally, the outside environment is a factor which affect the baking process. A high air humidity or hot weather will alter the optimal resting times and if not accounted for, will lead to over leavened doughs that either overflow in the cauldrons or bread that is over the technical limit in height. If loves reaches above the technical limit for height they can either get stuck in the leavening house or not fit correctly into the plastic bags resulting in the loaf being discarded.

4.1.7 Heat and environmental impact on production

The production of bread is dependant on the environmental conditions inside and outside the factory. As mentioned in the section above, temperature differences are a cause of scrap. According to operators the production is as most stable and well functioning during autumn, winter, and spring due to the more stable and colder weather.

The heightened temperatures that come with summer alter the way the production needs to be monitored. At standard temperatures, the leavening in the cauldrons after the mixing does not need to be heavily monitored and operators seldomly enter this area. During the hotter months, operators regularly need to check the temperature and the progress of the leavening to ensure that the cauldrons do not overflow. The dough after partitioning is also checked for temperature more regularly. The recipe also changes during summer months to combat the problem of faster rising doughs. The changes in seasons are also affecting the quality and behavior of the raw materials that go into production and can be a cause of altered quality.

The oven temperatures are reported to operators through a SCALA system monitored on the ovens. The temperatures can vary quickly when there is a gap in the feeding of new loaves into the oven, making the heat rise rapidly.

In close proximity to line LOAF a new line has recently been installed. This new line will elevate the temperature and therefore alter the conditions under which the production operates. This change in indoor temperature can become a cause for concern according to an operator.

4.1.8 Manual tasks

There are multiple parameters under the operators' control during baking. They can control the amount of yeast in the dough, as well as the time dedicated to the leavening processes. In general, changes in the fermentation process are made to counter the influence of the outside atmosphere, which could change suddenly and fluctuate during the day. Operators also need to keep the oven temperatures within acceptable limits. If the ovens are too warm, they need to be vented, which can be done by the operators. If they are too cold, however, technicians need to be summoned. This communication is done by phone call.

It is important that operators keep an overview of the full process and maintain communications from bakery to outbound logistics. The specific communication skills of operators has a significant impact on achieved delivery service. If an issue occurs at packaging, the packaging operators are responsible to inform the bakery. This can be done by walking to the nearest bakery operator on the line or by calling the supervisor, who informs the bakery. However, as the bread needs to cool for at least one hour, it could take hours before a problem is discovered and for the information to become actionable. Similarly, if a problem occurs in the bakery, the operators are obliged to inform outbound and baking.

4.1.9 Manual control routines

All quality reporting is performed by manually filling out paper reports. In close proximity to the production line there are binders with check forms that are supposed to be filled out with a specified time interval. These intervals are once every hour the production is running, as well as start, stop, and batch-switches. The first quality check is performed after the dough is portioned into individual portions. The second one after the bread has passed the oven, and the last after the bread has been placed in their plastic bags. The placement of quality checks is visualized in Figure 4.6, and the data obtained from these checkpoints are described in Table 4.2.

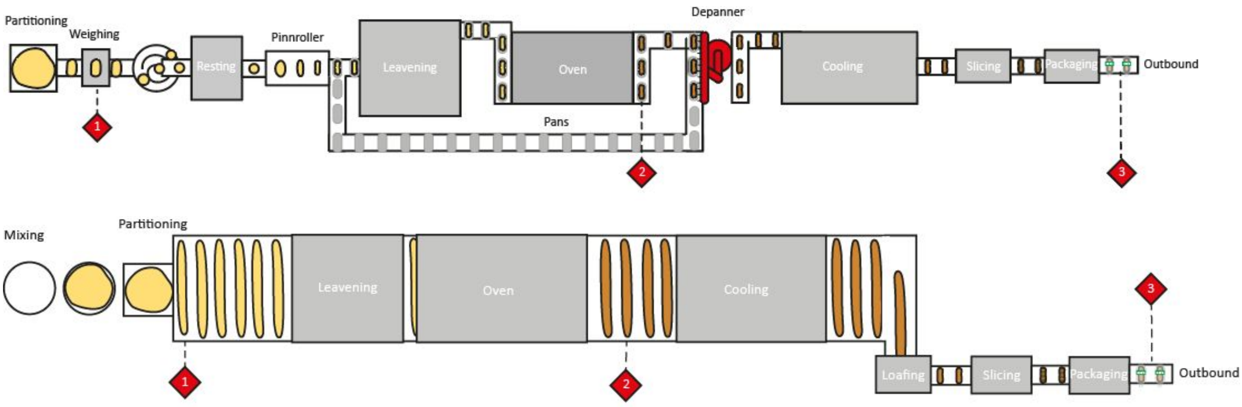

Figure 4.6. *Placement of quality checks. Top: line LOAF, bottom: line LONG Source: Authors.*

Table 4.2: *Attributes controlled at each quality checkpoint. Source: Authors.*

First Check	Second Check	Third Check
Core temp. of dough	Core temp. of loaf	Weight
Weight	Weight	Slicing
	Coating	Crumb
	Color	Appearance
	Height	Labeling, plastic bag
		Packaging
		Labeling, carton

According to multiple sources, the manual quality checks are not always correctly carried out. The information put in the binders is not always accurate, and sometimes not carried out at all. The reports are used to increase operators' insights, for diagnosis of issues, audits, and investigations after two or more customer complaints.

In addition to the quality reports, the operators fill out a stop report by pen-and-paper to log production stops. The operators express a belief that the manually-logged stops are digitized by the supervisors, thus followed-up. This is however contradicted by the supervisors themselves, who claim there is no follow-up on the stop data.

4.1.10 Quality issue routines

When the bread quality is uneven or does not follow established product norms, line operators are responsible to fill out a diagnosis. This is done by following a 19-step protocol, gathering measurements, and confirming that the machine settings are correct. If problems persist after correcting issues discovered by the diagnosis, process developers are called in as support, with the dual purpose of learning and correcting the issues. The metrics and settings that need to be collected to fill out this form are presented in Table 4.3.

There are indicators that the diagnosis is not always followed point by point, or that it contains incorrect information. Instead of filling out the form and reporting the problem, operators rely on their experience about what the issue is and adjust machine settings accordingly, before diagnosis is made. If the problem is not consequently solved, the issue will be hidden by the adjustments, making it harder for process developers to learn and address it, forcing a reset of the machines.

According to the R&D Department the data that is collected from the production is sufficient to track and find causes of possible production and quality problems. However, potential for improvement exist in the reliability of the information collected and how it is distributed within the organization.

Table 4.3. *Metrics and setting that needs to be collected to fill out the 19-step protocol. Source: Authors*

Area of collection	Way of collection	Collected metrics
Mixing of dough and leavening	Manually noting readings from Reimelt	Receipt number, setpoint and actual value for ingredients, alarms, water amount, water temperature, mixing time, resting time
	Manually by thermometer	Temperature of dough, temperature of air
Partitioning	Readings from partitioning machine	Program setting
	Manually by scale and ruler	Weight, dimensions of loaf
Leavening house	Readings from leavening control panel	Temperature inside leavening house, humidity, time in leavening house
	Manually by ruler and visually	Height, appearance
Ovens	Readings from oven control panel	Temperature in all zones, steam
	Manually by thermometer, scale, and visually	Color, core temperature, dimensions
Cooling	Readings from cooling control panel	Program setting, time in cooling, air temperature,
	Manually by thermometer	Core temperature

4.2 IT structure

Pågen has a myriad of systems that have a varying degree of integration between them. There is a mix of own developed and outsourced systems diverging in age and support for further development. As of today, the IT organization is going through a transformation where they are looking to replace many of the existing systems. Some divisions within the organization are using Microsoft Azure to support their IT functionalities and according to the executive board member for IT the vision is to transform and move more functionalities to this platform. Moreover, the database software used for the data collected from the production is not supported by the manufacturer anymore. Within many functions at Pågen, the consensus is that this database software should be replaced.

Figure 4.7 visualize the systems connected to the production and how they interact. The systems that are collecting information and are directly connected to the production floor will be further introduced in the following section.

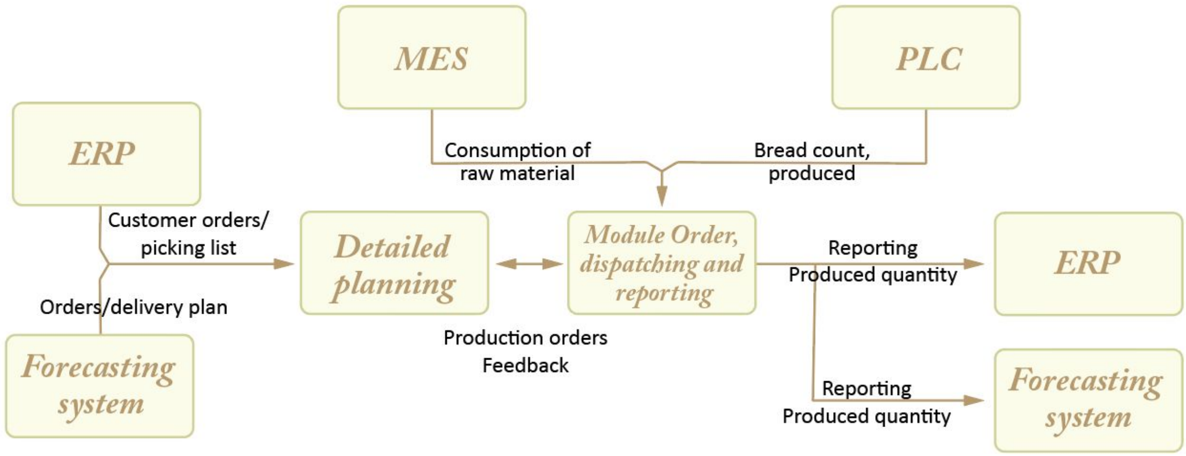

Figure 4.7. *IT-systems that are involved in the production process. Source: Authors*

4.2.1 Reimelt

Reimelt is both the hardware and software that controls the raw materials and the mixing of doughs. In Figure 1.1, Reimelt is defined as a manufacturing execution system (MES). This system is utilized on all production lines but depending on the line this system is correct to a varying degree. There is some acceptance of divergence of ingredients from the recipe, but at larger variances there will be a noticeable effect on the bread produced.

Reimelt is integrated with the ERP and automatically updates the production database of used raw materials. However, the batches that are to be produced need to be manually entered into the system.

4.2.2 Connected devices in production

There are multiple PLCs that are in use to control various parts of the production. According to the Automation lead at Pågen, all currently used PLCs in the bakery of line LOAF are connected to the internal network, while only some are connected in packaging. However, depending on the age of the line there are different possibilities.

As of today, there are multiple networks within one production line. For example, the slicing and packaging are connected to the same local network but the cooling racks have their own network. These two networks communicate with each other through a physical connection but none of them are connected to Pågen's local area network. To access the cooling racks, the technician needs to physically connect by ethernet cord.

The organization of IP addresses is a barrier to connecting more PLCs. This is the result of networks running out of space and new networks have been created to accommodate more connected devices. In return this has lead to an illogical way of assigning IP addresses, where devices on the same line and area can be assigned to different networks. There is an initiative to reduce this structural problem and install multiple hubs to organize addresses to the surrounding devices.

4.2.3 ProdMon

ProdMon is the system that is used to collect data of finished products from the production. ProdMon is based on QlikView and was created under 2018 as a proof of concept. The interface is connected to a PLC within the pallet loader in the packaging line and gets updated once a minute of the accumulated progress of the specific batch and line. The concept proved useful for the distribution and has been used since to control and monitor the flow of inventory from production to outbound logistics.

At this time, the data collected by ProdMon is presented as a cumulative graph. This is not optimal since the organization uses bread per hour as the measurement of which the production is evaluated from. This makes the information presented by ProdMon mainly useful for employees with the time and possibility to convert the cumulated numbers in Microsoft Excel. Additionally, there have been recordings of ProdMon collecting the wrong amount of finished products.

4.2.4 Axxos

Axxos was introduced on line LOAF in the early 2010s. It is a production monitoring system which logs all changes in production status, and through this follows up on OEE. During the implementation project, the goal was to be able to log causes of stoppages and through visualization of OEE encourage ideas and efforts for improvement. It also alerts supervisors when there has been longer stoppages, so they can respond and help the operators.

The Axxos system automatically logs stops, but relies on the operators to log the reason for each stop. This is not always done. As the same information is supposed to be logged in manually filled out stop reports as in the Axxos system, the work seems meaningless to some operators.

The system has been discontinued in use, as it was never able to become anchored in the company processes. At the moment there is an initiative at Pågen to investigate the possibilities with Axxos, with the goal to determine if it is possible to scale the Axxos-system to the other production lines, and increase its utility. Benefits identified with Axxos is that it is proven to be able to integrate with selected currently utilized softwares.

5 Potential benefits of digitalization

This chapter will, based on the literature review, present identified areas of benefits that an increased level of digitization can lead to. These benefits and areas of improvement will be placed into context of Pågen's manufacturing.

5.1 Decrease production stops

Production stops, both measured in absolute time the production stands still and the amount of stops, can be decreased by monitoring process parameters closely (Baire et al., 2019), visualization, and increased employee involvement (McKinsey & Co., 2016). Within the bakery at Pågen, the stops and their location are visualized through an alarm system gathering information from PLCs but is not gathered or visualized centrally. In the packaging, the alarms are not localized, gathered, or visualized. Monitoring of process parameters is limited to manual quality checks and recording of process setting when problems occur.

5.2 Increase quality of product

By digitization there is potential to improve quality of the product. This can be achieved by monitoring production parameters and in doing so, increasing the control of the baking process (Chhanwal et al., 2012)(Paquet-Durand et al., 2012) (Kondakci & Zhou, 2017). At Pågen, there is little analysis done on production parameters to optimize the baking process to improve quality. The quality of the product is optimized and controlled with tacit knowledge.

5.3 Reduce scrap

Reducing scrap can be achieved by monitoring and optimizing the baking process parameters (Baire et al., 2019; Yousefi et al., 2018), employing big data analytics (Fosso Wamba et al., 2015), and avoiding equipment failure by practicing predictive maintenance (Hashemian & Bean, 2011). Within the factory at Pågen, there is not enough collection of data to optimize the baking process to reduce scrap or to apply big data analytics. Predictive maintenance is an ongoing project.

5.4 Decrease manual input

According to McKinsey & Co (2016), decreased manual input will be an effect of increasing digitization at a company. By increased digitization it is possible to reduce and eliminate both blue and white-collar jobs. Currently at Pågen, there are many manual routines that could be subjected to automatization and therefore decrease the level of manual input.

5.5 Optimize inventory levels

By utilizing big data analytics, the possibility to forecast unpredictable scenarios increases, leading to companies being able to optimize their inventory levels more accurately (Fosso

Wamba et al., 2015). At the case company, the consumption of plastic bags is estimated using inexact numbers of scraped bread making inventory management less precise.

5.6 Increased adaptability

A digitized industry can reduce the time it takes from an unforeseen event happening to the time a countermeasure can take effect (Schuh et al., 2017) as well as improving forecasting of previously hard to predict scenarios (Fosso Wamba et al., 2015). At Pågen, there is potential for a long delay between an event happening and insights about the event becoming available as a bread can spend a long time cooling after it has been baked, ultimately being scrapped in the packaging area.

5.7 Improved decision making

By visualizing data it is possible to see the true value of data, thereby increasing the capability of making informed decisions and making ad hoc data analysis possible (Wang et al., 2015). Moreover, according to Ross et al. (2013), digitalization through SSoT is the first step towards evidence based decision making. McKinsey & Co (2016) claims that performing digital performance management can lead to a data-driven mindset, improving decision making, and Fosso Wamba et al. (2015) exemplifies that BDA can improve operations planning. At Pågen, metrics like daily scrap levels, output of production, and service level are available through different access methods at the company. However, there is no standardized platform for visualization and attainment of these metrics. Creating a setup for SSoT is a future goal of the IT department.

5.8 Lower silo barriers

Silo barriers can be lowered by digitization through visualization, making information more generally understandable (Wang et al., 2015; McKinsey & Co, 2016), as well as an SSoT setup, making information more widely available (Schuh et al., 2017). Currently at Pågen, the flow of information leaving the production to other departments is low.

5.9 Improve data handling

Using the SSoT model, it is possible to improve the data handling culture of an organization, reducing the need for data replication, ease data maintenance, and improve data security (Pang & Szafron, 2014). Isolated excel sheets located on employees' local hard drives are common at the case company.

5.10 Optimize resource consumption

The possibility to connect process data with its associated costs can make it possible to adjust and optimize yield, energy, and throughput (McKinsey & Co., 2016). Furthermore, case studies show that resource consumption can be significantly reduced through installment of sensors to track and analyze production critical parameters. (Bech et al., 2019;

Lycken & Luomala, 2019). Moreover, being able to record the actual yield of a dough cauldron, instead of estimating it, would improve possibilities to optimize it.

5.11 Decrease routine maintenance cost

Predictive maintenance relying on sensors makes it possible to decrease the need for “going the rounds” and performing unnecessary maintenance (Hashemian & Bean, 2011). Pågen is in the process of implementing predictive maintenance in order of component criticality and has also noted the benefit of being able to schedule maintenance during planned downtime.

5.12 Increase machine availability

According to McKinsey & Co. (2016), predictive maintenance can increase availability by 10-15%. Similarly, Hashemian & Bean (2011) state that it is possible to avoid noticeable problems stemming from equipment failure by utilizing PM. The OEE measures are also often used as a diagnostic tool to improve availability (Sohal et al., 2010). As a measure to track machine availability Pågen wishes to introduce OEE. Moreover, predictive maintenance is an ongoing project.

5.13 Root cause analysis

Collecting information from the process, such as digitized documentation (McKinsey & Co., 2016) and monitoring process parameters (Baire et al., 2019) would make it possible to adjust parameters to be in-line with recipes. As process metrics are not collected at Pågen, and the documentation is on paper, their impact on issues risk going undiscovered.

6 Success factors of digitization

This chapter will, based on the literature review, present identified success factors that needs to be considered when proceeding with digitization efforts.

According to the literature review many digitization projects fail with general transformations (McKinsey & Co., 2016) as well as big data analytics projects (Fahmideh & Beydoun, 2019). Due to the high difficulty of digitization projects, being aware of success factors is highly important. This chapter will discuss and categorize success factors identified through the literature review. The success factors are categorized on whether they are related to the transformation process or the final solution of digitization. Further, the factors are sorted into the four main structural areas of Industry 4.0 presented in chapter 3.

6.1 Key success factors regarding the transformation process

Laying the foundation for a successful digital transformation, there are several aspects to consider. Key aspects of these are presented and categorized in Table 6.1.

Table 6.1. *Key success factors regarding the transformation process by structural area*

Resources	Information systems	Organizational structure	Culture
Workforce with digital competencies (Schuh et al., 2017; McKinsey & Co., 2016)		High degree of cooperation within the network (Schuh et al., 2017)	Being pragmatic (McKinsey & Co., 2016)
Identify missing capabilities (Fahmideh & Beydoun, 2019)		Focus on customer benefits (Schuh et al., 2017)	Readiness to shift toward data-driven decision making (Bech et al., 2019; Sanders & Swink, 2019)
		Work organized in task or goal-oriented project groups (Schuh et al., 2017)	Connecting goals to company objectives (McKinsey & Co., 2016;
			Management support (Kotter, 1996; Sanders & Swink, 2019)
			Utilizing project management techniques (Kotter, 1996; Schuh et al., 2017)

6.1.1 Resources

It is imperative that the resources needed to fulfill a project are available. Firstly, current capabilities and desired benefits need to be combined through a gap analysis, to identify missing capabilities. The gap analysis will help avoid cost surges related to implementation.

The most important competencies needed are what Schuh et al. (2017) define as “digital”: to be able to do visualizations, big data analytics, data processing, etc.

6.1.2 Organizational structure

Organizationally, it is important that the transformation toward digitization is seen as a company-wide endeavor. It requires high degrees of communication between functions and should be led by a task or goal-oriented project group consisting of experts from many functions. This goal-orientation should be highly focused on what will bring value to the customer.

6.1.3 Culture

To be ready for increased digitization, the culture is highly important. Being pragmatic can avoid the pitfall of projects failing because they aim to bite off more than they can chew. The culture also needs to be made ready to shift toward data-driven decision making. To create a supportive culture, project management techniques, highlighted by Kotter (1996) should be utilized, whereas two of the main areas are to connect goals to company objectives and to ensure management support stays consistent.

6.2 Key success factors regarding the solutions

To make successful solutions for digitization, there are certain aspects which need to be highlighted. These are presented in Table 6.2.

Table 6.2. *Key success factors regarding solutions. Source: Authors*

Resources	Information systems	Organizational structure	Culture
Automated data acquisition (Schuh et al., 2017; Sohal et al., 2010)	User-friendly data (Bech et al., 2019; Sanders & Swink, 2019; Schuh et al., 2017)	Decentralized decision making (Sanders & Swink, 2019; Schuh et al., 2017)	Anchored processes and information systems (Kotter, 1996; Bech et al., 2019)
Structured communication (Sanders & Swink, 2019; Schuh et al., 2017)	Getting the right data in the right form at the right time (Sanders & Swink, 2019; Schuh et al., 2017; Bech et al., 2019; Jungyub Woo et al., 2018)	Incentive systems allowing flexibility (Schuh et al., 2017)	
Well structured and quality data (Schuh et al., 2017)	Automatic analysis (Schuh et al., 2017)		
	Data governance (Pang & Szafron, 2014; Schuh et al., 2017)		
	Cybersecurity (Schuh et al., 2017; McKinsey & Co., 2016; Noor Hasnan & Yusoff, 2018)		

6.2.1 Resources

A digitized production would require as simple and preferably automated data acquisition as possible. The communication within the company needs to be structured and standardized, in data as well as in usage, which would increase the possibilities for employees to explore the data and find value.

6.2.2 Information systems

It is necessary for the information systems to contain user-friendly data to encourage interactivity and generate insights. The right data should be in the right form at the right time, which is needed to enable decision making as close to events as possible. The analysis should also be done automatically, and solutions need a standardized data governance system and high cybersecurity.

6.2.3 Organizational structure

The organizational structure should make decisions as close to events as possible, made possible by high analytical capabilities and available information. To support this, organizational aspects include incentive systems that allow flexibility as well as organizational changes in decision making.

6.2.4 Culture

Culturally, it is imperative that the solutions are anchored within the organization. This can be done by proving the value of the solutions, with reliable data. This would enable trust, and therefore make employees more willing to utilize the results of the digitization projects.

7. Proposal of projects for improvement

To enable the benefits introduced in the chapter 5, and taking desires of key stakeholders in different departments into account, the following chapter will propose twelve potential projects to increase the digitization at Pågen. Each project will be thoroughly presented with how they can be customized towards Pågen's specific situation and needs, and what data is required to implement the projects.

The project proposals were developed in two phases. During the first phase, ideas were generated and initially identified benefits and implementation plans were formulated. After development, a focus group was utilized to generate feedback from the case company about perceived gains and implementability. During the second phase, the projects were refined. In the following sections, a map of Line LOAF will be used for the purpose of showcasing the solutions in the production. Line LOAF was chosen because it is more complex in its layout.

7.1 Introduction to projects

The projects were identified either by expressed wishes from stakeholders interviewed or by applying information from the literature review to observations of the case company's manufacturing process. The projects should be able to contribute to at least one of the benefits presented in chapter 5. In Table 7.1 the identified projects are associated with the benefits gained from implementation.

Projects

1. Introduce OEE
2. Track location of waste
3. Continuous collection of process metrics and settings
4. Track sources of stops
5. Connect scrap to causes
6. Communication to outbound
7. Enable data-driven feedback
8. Automate quality control
9. Predictive maintenance
10. Track energy usage
11. Create an SSoT
12. Create big data insights

Benefits of digitization

1. Decrease production stops
2. Increase quality of product
3. Reduce scrap
4. Decrease manual input
5. Optimize inventory levels
6. Increased adaptability
7. Improved decision making
8. Lower silo barriers
9. Improve data handling
10. Optimize resource consumption
11. Decrease routine maintenance cost
12. Increase machine availability
13. Root cause analysis

Table 7.1. *Summary of benefits driven by the projects. Source: Authors*

		Potential benefits													
		1	2	3	4	5	6	7	8	9	10	11	12	13	Sum
Project	1														4
	2														5
	3														5
	4														2
	5														3
	6														2
	7														5
	8														7
	9														3
	10														2
	11														3
	12														7
	Sum	6	4	7	2	1	4	6	4	2	3	2	2	5	

While the projects summarized in Table 7.1 are value-creating, project 0 is a supporting project, enabling value to be extracted from the following projects.

7.2 Project 0: Paring data to product category

To be able to do analysis, the data collected from the production should be categorized. A natural segmentation of data would be into products. The division of the data into product category is needed to draw further analysis than only by production line. Differences in performance from different products indicate that recipes could be improved. It would also make it possible to more accurately understand the capacity needs of a product, thus improving the production scheduling.

Implementation

Pairing data to product categories could be done in many ways, with varying automation. Firstly, the position of a batch of bread could be estimated by counting the time since dough was mixed, and connecting it with lead times and registered stops. As the weighing system knows what product it is mixing, it would be the main source of information. However, the weighing system would need to be integrated and automatically report on current batch.

Another approach would be to let operators report what is being produced, similarly using lead time and reported stops to estimate position. This approach would not necessitate integrating the weighing system, but would instead add a manual task.

A third approach would be to utilize changeover time between batches. This would require digitizing production orders, which has been requested from operators. Knowing the batch order, the analysis could utilize changeover time to signify a batch switch, and by comparing number of partitioned loaves to the orders, judge whether the data is reasonable.

The product could also be controlled after packaging, by scanning the packagings' bar-codes. This would add reliability to the data.

7.3 Project 1: Introduce OEE

OEE can be measured on entire production lines or individual machines. As baking and packaging are divided by a cooling lane, in effect acting as a mandatory storage, and the machines operate at different throughput capacity, it is needed to measure OEE separately for the packaging and baking. This will result in two OEE measures, one for packaging and one for the baking area. The case company has also requested that OEE can be presented over different timeframes over the day, since the demand for efficiency varies highly over a day. The OEE measures are recommended to be separated depending on day 0 production (from 9pm to 6am), i.e one OEE measure will be recorded for day 0 production and one for non-day 0 production.

The most valuable hours of production for Pågen are during day 0. Therefore, maximizing OEE and maximizing efficiency can be considered to be one and the same at this time of the day. In addition, OEE is a valuable KPI to visualize and report the efficiency of production during day 0. The separated measures for availability, performance, and quality can also be utilized to diagnose the production, to be able to make continuous improvement.

Production during non-day 0 is not as valuable per hour, but OEE measures collected at this time can also be informative. Its quality target would be the same, while availability and performance targets can be lowered to adjust to the lower demand. Free capacity can also be visualized highlighting new business opportunities.

Additionally, being able to visualize OEE per product category will make it possible to evaluate how well the process performs in relation to different recipes. Conveying this information can create better cost allocation and support decision making.

As a result of above mentioned reasons the dashboard, shown in Figure 7.1, is proposed by the authors of the thesis to visualize OEE at Pågen. When visualizing OEE it is important to show not only the overall OEE score, but to emphasize the underlying measurements, availability, performance, and quality. This is important to give a better understanding of the causation of how the OEE measure behaves and what areas are in need of improvement.

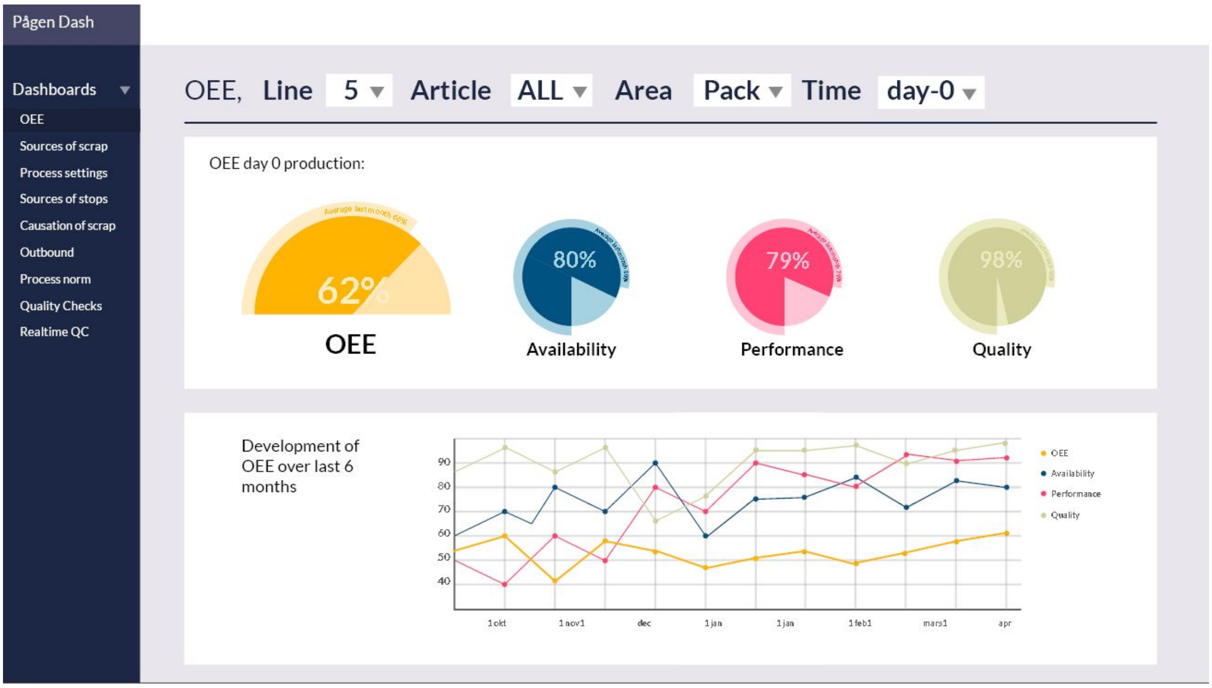

Figure 7.1. *Dashboard for visualizing OEE. Source: Authors*

Implementation

To measure OEE, the data needed from the production is how much bread has passed through a specific area in a specific time. The division of the OEE metrics in packaging and baking results in the need of having four separate measurement points to control when and how much bread has passed. These four measurement points are proposed to be placed according to Figure 7.2 and Table 7.2 with every measuring point recording all loaves of bread that are passing and a timestamp for each bread.

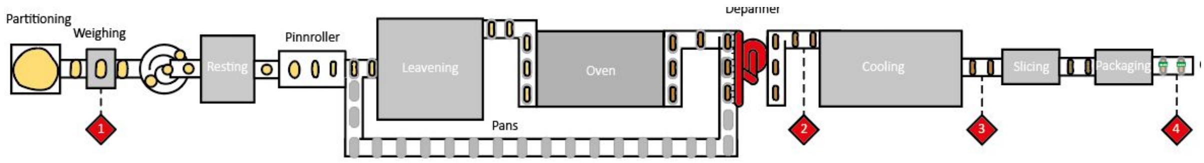

Figure 7.2. *Placement of sensors for measuring OEE. Source: Authors*

Table 7.2. *Description of measurement points for measuring OEE. Source: Authors*

	Meas. point 1	Meas. point 2	Meas. point 3	Meas. point 4
Data collection method	New sensor	New sensor	New sensor	New sensor or ProdMon
Placement of sensor	After partitioning, before rolling	After depanner, before entering cooling area	After elevator out, before slicing	After the cartoon packager
Data collected	Passed bread with timestamp			

When the mentioned data is collected the following information can be extracted from the production: production speed, output, input, and scrap. When combining this information with theoretical production speed and loading time, the OEE measures can be calculated accordingly to the formulas presented below. Since different batches have different production times, OEE needs to be calculated as a sum to get the daily OEE.

$$OEE = A * P * Q$$

$$Availability\ rate\ (A) = \frac{\sum Operating\ time\ (h)}{\sum Loading\ time\ (h)}$$

$$Performance\ efficiency\ (P) = \frac{\sum Theoretical\ cycle\ time\ (h) * Actual\ output\ (units)}{\sum Operating\ time\ (h)}$$

$$Quality\ rate\ (Q) = \frac{\sum Total\ production - Defect\ amount}{\sum Total\ production\ (units)}$$

Theoretical production speed and *Loading time* are parameters that must be defined by Pågen. There is good knowledge of the max speeds the equipment can produce at and it should be no challenge to get these metrics. In contrast, defining loading time is less straightforward and needs an internal discussion of how this value can best be chosen. Feedback on the proposed project also highlighted the risk of not taking different demands on production output over the course of 24 hours into consideration, as OEE incentivizes constantly high production.

The authors recommend that the loading time for day 0 OEE should be defined as between 9pm to 6am. During these hours, productions should be maximized, and consequently maximizing OEE should not lead to sub-optimization. The loading time for the daily OEE is proposed to be defined from the hours the lines are manned by operators.

7.4 Project 2: Track location of waste

The occurrence of scrap can be recorded at different granularity and preciseness in production. Today the granularity is high, and it is not possible to determine where in the production scrap occurs. Similarly, the preciseness of the amount of recorded scrap is low, with the reported amount of scrap being the difference between estimated output and measured real output. There is a need to lower the level of granularity and increase the preciseness of how the amount of scrap is recorded.

To lower the granularity of the recording of scrap location, the authors propose to visualize the scrap divided into five areas; *partitioning, leavening, baking, cooling,* and *packaging*. These areas will give a good indication of which processes in the production are problematic and need attention.

To increase the preciseness of data, the amount of scrap will be recorded as the difference between the amount of bread passing a specific measuring point, and the amount which passes the following one. This solution would therefore only allow access to data after a full batch has been produced.

The scrap should be visualized by its areas of occurrence as well as its division of articles, to guide decision making. The scrap dashboard would also visualize overall trends over a specified timeframe, and connect it to its impact in numbers by showing the total amount of pieces of bread that has been scrapped over the last 24 hours, see Figure 7.3.

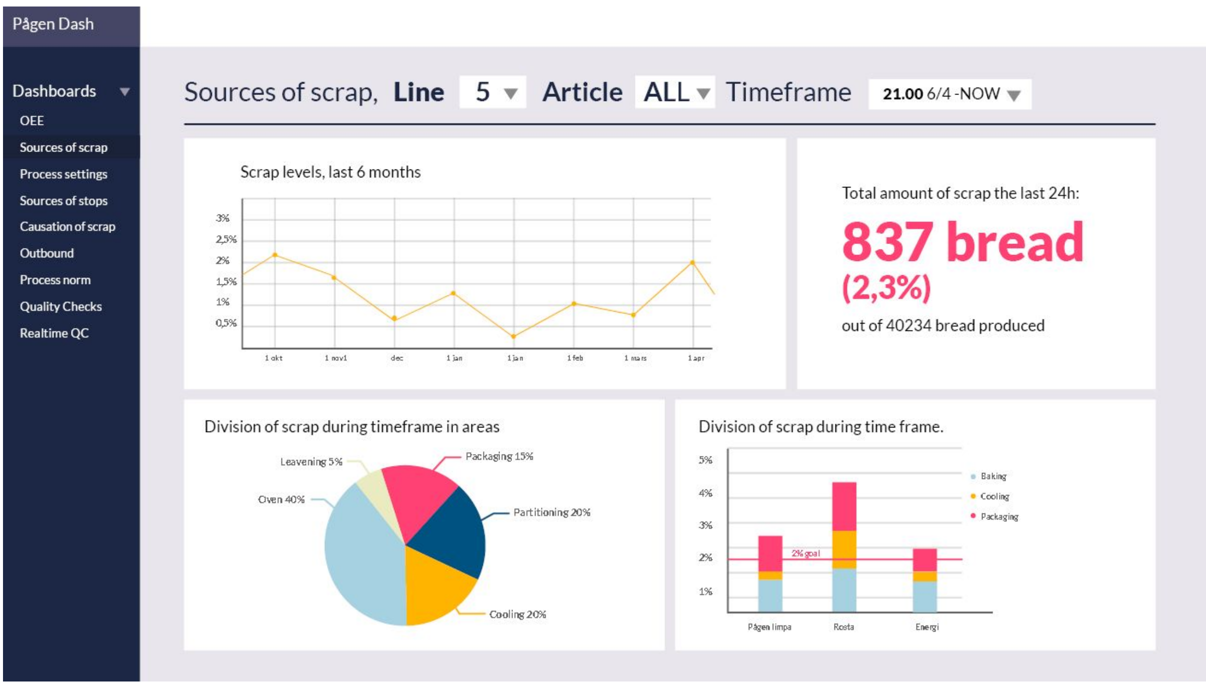

Figure 7.3. *Dashboard for visualization of sources of scrap. Source: Authors*

Implementation

To measure scrap in the five proposed areas, how much bread and when the bread passes needs to be measured at six spots at the production line, shown in Figure 7.4 and Table 7.3. However, the measuring points cannot account for scrap occurring before partitioning. For this area, the amount of pieces exiting partitioning could be compared to the expected amount Reimelt forecasted. If there is a significant divergence between these numbers it can be assumed that a cauldron of dough has been scrapped. It would also be possible to sum the weight of the doughs passing the first weighing station and compare this to the weight of ingredients measured by the Reimelt system.

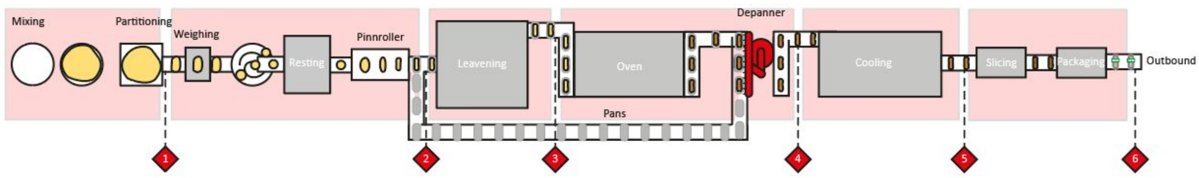

Figure 7.4. *Placement of measurement points, areas of scrap recording marked in red. Source: Authors*

Table 7.3. *Description of measurement points for tracking location of waste. Source: Authors*

	Meas. point 1	Meas. point 2	Meas. point 3	Meas. point 4	Meas. point 5	Meas. point 6
Data collection method	New sensor	New sensor	New sensor	New sensor	New sensor	New sensor or ProdMon
Placement of sensor	After partitioning, before kneading	After placed in pans, before leavening	After leavening, before oven	After depanner, before entering cooling area	After elevator out, before slicing	After the cartoon packager
Data collected	Passed bread with timestamp					

7.5 Project 3: Continuous collection of process metrics and settings

There are various panels and displays that collect and show process metrics and settings (for example oven temperatures and yeast amount) of the machines. This data is used for operators to control the production processes, as well as for process engineers to analyze the causes of larger issues. However, without automatic collection of the metrics and settings the data is always collected after a problem occurs, obscuring the conditions that led to the issue and making it difficult to do a root cause analysis.

Collecting process metrics and settings would foremost benefit the quality control department and production management. It would decrease the amount of time spent on troubleshooting, and thereby increase adaptability to unforeseen events. It would also increase the possibility to learn from mistakes through root cause analysis, and make continuous improvements possible, as it is possible to study the production metrics when, instead of after, the event occurred.

To be able to use the information collected for troubleshooting, the data has to be detailed and relevant. The main areas of interest are the mixing area (controlled by the Reimelt system), the leavening house, the ovens, and the cooling racks. Relevant metrics are displayed on the dashboard which is visualized in Figure 7.5.

Figure 7.5. *Dashboard for process settings and metrics. Source: Authors*

Implementation

There are two ways to approach the collection of metrics that are displayed on the control panels in the production. One way is to collect the data from the control panels and make use of the data that is already digitized and existing.The other approach is to install new sensors that measure the same metrics that are presented on the control panels. In Table 7.4 the information that needs to be collected from the four measurement points is presented, and in Figure 7.6 the locations of these measurements are shown. Additionally, the external variables (i.e. factory temperature) should be collected.

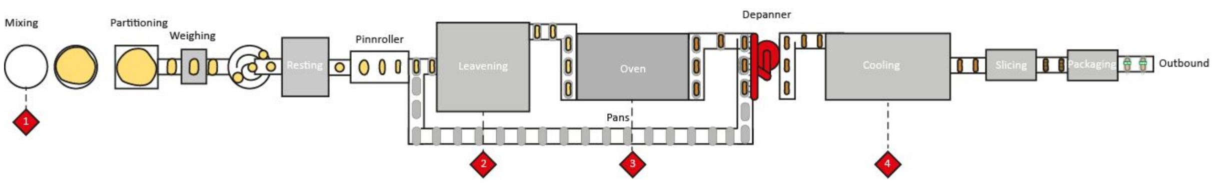

Figure 7.6. *Placement of measurement points collecting process metrics and settings. Source: Authors*

Table 7.4. *Description of measurement points collecting process metrics and settings. Source: Authors*

	Meas. point 1	Meas. point 2	Meas. point 3	Meas. point 4
Data collection method	Integrate Reimelt	Connect to PLC or new sensors	Connect to PLC or new sensors	Connect to PLC or new sensors
Placement of meas. point	Mixing	Leavening	Oven	Cooling
Data collected	Receipt number	Temp. inside leavening house	Temp. in all oven zones	Program setting
	Setpoint and actual value for ingredients	Humidity	Steam	Time in cooling
	Alarms	Time in leavening house		Air temp.
	Water amount			
	Water temp.			
	Mixing time			
	Resting time			

Connecting the various control panels to the software that will handle the analysis of the data might pose a challenge from an integrational point of view, which is argued in section 3.3.8, Enterprise system integration. Since the production equipment as well as the softwares controlling them is of varying age, there would be a need of having a defined method in how to integrate them. From the perspective of Pågen, integrating the control panels in the production is a doable project in the near future as one of the larger hurdles, connecting the PLCs to the network, is already overcome in selected areas.

Today, Reimelt is connected to the ERP in a limited way. To get the metrics from the area before partitioning would therefore be possible through continued integration of Reimelt. The solution of integrating Reimelt is also more plausible because of the difficulty of installing new sensors to perform the same task.

The information collected from measuring points two, three, and four can more easily be collected through installment of new sensors than measures from Reimelt. For example, temperature readings from both the leavening house, oven, and cooling racks can be collected with thermometers. Benefits to this approach, in comparison to connecting pre-existing PLCs, are that new sensors would make it possible to standardize both the implementation and the data throughout the factory and make it easier to integrate and analyze.

7.6 Project 4: Track sources of stops

As of today, the tracking of production stops is done by manually filling out a form in a binder by the operators. This information is used to a low degree with little to no feedback to operators. Knowing that the information that the operators collect is not used to its fullest extent is demotivating.

Stops in production are either caused by machines or by humans. Capturing the PLC signals that stops the conveyor would make it possible to measure the amount of time that parts of the production are inactive, as well as correlating the stops to a source. This information could be used for data-based decision making by identifying focus areas for improvement, both for production management and maintenance technicians.

The stoppage information would be presented through its impact in terms of minutes, as well as the historical trend as shown in Figure 7.7. It would also be broken down by article, and show the latest stops.

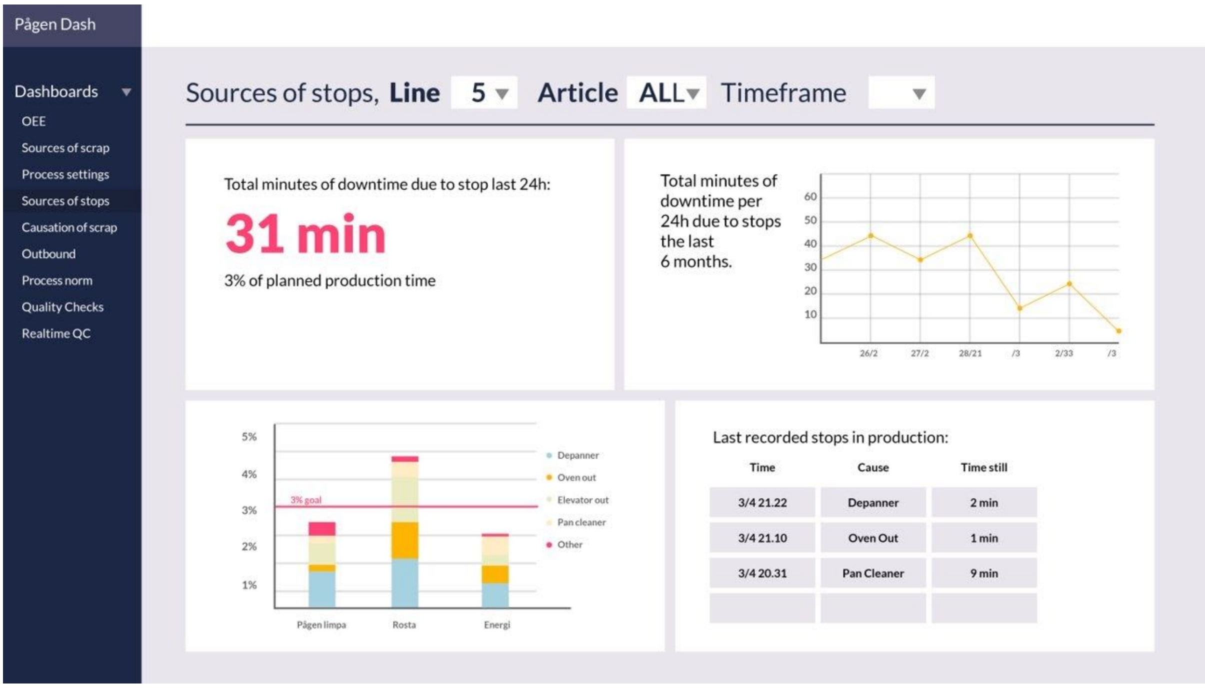

Figure 7.7. *Dashboard visualizing sources of stops. Source: Authors*

Implementation

To be able to automatically track sources of stops, the most promising action to take is to collect the alarms that alert operators when parts of the production stand still. This can be done through identifying the corresponding PLCs and collecting the signals from them. All PLCs in the bakery of line LOAF are connected to the internal network, and there are ongoing projects connecting more PLCs at other lines.

The initial project proposal which was presented to Pågen only collected data from the 13 PLCs currently reporting to the alarm central that alerts operators of production stops in the red area shown in Figure 7.8. The feedback suggested the data should be collected from the entire line. Therefore, the project would connect PLCs from the entire lines. However, the PLCs that are connected to this alarm central should be a starting point for development, as they are easily defined.

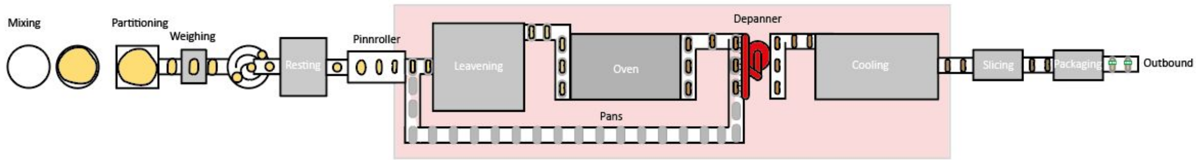

Figure 7.8. *Area covered by the alarm central. Source: Authors*

7.7 Project 5: Connect scrap to causes

Addressing scrap in the baking industry is difficult since there are many parameters that can change and affect the final product. Since the production process is continuous, a stop in production will ripple both upstream and downstream on the production line and possibly cause scrap. Quality problems originating in one part of the production may not be apparent until the bread reaches packaging. The location of scrap can therefore not fully explain the cause of it.

The prototyped dashboard for the need to track causation of scrap is visualized in Figure 7.9. This dashboard is aimed at operators, production managers, and technicians. The pie-chart will give a good overview of the major contributors to scrap, acting as support to both technicians and production management to be able to focus improvement measures. The real-time update of the largest causation to the latest produced batched will give fast feedback to operators of how the production is doing and which areas need tweaking.

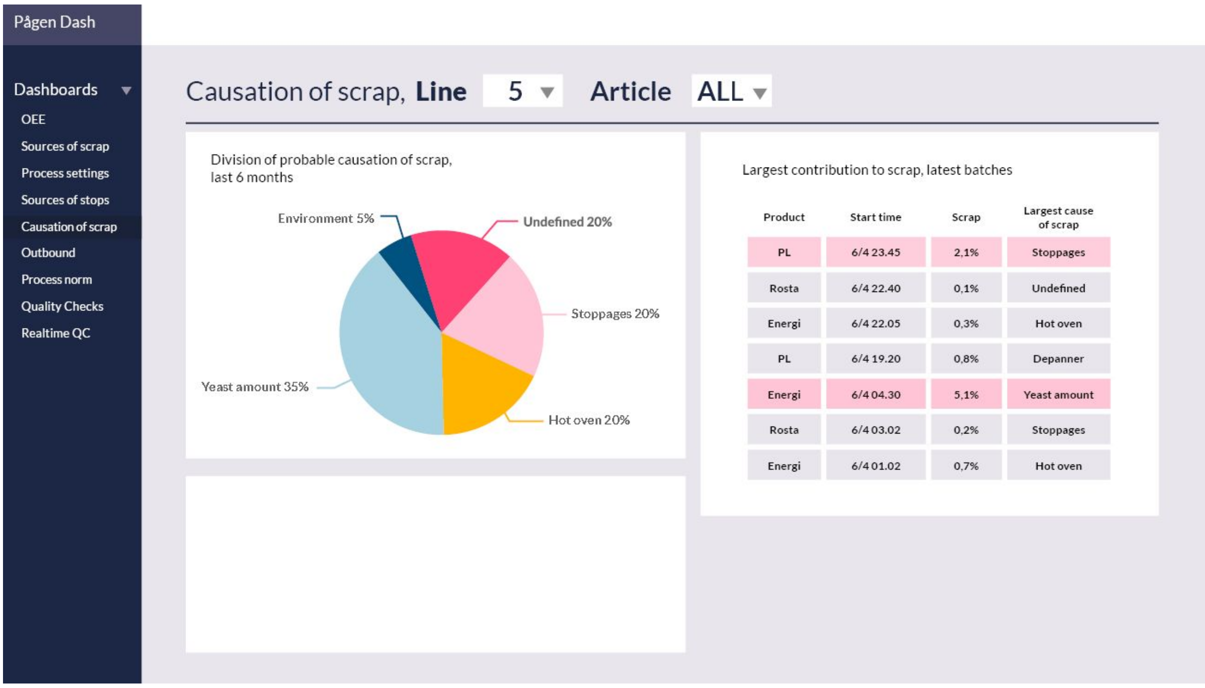

Figure 7.9. *Dashboard for visualization of causation of scrap. Source: Authors*

Implementation

To be able to get the information presented in the prototyped dashboard, a large amount of data from the production lines needs to be collected and analyzed. Since there are many parameters that affect the final quality of the product, the data from Project 2: *Track location of waste*, Project 3: *Continuous collection of process metrics and settings*, Project 4: *Track location of stops*, and Project 8: *Automate quality control* is a prerequisite for this project. To analyze and draw conclusions from this mixed data, big data analytics would have to be utilized. However, there are multiple assumption that could ease the job for the algorithm to find the causation of scrap.

The waste is in general caused either by technical issues or by quality issues, related to the process metrics. The technical issues mainly manifest as scrap in the bakery, and the quality issues mainly manifest in the packaging area. Applying this general assumption, it is possible to analyze separate data sets to determine what has caused the waste. Knowing this, it would be possible to determine the main contributors to waste, which should lead to initiatives focused on what creates the most value, as well as learning about the processes.

To analyze the impact of the technical issues, the scrap which occurred in the bakery needs to be analyzed by connecting it to the alarm PLC data. If an alarm has been raised, and bread has been removed, analysis can be made whether the two events are related.

Analysis of the scrap occurring in packaging would be based on the process metrics connected to Project 3: *Continuous collection of process metrics and settings* and Project 8: *Automate quality control*. When bread has been discarded, it would be possible to approximate through measurement of time what settings have been applied to it and the quality measures. If there are any metrics outside of tolerated levels, it would indicate that the scrap could be related to this fact. If this nevertheless would lead to many quality issues of unknown causes, the data could be analyzed further in order to generate insights, as described in Project 12: *Create big data insights.*

7.8 Project 6: Communication to outbound

The service level at Pågen is significantly impacted by the communication across the value-creating process, and the communication to outbound is no different. Today, the communication is based on ProdMon and individual interactions between outbound and production personnel. The ProdMon system reports the amount of bread ready for shipment, while the interpersonal communications can inform on other circumstances, such as production issues.

To further improve transparency of the process for the outbound logistics team and decrease dependency on individuals, the current progress of baking would be visualized. This information should increase adaptability and enable the logistics team to make decisions on when to release trucks, how to fill the orders, etc. How the information would be presented is visualized in Figure 7.10.

To be able to communicate to outbound logistics the amount of bread they will receive in a specified amount of time there are multiple aspects to be considered. Firstly, the correctness of the estimated amount of bread will increase downstream in the process. Secondly, there is a decrease in value of the information the later in the process it is accessible. To get a balanced estimation that will be correctly and early enough to be acted upon, the estimation will focus on the amount of bread that enters the cooling area. This will give outbound approximately one to two hours extra time to act upon, instead of getting the information after packaging (as they do today). To add to this estimation, there will also be a visualization of how batches move along the line.

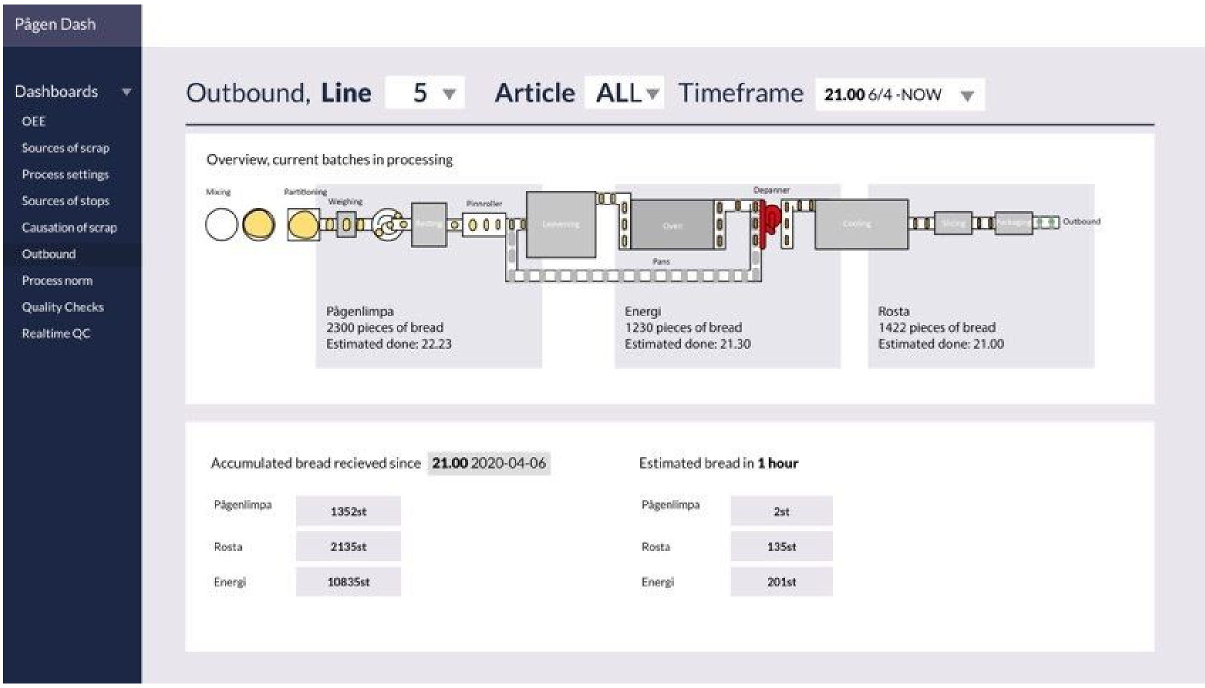

Figure 7.10. *Dashboard visualizing the information going to outbound. Source: Authors*

Implementation

This solution will be based on the same measurement points presented in Project 1: *Introduce OEE*: partitioning, depanner, before packaging, and after packaging. This will make it possible to know how much bread is in the bakery, cooling, and packaging at any specific time. The placements of measurement points are presented and described in Figure 7.2 and Table 7.2 in Section 7.3.

The estimated time for each bread divided into the four areas, baking, cooling, and partitioning, needs to be calculated to be able to estimate how long it will take for the batch to arrive to logistics. The lead times for leavening, baking, and cooling are available. However, at the beginning of implementation the actual times between the measurement points need to be gathered to get exact calculations.

The time for how long the bread is going to be on the cooling rack will alter during the day since Pågen builds up a queue before 21.00. However, when the cooling rack starts emptying at 21:00, it will be done by First In First Out (FIFO) logic, and should, therefore, be possible to account for.

7.9 Project 7: Enable data-driven feedback

It is difficult for operators to get feedback on their work, as the lead time between what occurs in baking and the resulting product is several hours. This makes it difficult to correlate process settings in the bakery to the quality of the finished product. Collecting the amount of time the process metrics are within tolerated levels, and connecting it to the quality level would visualize the effect the process settings have, and therefore make it easier to give feedback.

Visualizing the process norm adherence should be connected to the achieved quality level, thereby be able to discover deficiencies in either the process or the recipes. It would also incentivize keeping the bakery running on optimal settings, as well as giving the operators direct feedback on performance. The adherence to process norms should also be possible to divide into the four different areas of where the information originates from. How the information could be presented is shown in Figure 7.11.

Figure 7.11. *Dashboard for process norm. Source: Authors*

Implementation

This solution is based on the implementation and data collection of Project 3: *Continuous collection of process metrics and setting*. With the information available through the implementation of that project the following calculation would be done to attain the desired KPI.

$$\%\ of\ time\ within\ tolerances\ =\ \frac{\sum_{m=1}^{M}\sum_{t=0}^{T} sample\ time_{mt} * \alpha_{mt}}{M * Total\ production\ time}$$

M is the total amount of points where measurements have been taken from, T is the total amount of time measurements were taken under, α_{mt} *is a dummy variable of either 0, when the data points are outside of tolerances, or 1 when inside of tolerances.*

Additionally, Project 1: *Introduce OEE* or Project 2: *Track location of waste* needs to be implemented to get access to the level of quality.

7.10 Project 8: Automate quality control

The three quality control checks carried out along the bread baking lines are used for four main purposes. The first is for operators to get insights into issues as soon as possible. The second is for quality engineers to be able to diagnose issues with the bread. Finally, the files are used when two or more issues have been reported from customers, leading to a review, and during audits.

Automating the quality controls would digitize the data, and make it available for further analysis, which in turn can improve the quality of the product. It would also decrease the interval of how often the bread is checked for quality, therefore decrease the amount of time it takes to generate insights of issues. Because of long cooling times separating the bakery and packaging, where many quality issues are discovered today, the potential for shortening the reaction time is high.

This information would be presented in two ways. First, there will be a live feed to the operator that will visualize the real-time data from individual quality checks, warning the operator if the result is unsatisfactory, see Figure 7.12. Secondly, there will be an interface to be able to see the historic data of the production, see Figure 7.13.

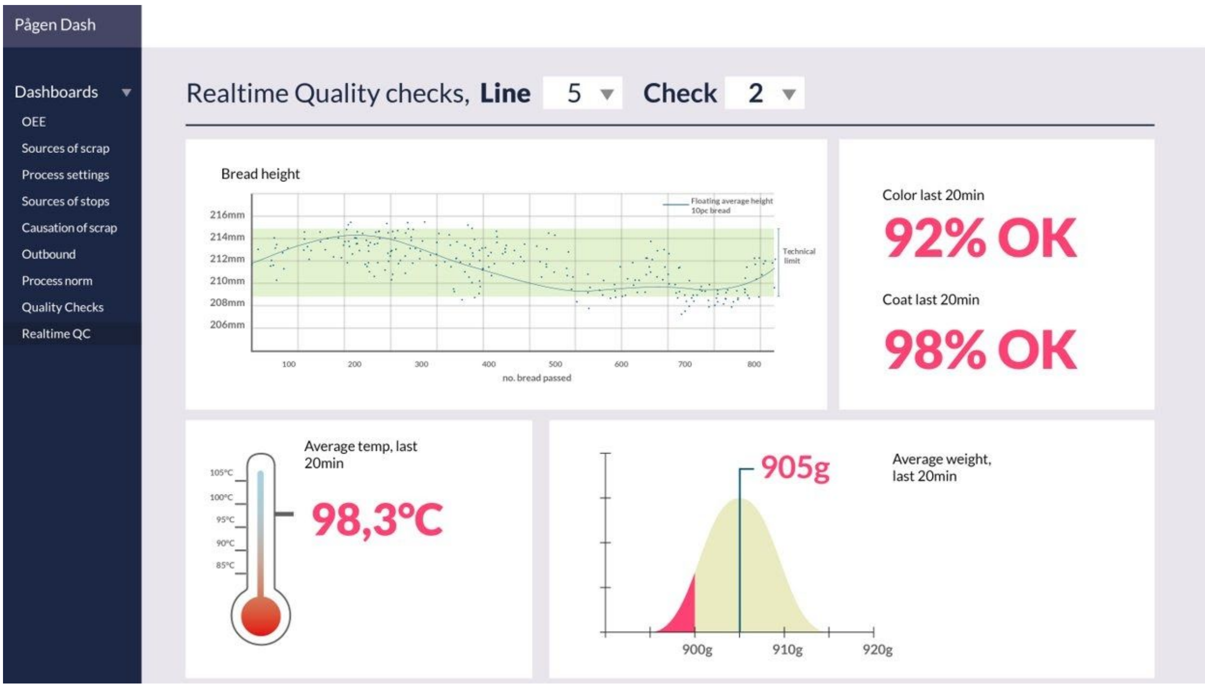

Figure 7.12. *Dashboard for real-time quality measurements. Source: Authors*

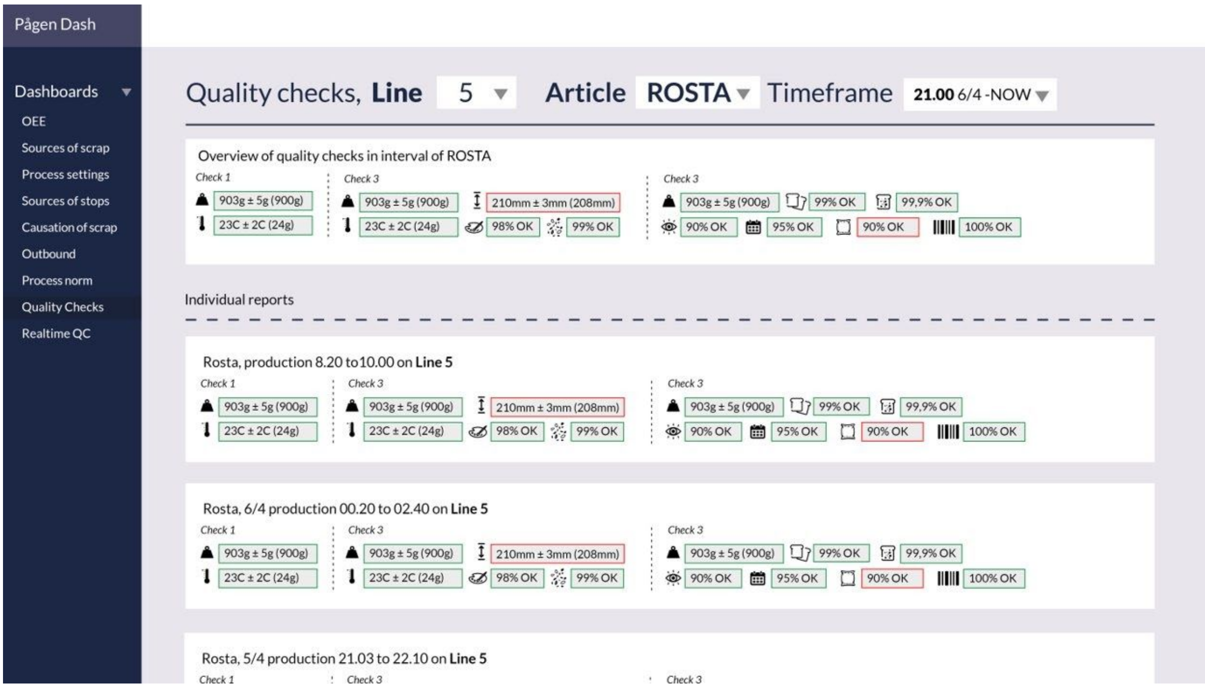

Figure 7.13: *Dashboard of historic data. Source: Authors*

Implementation

To automate the quality checks would pose a challenge because the control points are invasive and requires operators to remove a product from the conveyor to take measurements. In Table 7.5, the measures taken with the possible technologies that could automate these measurements are presented. Figure 7.14 shows the placements in the production of these checkpoints. The control measures marked in red are the measurements that would not be able to automate without having contact with the bread.

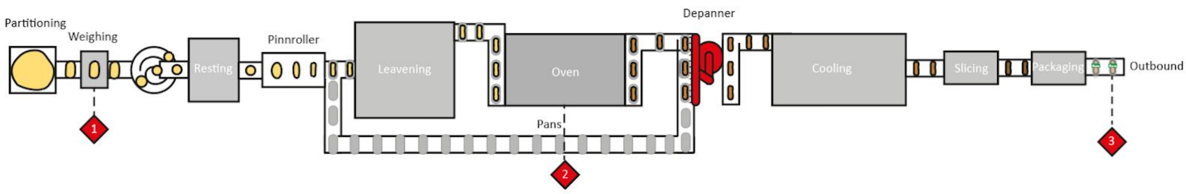

Figure 7.14. *Position of quality checkpoints. Source: Authors*

Table 7.5. *Control measures in the three quality checkpoints with corresponding possible technologies to automate these. Source: Authors*

First Check		Second Check		Third Check	
Control meas.	Possible technology to use for automation	Control meas.	Possible technology to use for automation	Control meas.	Possible technology to use for automation
Core temp. of dough	Thermometer	**Core temp. of loaf**	Thermometer, CFD modeling (Chhanwal et al., 2012)	**Weight**	Scale
Weight	Scale	**Weight**	Scale	**Slicing**	Imaging
		Coating	Imaging	**Crumb**	MRI, microscopy, ultrasound, X-ray microtomography (Koksel & Scanlon, 2016) C-Cell (C-cell, 2020)
		Color	Imaging, CFD modeling (Chhanwal et al., 2012)	**Appearance**	Imaging
		Height	Laser, imaging	**Labeling, plastic bag**	Imaging
				Packaging	Imaging
				Labeling, carton	Imaging

To automate the measuring of core temperature is problematic since the most straightforward way of attaining the measurement requires a thermometer to be inserted into the bread. The other option, CFD modeling, requires large computational power and highly specialized knowledge in the area, and the literature only addresses CFD modeling in reference to temperatures after baking, not on unbaked dough. Thermal imaging is a technique that surfaces when addressing automation of temperature measurements. However, thermal imaging measures the temperature of the crust. There is no linear correlation between core and crust temperature which makes it hard to assess the breads readiness based on this measure.

The core temperature of bread is taken to assess if the bread is correctly baked. For this purpose there are other possible methods that can be leveraged. Chimenti & Faeth (2000) suggest a method of subjecting the bread of an ultrasonic sound wave and measure the vibrations of the bread as a way of analyzing whether the bread is baked properly. Moreover, the usage of color as an evaluation for bread readiness could argue against the importance of measuring the core temperature.

Addressing the other red marked measurement, weight, there would be a need to integrate a scale into the conveyor to be able to take this measurement. After partitioning, where the first check takes place, a scale is already integrated in the conveyor, making it possible to collect the weight measurements. The same goes for the packaging area, check three, where an automatic scale is installed today. However, after the ovens where the second check is situated, there is no scale integrated in the line which would make it necessary to make changes to the conveyor to get hold of this information. The weight after ovens would be able to give insights of the moisture loss through the ovens, and in doing so giving an indication of the quality of the crumb of the bread.

For the control measures that can be automated by imaging there are multiple companies that can be of assistance to employ the technological solutions (Wipotec-ocs, 2020; Sightline Process Control Inc, 2020; EyePro Systems, 2020). Because of this, the third check could be automated to a high degree with the help of the technology available from similar distributors. The technological factor that hinders the automation of the third check is the check of crumb. Today this is done by ocular inspection by assessing individual slices in the loaf, and after this the loaf is thrown away. There are ways of assessing the quality of the crumb through either MRI, microscopy, ultrasound, X-ray microtomography, and c-cell test. However, none of these methods have the speed and capacity to perform the analysis on every passing bread, making the automation difficult with today's technologies.

If there would be a need for prioritization of implementing the automation of quality checks, the second check would be of greatest value to automate. Automation of this checkpoint would decrease response time connected to the quality issues of the bread that would otherwise be discovered in packaging. The benefits would be seen without the automation of the core temperature and weight measures, making the solution more plausible to implement in a near future.

7.11 Project 9: Predictive Maintenance

Because of the nature of the production at Pågen, with the need for high efficiency at day 0 and slower production rate the remainder of the day, it is important to schedule maintenance accordingly. With PM it would be possible to avoid technical malfunctions during day 0 production and schedule maintenance to planned downtime. Predictive maintenance also reduces the amount of time maintenance technicians spend on routine maintenance.

During the construction of a new bakery line at Pågen, predictive maintenance was installed in collaboration with a bearings and a robotics manufacturer. The utilization has been successful, and Pågen is therefore currently expanding predictive maintenance to its existing machinery. This is done by mapping machine components and assessing their criticality. Installing PM is ongoing in order of criticality.

Implementation

A standardized approach to implementing predictive maintenance would be to adopt new sensors that measures critical factors such as vibrations, temperature, and pressures. This could be standardized throughout the machine park. It would however require a high level of competence in this area, and should be done in close collaboration with machinery manufacturers.

7.12 Project 10: Monitoring oven energy consumption

Monitoring oven energy consumption can give valuable insights into processes, such as status of the processes and machines. As energy consumption during an ongoing process is stable, it is possible to benchmark. An increase above the benchmark would be a reliable indicator of a machine issue, and technicians should be investigating during the next production downtime.

Energy consumption data would also be valuable to do further analysis. By increasing the monitoring of the production processes, minor adjustments in production can achieve better energy efficiency without compromising the quality of production according to Bech et al. (2019) and Mukherjee et al. (2018). However it is important to be able to use the data collected to identify inefficiencies. Feedback from Pågen also addressed that the data needs to be actionable, as consumption data can only highlight that inefficiencies exist, instead of where.

Implementation

Data needed to monitor gas flow consumption would be extracted through sensors on inflow pipes. To further the analysis of energy usage, aspects such as fan frequency and temperature also need to be considered. The sensors needed for this solution would be installed in the red marked area in Figure 7.15.

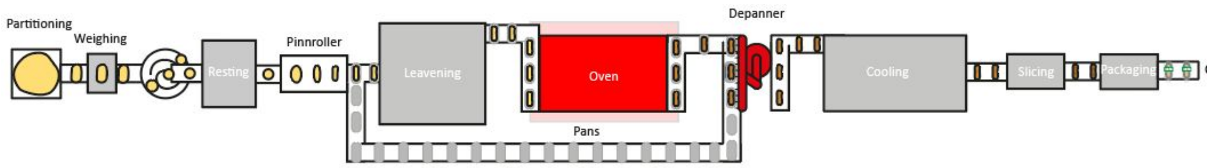

Figure 7.15. *Placement of fuel consumption sensors would be focused on the oven. Source: Authors*

7.13 Project 11: Create a single source of truth

The centralization and visualization of manufacturing data can lay a foundation for creating a single source of truth. The SSoT would make the process data easily extractable from an authorized source, but would also contain the data needed to do the calculations needed for the visualizations, for example lead time and production capacity. An SSoT would make more data available where it is needed, without compromising on security, which would improve data handling and decrease silo barriers.

Implementation

To introduce a single source of truth, it is important that all data is standardized and processed in such a form that anyone in the company could use it. It also needs to be defined who the owner is and what data should be available and for whom. The main challenge to implementing a single source of truth is however cultural. Employees need to be trained in using the SSoT, and using it needs to become anchored in the organization. The SSoT data also needs to be maintained, and responsibilities for this needs to be set.

In feedback, it is apparent that introducing an SSoT is foremost requested by supporting departments, such as controlling, while there is less need for it in production. It could therefore be culturally challenging to adjust and anchor new data handling behaviors from the production department, who are the owners of the requested data.

Creating an SSoT would start with creating standardized data structures. This would be followed by focused efforts on smaller projects and expand as more data becomes available, building on the experience gained. The data collection should be as automatically collected as possible.

7.14 Project 12: Create big data insights

Future applications of digitalization will lead to possibilities in big data analysis, and this project highlights the need to combine data extracted through previous projects to create added value. To create big data insights would include the analysis of combined data from multiple sources to draw valuable insights. Therefore, this solution would build on access to many data points in the production and on other solutions being implemented beforehand.

As stated in the literature review, big data analytics have the possibility to improve forecasting of hard to predict scenarios. For Pågen one hard predicted scenario would be to predict the behavior of the baking process dependent on environmental conditions. Being able to more accurately predict how the process gets affected by the environment and machine settings, would make it be possible to get real-time recommendations for optimal settings and recipes.

Implementation

Big data analytics works by testing hypotheses, using large amounts of data. As much quality data as possible would be needed, which would be drawn from sources indicated in previous projects, but data could also be needed from other sources. The implementation of big data analytics would be incremental, and sensors should be installed when they are needed for further hypothesis testing.

There are multiple challenges regarding the development of big data analytical capabilities. Firstly, the analytics capabilities need to be procured, through internal development or procuring externally. It is also important to be able to maintain and find continuous value for performing the analysis. This is facilitated by a culture where main stakeholders sending requests for analysis is anchored within the organization, and are willing to act on the insights.

8 Success in implementation

The following chapter will discuss the relationship between the proposed projects, as well as their complexity, and the risk connected to the implementation. Thereafter, these factors will be summarized as an order of implementation of the projects to maximize the success of the digitization.

8.1 The interlinkage of projects

The proposed projects are intended to create value for Pågen individually, but their purpose is also to further their progress toward Industry 4.0. When creating a roadmap of implementation of the projects, it is important to keep in mind that they are interconnected and related.The relationship between projects is illustrated in figure 8.1. In the illustration, when two projects are contained by the same square they require the same data to be collected from production but may require different capabilities in terms of software. The majority of projects have clear dependencies on others.

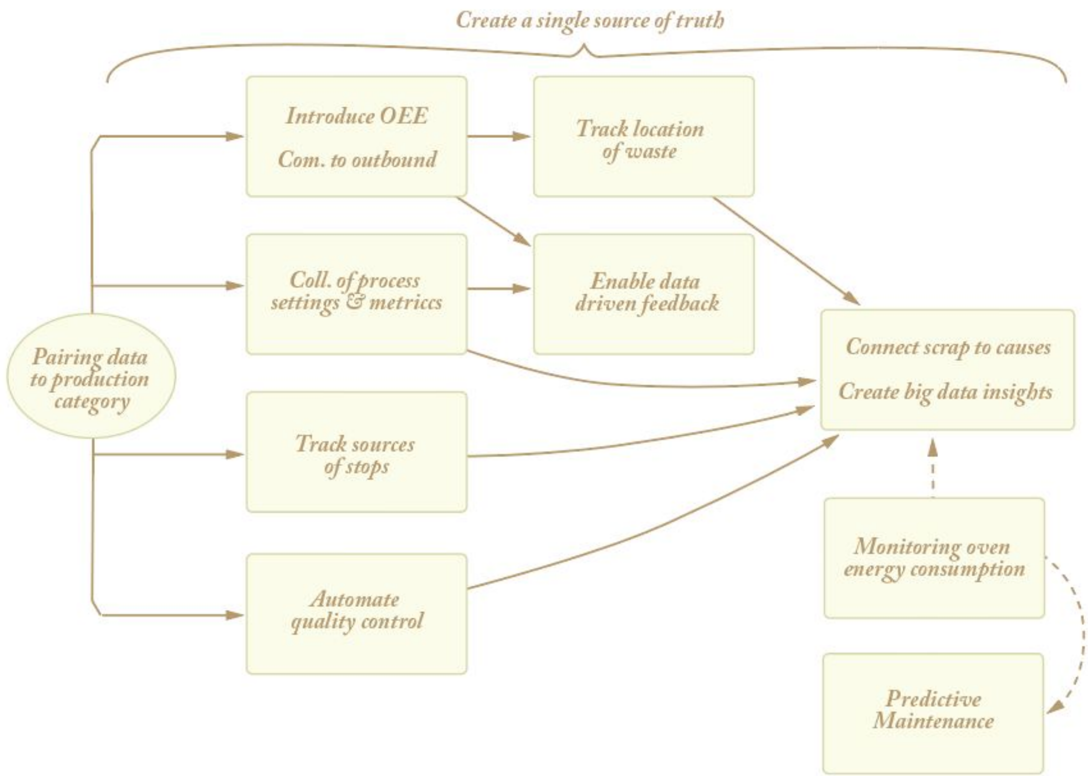

Figure 8.1. *Dependencies of projects. Source: Authors*

Figure 8.1 illustrates that Project 0: *Pairing data to production category* is a prerequisite for all projects except predictive maintenance and energy usage. Similarly, Project 11: *Create a single source of truth* is pictured to be a universal project that would influence and lay the foundation for the implementation of all other projects.

The synthesizing projects that take advantage of all collected data from the production are Project 12: *Create big data insights* and Project 5: *Connect scrap to causes.* These projects highlight the need to structure the collected data from the initial projects in a cohesive way to be able to make use of and gain advantage of the information in future endeavors. Having well-structured data will make it possible to continue doing valuable analysis on the information and gradually add complexity.

The predictive maintenance project, Project 9, is the most unique. It is focused on machine parts and their upkeep, instead of production efficiency or effectiveness, which are only a secondary result of its introduction. However, Project 10: *Monitoring oven energy consumption* is contributing to predictive maintenance by monitoring fuel flow rates.

8.2 Complexity of solutions and implementability

The complexity of the different projects vary significantly and is not reflected in Figure 8.1. Therefore, it will be analyzed in accordance with the following three barriers that would be needed to overcome at the case company: *technical barriers, data analytics barriers, and cultural barriers.* Technical barriers refer to the hardware and the inhouse competence needed to develop the operational technologies. Data analytics barriers refer to the data handling abilities needed, including abilities to analyze and derive statistical evidence from production data. Lastly cultural barriers refer to the strategic and communicational skills needed from the case company to utilize the project to its fullest potential. These classifications are based on the feedback from the focus group, where difficulty of implementation was discussed. The level of difficulty of the three types of barriers are presented for each project in Table 8.1.

Table 8.1. *The level of barriers met for implementing each project, L = low, M = medium, H = high. Source: Authors*

Barriers	Projects											
	1	2	3	4	5	6	7	8	9	10	11	12
Technical	L	L	M	L	L	L	L	H	L	M	-	L
Data analytics	L	L	H	M	H	L	L	H	L	L	L	H
Cultural	H	L	L	L	L	L	H	M	L	H	H	H

1. Introduce OEE
2. Track location of waste
3. Continuous collection of process metrics and settings
4. Track sources of stops
5. Connect scrap to causes
6. Communication to outbound
7. Enable data-driven feedback
8. Automate quality control
9. Predictive maintenance
10. Monitoring oven energy consumption
11. Create an SSoT
12. Create big data insights

Project 1: Introduce OEE receives a low score on technical barriers to overcome since the project requires installation of new sensors in the production which are deemed simple to install. The data from the new sensor would be easily standardized and analyzed, making the effort to use and analyze the data low. However, the introduction of OEE is met with skepticism of its benefits from parts of the organization, and it is supported in the literature review that resistive cultures is the main barrier to introducing OEE, making the cultural barrier high.

Project 2: Track location of waste is an extension of Project 1: *Introduction to OEE*, only needing to install two additional sensors. Therefore, this project receives the same score on the technical and data analytics barriers. However, the visualization is easy to interpret and extract information from. Therefore the cultural barriers are low.

Project 3: Continuous collection of process metrics and settings is classified as having a medium level of technical barrier, as the sources of information need to be identified and connected. Because the data has many different origins, the data analytical capabilities needed are high to be able to configure and integrate the data. The usage of the information gained from the project is however straightforward to use and gain knowledge from, making the cultural barriers low.

Since progress toward connecting the PLCs in the bakery to the internal network is already ongoing, ***Project 4: Track sources of stops*** has low technical barriers. The amount of data points that are needed to collect and analyze data from, classifies this project as medium on data analytical barriers needed to overcome. The visualization is easy to comprehend and act upon, resulting in low cultural barriers.

Project 5: Connect scrap to causes has a low technical barrier since if the prerequisite projects have been implemented, no more data needs to collected from the production. However, being able to make statistically significant interpretation of the data requires high analytical knowledge. In reference to the cultural barriers, the information and insights that this project will lead to are easily incorporated into the organization.

For ***Project 6: Communication to outbound*** the technical barriers are the same as for Project 1: *Introduce OEE*, as it is based on the same sensors. The complexity of data analytics needed to get the desired information is considered simple. Culturally, in the past the outbound team has been shown to fast incorporate new technology, arguing that the cultural barriers are low, given that the project would prove valuable.

Project 7: Enable data-driven feedback is based on the technical solution of Project 3: C*ontinuous collection of process metrics and settings* and combining these measurements with the quality level recorded from Project 1: *Introduce OEE*. If these two projects have been implemented, both the technical and data analytical barriers are low. However, introducing new metrics to measure production could be met with suspicion, and would need to take many perspectives into account, not least from operators. The cultural barriers could therefore be high.

Project 8: Automate quality control requires extensive technical additions to the production line, and even so might not be possible to automate the entire process. The technical barriers are therefore high and would be considered relatively high if only selected parts of the quality control were to be automated. Like so, the analytical capabilities needed would include image analysis and processing of real-time data making the analytical barriers high as well. To fully get the benefits from this project, operators would need to shift their focus to work preventative than today's reactive. However, the information is difficult to misinterpret making the cultural barriers medium.

Project 9: Predictive maintenance is an ongoing project at Pågen today. In so, the knowledge and acceptance of the work are high making all the mentioned barriers low.

Project 10: Monitoring oven energy consumption would require installation of gas flow monitors. This project is considered of medium technical difficulty. The data analytical capabilities required would be low. The main cultural barriers are related to how the project creates value. Since it is a risk-decreasing and monitoring project, the value can be hard to observe, making it harder to anchoring the practices in the organization. Therefore, the cultural barriers are considered high.

Project 11: Create a single source of truth does not require any hardware to be handled in the production, making the technical barriers inapplicable for this project. Moreover, the framework needed to create an SSoT is said by employees of the IT section to be simple to develop. However, changing the way the organization handles and access their data may pose a cultural challenge, ranking this barrier as high.

Project 12: Create big data insights builds on the prerequisite projects, but it would also be possible that more data needs to be extracted to maximize value. Even so, the foundation of the technical solution for data collection would be in place, making the technical barriers low. However, the analysis of data required to find and track correlations might pose a challenge making the data analytical barriers high. To get continued value from the technical and analytical capabilities acquired, the organization must move towards being more agile and data-driven in its decision making, resulting in the cultural barriers being high.

8.3 Scalability

For an enterprise developing Industry 4.0 capabilities it is important to balance being flexible and practical with creating solutions that are scalable. There are many types of baking lines at Pågen, and this thesis is focused on the two lines LOAF and LONG. Their generality is that their main processes are mixing, leavening (twice for each process), partitioning, baking, cooling, and packaging.

However, there are differences between the lines which necessitates adjustments of solutions. For example, line LONG would in baking need less frequent sampling, but dividing the long 15kg loaves into the final consumer products would need to be handled when processing the data. To introduce and adapt the implementation of the projects to more lines, the information needed to be collected about the individual line is:

1. Lead time and production capacity of main baking and packaging areas
2. Detailed movement of bread
3. Loaves per cauldron and consumer products per long loaf
4. Recipes, containing ingredients as well as process metrics
5. PLCs connected to the line
6. Machine components

The lead time and production capacity are needed for the OEE metric. Detailed movement of bread is needed to understand yield losses as well as connecting process metrics to loaves of bread. The stated recipes are used to create the process metrics KPI, and PLCs connected to the line are used to track and visualize stops. Understanding the machine components is important to implement predictive maintenance. Additionally, standards for SSoT need to be decided for a scalable solution.

8.4 Risks

It is important to highlight the risks which are carried by the proposed projects. The authors have identified risks regarding the decision-making of the company, its incentive alignment, its transformational readiness, cybersecurity, and its consumption monitoring. These are presented below.

1. **Over-reliance on data.** The dependency on data will increase with the digitization efforts. To be able to base decisions and analyses of off the data, the need for integrity of the collected information is high. Areas which pose a risk to the accuracy and completeness of the data are sensors, PLCs, hardware, and MES. If a unsuitable sensor is chosen for a specific task, this can result in inaccurate readings and invalid decisions being made from the analyzed data. The accuracy can also be threatened by the hardware. For example, large air pockets in the flour can result in the wrongful measurements of ingredients entering a cauldron leading to the weighing system reporting a higher amount of the ingredient than reality. Without control weighing of the cauldrons, this risk can be difficult to address.

2. **Cybersecurity.** Further risks pertaining to data are cybersecurity. Cybersecurity is one of the pillars of IIoT and additional nodes on an internal network could constitute a potential entry of breach. The projects would therefore create potential risk areas if not properly setup. Addressing the availability of the data, i.e. who are authorized to use/access/alter the data can also pose a risk if done improperly.

3. **Incentive alignment.** There are risks pertaining to the organizational structure of the case company. One aspect to be wary of is whether the incentives for digitization are aligned within the company. For example, the projects regarding KPIs, *introduce OEE,* and *enable data-driven feedback*, need to be critically considered. The OEE metric could incentivize effectiveness without regard for efficiency, while *enable data-driven feedback* could decrease flexibility to adjust recipes, for example

lowering oven temperature in advance of a batch switch. The targets of both KPIs would therefore need to be carefully considered before introduction.

4. **Readiness for transformation.** To get the support of the organization, it is important that digitization of the production can create short-term wins fairly quickly. As digitization projects such as Axxos and visual quality assurance have been carried out in the past, resulting in abandonment of the resulting product, it is important to prove value and build momentum for further digitization. Otherwise, there is a risk of demotivation and skepticism toward further change efforts.

5. **Lack of source criticism.** When conducting analyses, there is also a risk that there are errors in the insights created by analytics. The risks can be based on process errors and logical errors, and could lead to decisions that are not supported by the information. To counter this risk, decision makers still need to think critically.

6. **Normalizing issues.** Monitoring energy consumption in ovens would be based upon current measurements setting a benchmark, and warnings occurring when consumption differs. This assumes that the ovens do not currently leak, which could lead to a too-high consumption being considered normal.

8.5 Recommended order of implementation

Based on the aspects discussed previously in the chapter, a recommended roadmap of project implementation will be presented. This will incorporate the risk but also take managerial aspects into account to deliver fast results and momentum for the digitization. In Figure 8.2 the implementation order is visualized. The roadmap does not address whether to progress a step or instead focus on upscaling the solutions for multiple production lines.

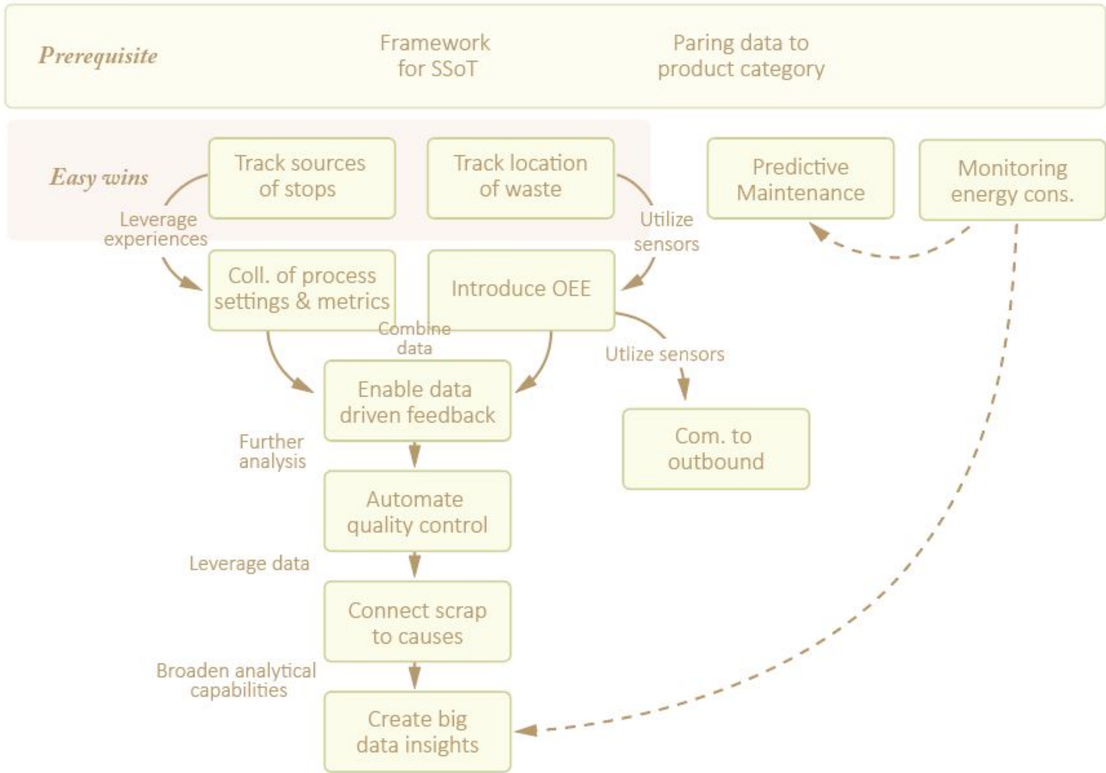

Figure 8.2. *Recommended roadmap to digitization. Source: Authors*

Before implementation of the projects, two main activities are recommended to be done. A standard for data handling needs to be set, laying the foundation for SSoT, to make the collection of data automatic and easily usable. It is also recommended to develop the ability to pair the data to product category before further advancements on the projects are made.

After the prerequisite projects have been solved, there are four possible projects to continue with. The case company is recommended to implement *monitoring oven energy consumption, predictive maintenance, track location of waste,* and *track sources of stops* in unspecified order with the possibility of doing multiple projects in parallel. The monitoring oven *energy consumption* and *predictive maintenance* projects create indirect value from risk mitigation and decreasing cost while having low implementation barriers.

Track location of waste would install sensors needed for further projects, while *track sources of stops* would create a possibility to add experience to the project team in how to handle data fed from PLCs. Both projects should create quick short-term value and prove the potential of digitization, which should be used to generate momentum for further change.

When the implementation of either *track location of waste* and *track sources of stops* is completed, there is a logical order of projects that follows. *Track location of waste* starts a chain of projects that are dependent on the installation of new sensors for measuring bread quantity passed. The momentum gain from *track location of waste* would be beneficial to implement OEE. While the technical and data analytics barrier to implement OEE are low, the cultural barriers are considered high. Therefore, using the sensor data to implement OEE would be secondary to tracking location of waste even though OEE requires fewer sensors being installed. *Communication to outbound* is prioritized to be implemented after introduction of OEE as some transparency already exists, and the value of the project needs to be proven.

Track location of scrap is recommended to be followed by *continuous collection of process metrics and settings.* This project is more complex than *track sources of stops* because of a higher variety of signals from a multitude of sources. Therefore, the experience gained from *track sources of stops*, which already has labeled data sources, would be beneficial to be able to process the increased amount of data needed.

Combining the data collected from *continuous collection of process metrics and settings* and the level of quality would facilitate the implementation the KPI presented in *enable data-driven feedback.*

To further deepen the knowledge and understanding of the production process the project *automate quality control* is suggested to follow after *enable data-driven feedback.* Since the high complexity of the project it will be beneficial to have experience from both installment of new sensors and connecting PLCs.

At this point many aspects of the factory are captured. The next step would be to combine the existing data to create valuable insights. *Connecting scrap to causes* has a low cultural barrier and would therefore be a good first project for developing advanced analytical skills. When this project has proven successful, continuous data analytics should be performed by *create big data insights.* Adding energy consumption data would further the insights possible.

8.6 Success factors at the case company

The identified success factors regarding the transformation process, presented in section 6.2, are important to consider when following the recommended roadmap. However, the authors want to highlight aspects which are believed to be highly applicable to the situation at the case company.

Pertaining to key resources, the success factors are to have *workforce with digital competencies* and to *identify missing capabilities.* For the case company, to avoid developing a solution that will be difficult to maintain and utilize to its fullest extent which became the case with Axxos, developing the inhouse skills will be of high importance. It is therefore the authors' recommendation to follow the order of the proposed roadmap which would develop the skills needed incrementally and to as a far extent as possible rely on in-house competencies.

Concerning organizational structure, the authors believe that it will be crucial for the success of the digitization to assign a task or goal-oriented group to tackle the assignment. Since the digitization will prove beneficial to the organization as a whole, it is important to have cross-functional teams, involving more than one or two departments. It is also noteworthy that an increased level of digitization will increase communication within the company.

However, a high degree of communication is also considered a success factor making a cross-functional team, with ties to multiple departments at the case company, even more important.

Regarding the cultural aspects, to align the goals of the projects with the company strategy is, according to the authors, a key for a successful implementation. The goals of the company need to be communicated well, gather the support needed for anchoring, have top management support, and to enable a pragmatism focused on realizing the value creating aspects of the projects. At the case company, digitization has been a topic of discussion for a while, making it a clear priority. Furthermore, the guiding principle of being “Europe’s most modern bakery” is well anchored since the Malmö plant was founded in 1965. However, different departments can have differing interpretations of the meaning of digitization for the case company.

9 Conclusion

This chapter will answer the research questions as identified in the start of the thesis and address the contributions and limitations of the thesis.

The purpose of this thesis project is to propose how and where Pågen should establish measuring points in its bakery lines in order to achieve productivity improvements, minimize manual input and improve continuous monitoring. To achieve this purpose, the research questions are answered below.

9.1 Research question 1

What benefits could be generated from a more digitized bread production?

The bread industry has a low level of digitalization and is often dependent on multiple legacy systems, making a low amount of information available from the production. The production also operates with long lead times from mixing of dough to packaging, and is affected by external factors such as temperature. This thesis identified thirteen potential benefits from digitizing a manufacturing site, and proposed twelve projects to realize the benefits in the bread factory. The benefits and the number of projects they are applicable to are presented in Table 9.1. It is important to point out that it does not reflect the potential value of the individual benefits.

Table 9.1. *Potential benefits and number of times they are addressed by the digitization projects.*

Benefit	Number of occurrences	Benefit	Number of occurrences
Reduce scrap	7	Optimize resource consumption	3
Decrease production stops	6	Increase machine availability	2
Improved decision making	6	Decrease routine maintenance cost	2
Root cause analysis	5	Decrease manual input	2
Increase quality of product	4	Improve data handling	2
Lower silo barriers	4	Optimize inventory levels	1
Increased adaptability	4		

The benefit which was addressed most frequently by the projects connected to the bakery was to reduce scrap. The scrap level is related to internal and external process variables as well as long lead times in production. Digitization could lower the scrap level by visualizing and utilizing the many variables, and by increasing adaptability. The benefit which was least frequently addressed by the projects was optimizing inventory levels, which is explained by that the consumption of most raw material occur at the start of the production process, resulting in high visibility of inventory as is.

At the case company, digitization has the potential to reap benefits from all identified areas. However, there are some that have a higher level of relevance for the case company.

9.2 Research question 2

How can the identified benefits be realized at the case company?

The thesis proposes twelve projects to achieve the identified benefits connected to increased digitization, listed below. The projects combine the usage of connected PLCs, SCADA, and ERP systems, and installing new sensors. The projects addresses both low hanging fruit, as well as future application such as *connect scrap to causes* and *creating big data insights*.

1. Introduce OEE
2. Track location of waste
3. Continuous collection of process metrics and settings
4. Track sources of stops
5. Connect scrap to causes
6. Communication to outbound
7. Enable data-driven feedback
8. Automate quality control
9. Predictive maintenance
10. Monitoring oven energy consumption
11. Create an SSoT
12. Create big data insights

The complexity of the projects were analyzed, revealing a high degree of implementability at the case company. There are multiple technical solution in place today which could be utilized to a higher degree and the possibility to install simple sensors for counting bread to quickly realize benefits. By adjusting the projects in accordance to six aspects, all projects are scalable to additional bakery lines.

The projects are recommended to be implemented in the order specified in Figure 9.1. This order of implementation would facilitate an incremental approach to digitization with organizational knowledge development at its core. Acquiring capabilities to increase digitalization, developing the projects in cross-functional teams, and connecting the projects to the company strategy would contributing to the success of the digitization efforts at the case company.

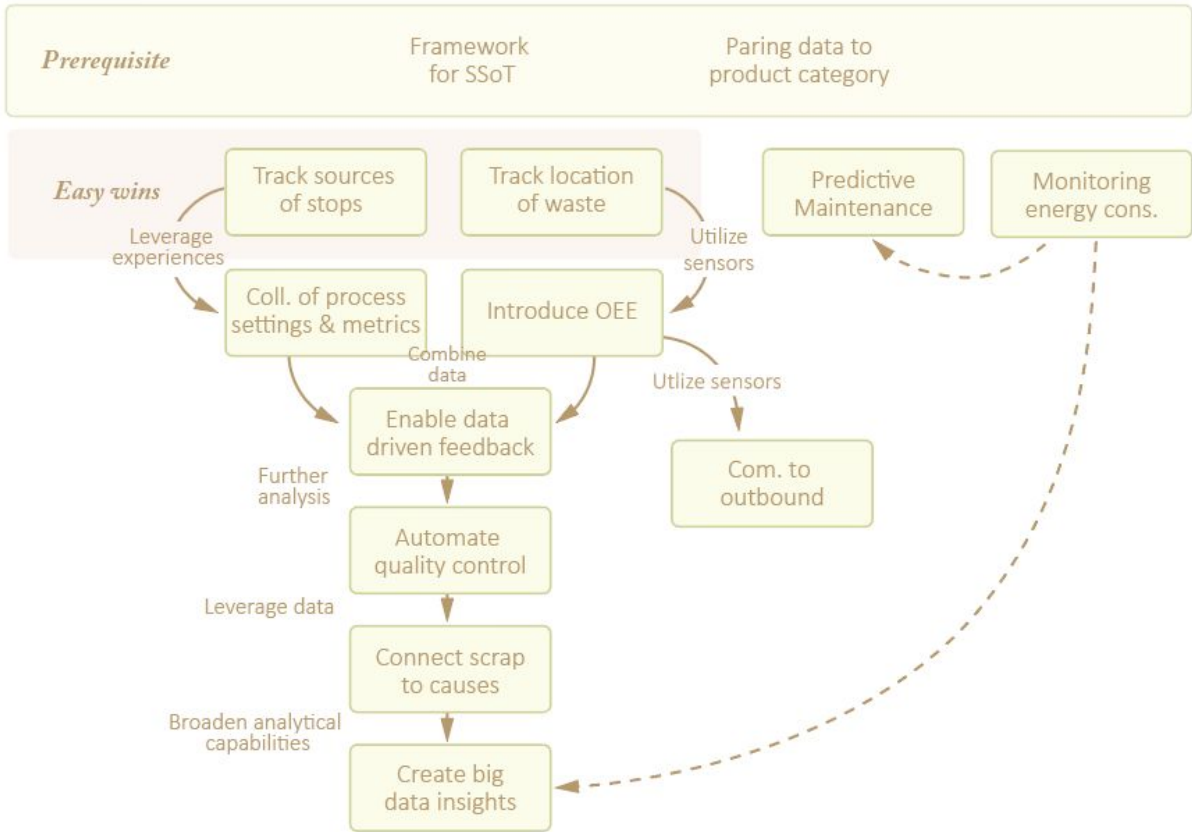

Figure 9.1. *Recommended order of implementation. Source: Authors*

9.3 Research question 3

Where should measurement points be placed in the production?

Numerous measuring points are recommended to be placed in the bread production. These include sensors counting bread, sensors or PLCs reporting process variables, and sensors measuring resource consumption, including ingredients and fuel. Furthermore, PLC data reporting stoppages is recommended to be collected and quality controls should be automated and digitized. It is also recommended to integrate the MES system, making it possible to pair data with the products. Maintenance sensors are recommended to be installed on the machine components.

Summarized, the production can be divided into six areas by sensors measuring quantity, with various added information collected from each area. In Table 9.2, the information wished to be collected is displayed and in Figure 9.2 the areas are visualized. The table and the figure exclude the connected PLCs to record stoppages and sensors needed for PM. For specified measurement points per project, see chapter 7.

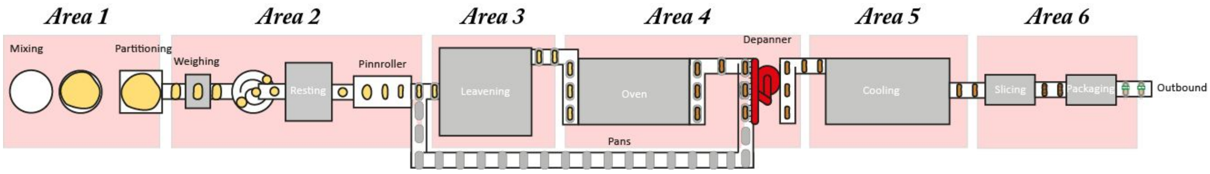

Figure 9.2. *Division of areas by sensors measuring quantity. Source: Authors*

Table 9.2. *Data recommended to be collected from each area if implementing all projects. Source: Authors*

Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
Mixing	Partitioning	Leavening house	Oven	Cooling	Packaging
Ingredients	Bread counters	Bread counter	Bread counter	Bread counter	Bread counter
Current product WIP	Weight	Temperature, leavening house	Temperature, oven	Program setting	Weight
Alarms	Core temp. of dough	Humidity	Fuel consumption	Time in cooling	Slicing
Water amount		Time in leavening house	Steam	Air temp.	Crumb
Water temperature			Core temp. of loaf		Appearance
Mixing time			Weight		Labeling, plastic bag
Resting time			Coating		Packaging
			Color		Labeling, carton
			Height		

9.4 Contribution

It is apparent to the authors that research on Internet of Things and digitization is currently in transition from being visionary to being practical. Sources detailing IoT as a concept are usually published around 2016, while practical studies were published around year 2019. To the best of the authors' knowledge, there are no practical single case studies which focus on the organizational benefits of a digitized production system, but the practical studies instead focus on experimental hypotheses testing. This thesis contributes to filling that gap.

In addition, the thesis takes the IoT concept into the context of the bakery industry, with its specific challenges. The bakery industry has a low degree of digitization, with many legacy systems, and the quality of its products is also affected by many variables of production, internal and external. Its production is highly automated, but also very sensitive, which makes it particularly interesting.

The thesis’ implications for the case company is a recommended plan to digitize its factory, as well as a mapping of data needed to be extracted on a typical bakery line. The company is also presented with key aspects to consider while preparing for the transformation as well as for the final solutions.

9.5 Limitations and future research

The thesis is limited in that production data is not available. The value of the projects can therefore not be proven, except by the qualitative judgments of employees. It is also limited by the amount of available applicable source literature. The claims of the thesis could be strengthened further by the availability of more research in the area of digitization of large scale bread bakery and how to utilize specific bread baking control strategies in an industrial setting.

Future research would be to longitudinally study the case object and their progress toward a digitized bakery, quantifying the return on investment as well as developing on challenges and solutions. It would also be interesting to incorporate the data created by suppliers, for a larger supply chain perspective, and research the value of this data to Pågen. One parameter which could be of particular interest is that of the flour quality’s effect on scrap levels, and whether this can be used in cost analysis or be utilized by altering process parameters. Lastly, the economic impact of the proposed project would need further research to be able to show the value of the final roadmap.

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Appendix 1: Interview guide

The interview guide presented below contains questions used during semi-structured interviews. The interviews began with general introductory questions, before in-depth questions pertaining to the purpose of the interview were addressed. Commonly asked questions appertained to potential benefits with digitization, organizationally and individually, as well as the subject's contact with the production department.

General introductory questions

1. Vad är din roll inom Pågen?
2. Hur länge har du arbetat inom Pågen?
    a. vilka andra roller har du haft?
3. Hur ser en vanlig arbetsdag ut för dig?

Organizational questions

1. Vilka arbetar du med?
2. Hur ser din avdelnings relation ut till produktionen?
3. Om man skulle utveckla IT-förmågor i produktionen, vilken avdelning skulle ta ansvar för det tycker du?
4. Vad har ni för kontaktpunkter med produktionen idag?

Machine related questions

1. Hur uppkopplad är dagens PLCer i produktionen?
    a. Vilken sorts information skickar de?
2. Motorerna för löpande bandet, finns det möjlighet att koppla upp sig till dessa och på sånt sätt veta om bandet rullar eller inte?
3. Finns det något sätt att hämta informationen från paketeringens våg?
4. Hur fungerar utströmmen från svalbanorna?
    a. Vad är logiken som gör att det går åt ena hållet eller den andra?
5. Var du en del i att koppla upp den sista mätpunkten i packen mot ProdMon?
    a. Hur gick det arbetet i sådana fall? Enkelt?
6. Var finns störst potential?
7. Vilka system är standardiserade på alla brödlinjer?
8. Hur mycket jobb är det att koppla upp maskiner på nätet?
    a. Vilken avdelning tar störst ansvar för sådant arbete?
9. Har ni några särskilda industriella krav på sensorer och teknik i produktionen?

Production questions

1. Hur ofta sker städning på lina lång och hur lång tid tar det?
2. Hur dokumenteras stopp?
3. Vilka toleranser finns det i ledtiderna?
4. Hur viktigt är det att du får snabb återkoppling från produktionen när ett fel uppstår?
5. Vilken del av produktionen är mest problematisk/känslig?
6. Finns det några andra problem?
7. Vad har ni för ambition i samband med Axxos? Starta upp det på nytt?
8. Hur ofta sker det ofrivilliga driftstopp på den linje du jobbar med?
    a. Vad är de vanligaste anledningarna till dessa?
9. Om det sker ett stopp, brukar detta resulterar i kassationer?
    a. Hur rapporteras detta?
    b. Är du nöjd med hur det hanteras eller finns det förbättringsmöjligheter?
10. I vilken del av produktionen uppstår det kassationer?
    a. Hur rapporteras det?
11. Under ett pågående pass, sker det någon uppföljning om hur väl ni producerar mot tänkta dagsmål?
12. På samma spår, kan du se några (andra) indikationer för när det kommer bli eller har varit en bra eller dålig batch? En bra eller dålig natt?
13. Vilka kvalitetskontroller utförs?
    a. Vad görs med dessa rapporter?
    b. Hur väl följs rutiner runt dessa rapporteringar?
14. Hur ofta behöver ni ändra/anpassa inställningar från standard/grundrecept för att rätta till problem i produktionen? (hälla i jäst, mer vatten, längre jästid)
15. Finns det någon variation i hur arbetet utförs mellan operatörer?

Data needs questions

1. Vilken information måste du förlita dig på för att kunna utföra ditt jobb?
    a. Till hur stor utsträckning bedömer du att denna information stämmer överens med verkligheten?
2. Finns det någon information/indikator som du ser är viktigare än någon annan? Som ofta leder till problem eller som är till stor nytta i att identifiera problemen?
3. Om du fick önska, finns det mer information och parametrar du skulle vilja få ut från produktionen? (Tänker specifikt på de kvalitetsmått som mäts idag, vikt, temp, osv)
4. Räcker de mått som finns idag för att diagnostisera och förutses brödkvaliteten?
5. Personligen, vad ser du för möjliga förbättringar genom digitalisering?

6. Vad tror du Pågen i stort har att vinna av en digitalisering?
7. Vilka kalkyler/beräkningar arbetar du efter?
8. Vilken komponent i kalkylerna diffar mest?
9. Hur följer värdet brödet? Finns det uppföljning?
10. Vilken data tror du skulle vara bra att ha?
11. Om du fick önska fritt, vilken info skulle du vilja ha från produktionen?

Benefits

1. I stort, vilka områden är din avdelnings fokusområden just nu?
2. Vad vill man uppnå med en mer digitaliserad produktion?
3. På vilket sätt används OEE idag?
4. Har du några områden som du tycker att produktionen borde bli bättre inom?
5. Personligen, tror du att detta projekt skulle kunna förenkla ditt dagliga arbete på något sätt?
6. Vad tror du är de främsta fördelarna för Pågen i stort man kan dra av att installera fler mätpunkter i produktionen och visualisera dessa?
7. Finns det några nackdelar med att installera mätpunkter?