JÖNKÖPING UNIVERSITY
School of Engineering

Control and Reduction of Deviations in Production Processes

”An Intelligent Quality Management approach”

PAPER WITHIN *Production Development and Management*
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Abstract

Companies situated in the manufacturing industry are facing many challenges. In order to stay competitive and to be able to meet customer needs the product and process quality must be ensured through efficient Quality Management (QM) activities. In this context, occurrences of deviations in production processes are often a significant problem causing an increased rate of scraps and rework actions, which have a direct impact on the production system performance. Therefore, the purpose of this thesis is to explore the concept of IQM in connection with ways to control and reduce deviations within production processes.

The single case study approach has been chosen to fulfill the purpose and to answer the research questions of this study. The selected case company is a large wooden furniture manufacturer located in the south of Sweden. The company is a subsidiary of one of the biggest global groups, which is designing, producing and selling furniture and home accessories. Within this case study design, a technique triangulation of observation, document study and interview has been executed in order to gather valid research data.

The results of this thesis are, that deviations in production processes (re-)occur due to human, technological and organizational (HTO) shortcomings, where the interfaces between the three segments play major roles. Moreover, the HTO approach can be the basis for identifying the reasons for deviations, which facilitates the adoption of QM principles, practices and techniques to handle deviations in production processes. The concept of IQM could support the control and reduction of deviations in production processes, but also entails a risk of causing more deviations if it is poorly implemented. Moreover, a framework has been created, which provides an understanding on what role IQM could play in the context of deviations in production processes. It can be concluded, that a good basis for future research regarding IQM has been built. Future research needs to verify the gathered results of this thesis in different settings as well as practically implement IQM to a company´s system.

Keywords

Intelligent Quality Management, Deviations, Quality Management, Production Processes, Industry 4.0

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List of Abbrevations

CPS – Cyber Physical Systems

DMADV – Define, Measure, Analyze, Design, Verify

DMAIC – Define, Measure, Analyze, Improve, Control

FMEA – Failure Mode and Effects Analysis

HoQ – House of Quality

HTO – Human, Technology, Organization

IoT – Internet of Things

IQM – Intelligent Quality Management

JiT – Just in Time

KDD – Knowledge Discovery Database

KM – Knowledge Management

KPI – Key Performance Indicator

MSA – Measurement System Analysis

PDCA – Plan, Do, Check, Act

QDD – Quality Discovery in Databases

QFD – Quality Function Development

QM – Quality Management

RCA – Root Cause Analysis

SPC – Statistical Process Control

SPS – Standard Problem Solving

TPM – Total Preventive Maintenance

TQM – Total Quality Management

VoC – Voice of Customer

VSM – Value Stream Mapping

1 Introduction

In today's highly competitive and fast changing market manufacturing companies face various challenges in order to sustain and compete profitably (Kim, et al., 2012). Many companies offer the same products, which means there is a clear need to be better than the competitors to convince customers to buy the products (Weckenmann, et al., 2015). Therefore, it is vital for these companies to have clear goals and a well-organized production line especially when it comes to ensuring the product quality (He, et al., 2017). According to Prashar (2014) the main objective for any company is to generate a profitable margin and sustainable competitiveness in the market. In order to be able to compete by offering a high product or service quality, Quality Management (QM) and all its implications can be indicated as the basis of all ideas and paradigms (Weckenmann, et al., 2015). Moreover, the process quality, which is directly linked to the production processes is a vital aspect of QM (Wang, 2009). According to Wang (2009) poor decisions on processes lead to decreased customer satisfaction as well as increased rework or waste of products and materials. These pitfalls need to be avoided by companies through the efficient practice of QM throughout their operations.

1.1 Background

The concept of QM has been present for a long time, which means that a lot of research has been conducted. According to Dean & Bowen (1994) "Total Quality *is a philosophy, characterized by its principles, practices and techniques*" (p.394). Principles can be identified as customer focus, continuous improvement and teamwork, among others, whereas practices can be defined as "activities such as collecting customer information or analyzing processes" (p.394). Practices are supported by techniques, which are also often called tools or methods. According to literature, there are various methods and techniques within the field of QM in order to improve the quality for manufacturing companies. Blaga & Joszef (2012) provide an overview of quality tools and human resources to be able to further improve the efficiency in production systems. Blaga & Joszef (2012) also identify Quality Circles as an instrument for solving problems, process proposals by using modern methods, creative techniques and statistical analysis. Prashar (2014) strongly focuses on another quality methodology namely Six Sigma by using the Define, Measure, Analyse, Improve and Control (DMAIC) phases in order to reduce the "cost of poor quality". Furthermore, Andersson et al. (2006) identify the similarities and differences of the quality approaches and methods, such as Lean, Six Sigma and Total Quality Management from a practical viewpoint to facilitate the usability.

In current times, Industry 4.0 as the fourth industrial revolution is an almost omnipresent term concerning the manufacturing industry. Hermann et al. (2016) define Industry 4.0 as a comprehensive term for technologies and concepts of a value chain organization, which monitor real-life processes and create a virtual copy of it, in order to make decentralized decisions. The Internet of Things (IoT) is a crucial aspect of Industry 4.0, expressing the interconnectivity of, for example, production systems (Hermann, et al., 2016). Therefore, an ongoing development towards a more digitalized and interconnected production system can be identified for many companies in the manufacturing industry, which also affects the concept of QM. According to Wang (2009) it is essential, that the use of data mining and knowledge discovery technologies are further used and developed within QM. This can already be seen as the beginning of the so-called Intelligent Quality Management (IQM), which focuses on the use of data mining, interrelating to terms like Big Data and Industry 4.0. These technologies and concepts have a huge potential impact on the future of new product and production development.

In this context, deviations can be one of the major challenges which the companies have to deal with in order to guarantee the process quality and keep the scrap and rework rate low (Prashar, 2014). Even tough with all of the research that has been executed in this field already, there is no common term in literature references regarding "deviations in production processes." Moreover, it can be recognized in the literature, that the aspects of Industry 4.0, especially the concept of IQM provide a potential to further investigate the interrelation to deviations in production processes.

1.2 Purpose and research questions

The purpose of this thesis is to explore the concept of IQM in connection with ways to control and reduce deviations within production processes. In order to be able to develop a framework with prospect to the purpose, it is crucial to have a well-grounded starting point. This starting point is set by exploring the possible reasons for deviations in production processes according to current literature. This leads to the first research question of this study:

> *RQ1: What are the reasons for deviations within production processes?*

Upon identifying the reasons for deviations in production processes, the next step is to explore the usability and applications of QM methodologies and tools which are available in current literature to effectively manage the deviations and reduce or eliminate reoccurrence. Therefore, the following RQ is formulated as follows:

> *RQ2: How can deviations in production processes be reduced and controlled?*

Thereby, a recent concept of QM is used in order to evaluate whether it can have a positive impact on the present problem of handling deviations in production processes. According to this, the research question is formulated as follows:

> *RQ3: What role does the concept of Intelligent Quality Management play in handling and reducing deviations in production processes?*

These research questions built the basis of this study under the consideration of the present delimitations, which are outlined in the following paragraph.

1.3 Delimitations

This thesis is mainly theory-focused and explores the role of IQM in the control of deviations in production processes. Therefore, the implementation of IQM, including its practical implications, is not included in this thesis. Moreover, the IT aspects of IQM, such as programming and software installation, are not within the scope of this study. This study is built on a single case company, where stakeholders and other external parties are not taken into consideration. The focus within the case company is limited to a single manufacturing facility which includes a production system with two separate flows. These are rather evaluated as a whole production process than independent flows. Areas such as purchasing, and logistics are not considered within the study. The quality of raw materials is also excluded.

1.4 Relevance

This study is relevant to both research and practice, as outlined in the following sections.

1.4.1 Relevance to research

The theoretical base of QM is quite extensive and offers a lot of previous knowledge because the concept of QM has been present for almost one century. The contribution to current research is the investigation of the role IQM concerning deviations in production processes. IQM as a concept is rather new and its application in control of production processes has not been widely investigated.

1.4.2 Relevance to practice

This thesis contributes to practice by enlightening the companies´ managers and employees regarding the reduction and control of deviations in production processes. Deviations in production processes are dealt with the support of both traditional QM approaches such as TQM, Six Sigma and Lean and, the consideration of IQM.

1.5 Outline

The chapters of this thesis are structured as follows:

Chapter 2 contains the theoretical background on QM, deviations in production processes and Intelligent QM.

In *Chapter 3* the research design, the data collection methods as well as the research process is outlined

Chapter 4 presents the findings of the study

In *Chapter 5* the findings are analyzed

Chapter 6 presents the discussion of the findings with regards to the purpose and research questions

Chapter 7 provides the conclusion and directions of future research

The chapters are followed by a list of references and appendices

2 Theoretical background

This chapter provides the theoretical background, which is essential in order to be able to answer the research questions. Thereby, “Deviations in production processes” represents the foundation to answer research question one. Research question two is answered through the knowledge basis of “The development of QM” and “Quality methods to control and reduce deviations”. To investigate research question three the theory “Intelligent Quality Management” is of key importance.

2.1 The evolution of Quality Management

The term quality has been used throughout history, but its meaning and importance has changed significantly over the years (Lu, 2001). Weckenmann et al. (2015) provide a good overview on the historical development of QM, which is summarized and visualized in the following figure, based on Weckenmann et al. (2015).

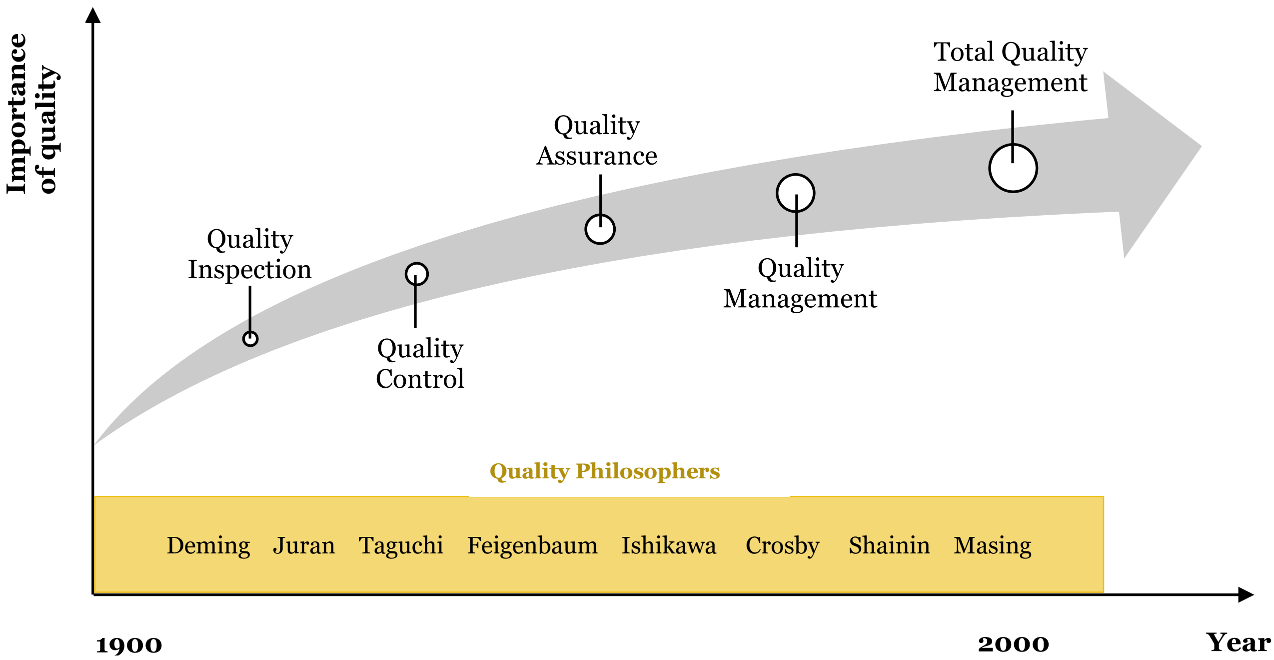

Figure 1: Evolution of Quality Management according to Weckenmann et al. (2015)

According to Weckenmann et al. (2015) the first ideas of QM can be identified in the beginning of the 20th century where the mass production has been developed. During that period of time, quality activities were focused on the inspection with the goal of delivering manufactured products without known disfunctions and defects (Schmitt & Pfeifer, 2010). Hence, inspection was added as a first quality activity to the end of the production line (Juran, 2003).

Although fewer defective products went out the door, the inspections resulted in some negative outcomes such as higher costs for detection and repair as well as higher wastages (Qiu, 2014). Furthermore, excessive time was allocated for the additional step of inspection at the end of the production process. These implications led to an evolution of quality practices. The focus moved from a product quality perspective towards process quality, which meant that parameters such as quality, costs and time became of interest. This change of perspective was based on the idea, that mere detection of defects is not as efficient as identification and elimination of the source of the defects (Schmitt & Pfeifer, 2010). Here, the next step of QM can be identified as progression from inspection to control (Juran, 2003). According to Juran (2003) the Second World War was a trigger for this progress in the history of quality movement. This was due to significantly low quality during shortages, which were directly connected to the impacts of the war. Furthermore, tools like the "Deming Cycle" and the "Statistical Process Control" were developed and used in order to control process quality and eliminate the defects more efficiently (Qiu, 2014).

In the following years, the quality movement continued to grow. The idea was to not just control and react according to the product and process quality, but also to include preventive actions by recognizing potential risks, which should be dealt with before they turn into actual problems (Schmitt & Pfeifer, 2010). Thereby, methods for preventive analysis like the well-known "Failure Mode and Effects Analysis" (FMEA) were introduced to the industries (Schmitt & Pfeifer, 2010). Juran (2003) describes this trend by mentioning the "Japanese Revolution", where Japan began emerging as the frontrunners of the quality movement in the 1960´s and 1970´s. During that period the Japanese manufacturers significantly increased their influence on the American market due to "superior quality" (Juran, 2003). The western countries reacted by adopting the Japanese practices, where various tools and methods were implemented in their operations (Juran, 2003). Some of these tools or methods are still used to a certain extent in many companies, for example the "Fishbone Diagram" by Kaoru Ishikawa or the "Quality Function Deployment" by Yoji Akao and Shigeru Mizuno. In addition, the so-called "systems thinking" was added to the QM practices by widening the application of the product and process perspective even further. From then on, a system-wide perspective along the "value-creation process" was adopted, which also takes the interdependencies between the different processes into consideration (Weckenmann, et al., 2015).

In general, it can be said, that after the Second World War the modern QM has begun to develop and progress. That is also the reason why QM became more complex and crowded with different methods and tools incorporating a systems perspective. Especially between the different companies it was difficult to have a mutual trust regarding quality activities and their documentation (Weckenmann, et al., 2015). Therefore, it was a logical consequence, that quality standards and definitions were introduced. The ISO 9000, ISO 9001 as well as ISO 9004 met the existing need and also created the possibility of "certification", which granted the standardization between suppliers and customers to build trust on levels of performance (Weckenmann, et al., 2015).

According to ISO 9000 (2015) the definition of "quality" can be described as *"The quality of an organization's products and services is determined by the ability to satisfy customers and the intended and unintended impact on relevant interested parties (p.10)*

Currently, there exist a number of different definitions of quality, which need to be considered in the context of QM. The definition above is just one example, among many others. Juran & Godfrey (1999) define quality as "*features of products which meet customer needs and thereby provide customer satisfaction*" (section 2.1).
In addition, these authors outline quality as "*freedom from errors that require doing work over again (rework) or that result in field failures, customer dissatisfaction, customer claims, and so on.*" (section 2.2)
According to Crosby (1979) quality is the "*conformance to requirements",* where requirements imply both product and customer perspective (Crosby, 1979).

Dean & Bowen (1994) also provide fundamental definitions and categorizations of QM in order to be able to differentiate between the existing terminologies. Dean & Bowen (1994) focus on Total Quality and its meaning as well as its relation to other terms in QM. As mentioned within the earlier chapter, Dean & Bowen (1994) describe Total Quality as a comprehensive philosophy, characterized by its principles, practices and techniques".

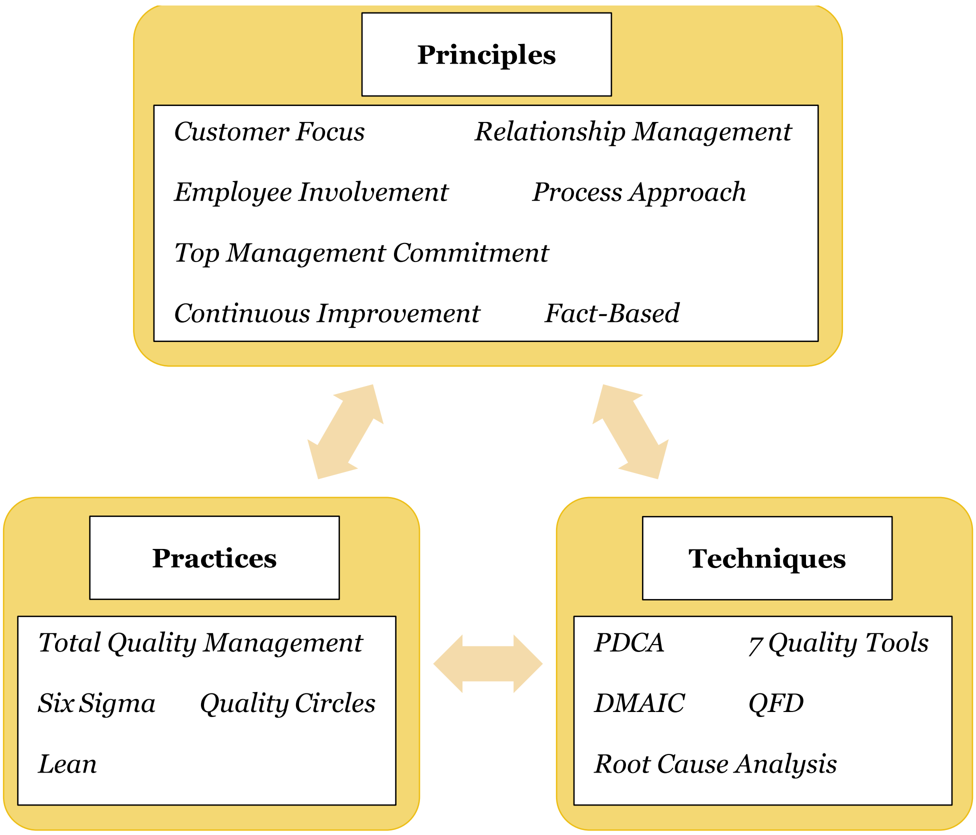

Figure 2: Quality Management Principles, Practices and Techniques (Dean & Bowen, 1994)

Figure 2, which based on Dean & Bowen (1994) provides an overview of essential principles, practices and techniques within QM. By understanding the definitions and the terminologies within QM, misconceptions regarding the use of quality terms can be avoided when dealing with those principles, practices and techniques within QM, which is necessary for the following chapters of this study.

2.1.1 Quality Management Principles

Seven QM principles are identified as the foundation of QM practices and techniques. These fundamental principles are explicitly outlined within ISO 9000 (2015), as follows:

Customer Focus:
According to ISO 9000 (2015) the main focus of QM is to fulfill customer needs and to strive for even surpassing customer expectations. Thereby, it is important for a company to keep a sustainable relation to customers, which facilitates the mutual trust. Therefore, it is crucial to understand current and future needs of customers, in order to sustain the success for the company.

Top Management Commitment:
ISO 9000 (2015) outlines, that management commitment facilitates the engagement of employees, who are consequently focusing on achieving the company´s quality goals.

Employee Involvement:
ISO 9000 (2015) emphasizes the involvement of employees, who are vital to improve the company´s operational capabilities. In this connection, it is important to respect and involve all employees at all levels.

Continuous Improvement:
According to ISO 9000 (2015) every successful company must follow the principle of continuous improvement, which is essential to be able to maintain current levels of performance, react to changes and to generate new opportunities.

Process Approach:
Through the understanding of how outcomes are created by the system, a company is enabled to optimize the system and its performance (ISO 9000, 2015).

Fact-Based Decision Making:
According to ISO 9000 (2015) decisions based on analysis and evaluation of data are more likely to create the wanted results. Guesses and making assumptions always lead to subjectivity, whereas using facts and analysis of data results in a greater objectivity and certainty in decision-making.

Relationship Management:
ISO 9000 (2015) also underlines relationship management as an important principle for a company to adopt. Relationships to suppliers and other external partners have a significant impact on the performance of a company. Therefore, it is vital to efficiently manage these relationships.

2.1.2 Quality Management Practices

Total Quality Management:
One of the most popular developments in QM is outlined in various literature as Total Quality Management (TQM). According to Patyal & Maddulety (2015) TQM is a common practice in companies. Dale (1999) outlines that TQM incorporates various elements which are supported by quality philosophers such as Deming, Juran and Crosby. TQM follows an understanding of delivering high quality products and services, which are no longer dependent on the market pressure as a driving force (Weckenmann, et al., 2015). TQM also focuses on the commitment of employees as well as their relationship to leadership by following a more holistic approach (Dahlgaard, et al., 1998). There are many quality techniques, which are used within the framework of TQM (Dale, 1999). But according to Melsa (2009) there is no one best suited for all applications. The use of techniques is strongly dependent on several factors such as resources, purpose and company´s culture (Melsa, 2009). Hellsten & Klefsjö (2000) also emphasize the importance of aligning the QM practices and techniques with the company´s culture, based on corporate values. The main principles of TQM are top management commitment, continuous improvement, customer focus and employee involvement, which have been outlined in the previous section. According to Patyal & Maddulety (2015), top management commitment is the foundation of TQM and directly affects the main principles of TQM by adopting a top-down approach. Tari et al. (2007) mention that top management commitment is a main driver of TQM because strong involvement of top management enables leaders to create shared goals within the company. Hence, employee involvement becomes easier due to transparent goals (Patyal & Maddulety, 2015). Moreover, Patyal & Maddulety (2015) outline, that shared goals and employee involvement facilitate continuous improvement, which affects the product and process quality as well as customer satisfaction. Thereby, the essential value of customer focus adds a market perspective and selling prepositions to the operational thinking.

Six Sigma:
Pyzdek (2003) describes Six Sigma as a practice involving a highly-effective set of QM principles and techniques, which incorporates many elements from the work of various quality practitioners. Six Sigma strives for an error free operational performance by improving quality, productivity and bottom-line financial performance (Franchetti, 2015). The Greek letter Sigma (σ) is used by statisticians in order to measure the variability in processes (Patyal & Maddulety, 2015). Generally, the performance of a company can be evaluated on the sigma level of their business processes and companies traditionally accept a sigma level of three or four as the norm (Pyzdek, 2003).

In a production context, Six Sigma can also be defined as an improvement program for reducing deviations, following the purpose of satisfying the customer (Patyal & Maddulety, 2015). According to Linderman et al. (2003) the name of Six Sigma emphasizes a goal of 3.4 defects per million opportunities, which represents the accuracy of the sixth sigma level. But Linderman et al. (2003) also outline, that not all processes should aim for the sixth sigma level because there is an essential dependency on the strategic importance of the process as well as on the cost of improvement regarding to the benefit. Figure 4, which is based on Lindermann et al. (2003), illustrates this fundamental interrelation for the sigma levels.

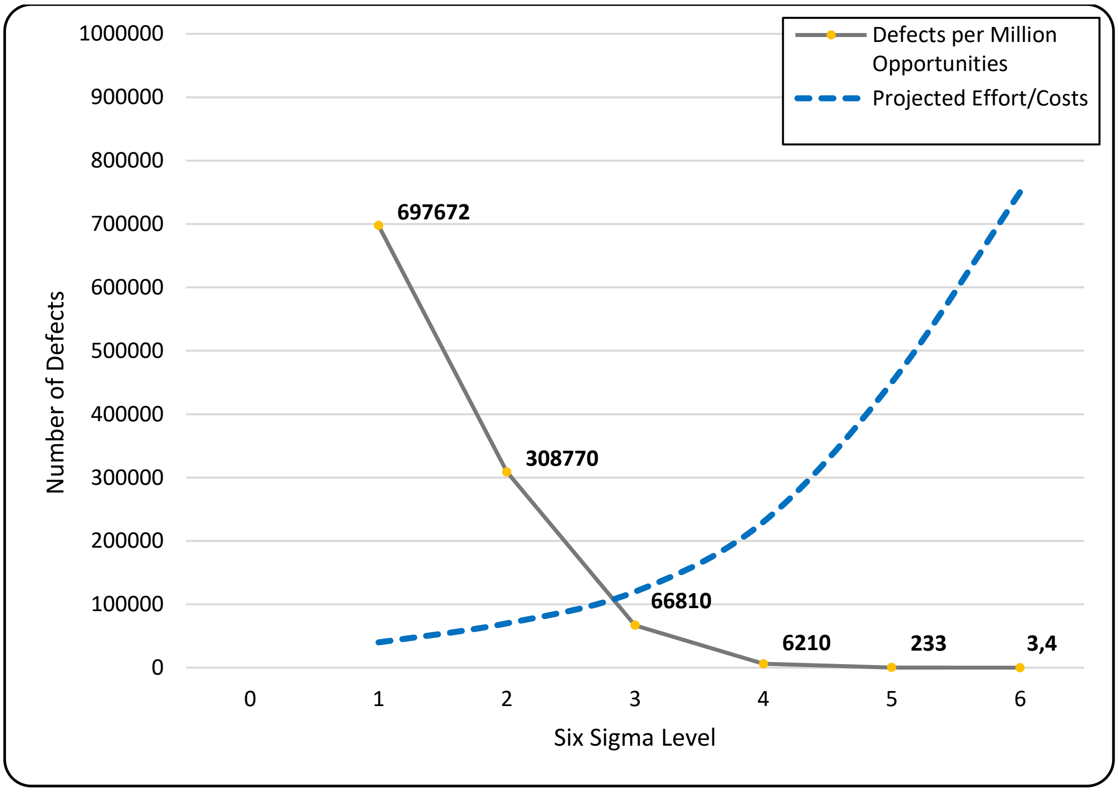

Figure 3: Interrelation of Six Sigma levels and Cost/Effort, based on Lindermann et al. (2003)

For example, a process at a level of two or three sigma will be relatively easy and cost-efficient to reach and maintain whereas a higher six sigma level requires way more determination concerning the use of statistical tools and resources (Linderman, et al., 2003). In general, the effort and the costs increase exponentially as the sigma level for the process increases (Linderman, et al., 2003).

According to Zhang et al. (2011) five views and five core elements of Six Sigma can be described. The five different views for the Six Sigma implementation can be outlined as follows.

Metric view - puts the focus on "*sigma metric, process capability metric and high-level balance scorecard metric*

Tool view - highlights the Six Sigma techniques. These are mainly related to statistical and process mapping procedures.

The program view - emphasizes creating, choosing, planning, controlling and closing a portfolio of projects.

The philosophy view - focuses on the interrelations of philosophies and its impacts on the company´s values and corporate culture.

The project view - mainly takes project management skills and the practice of DMAIC (Define, Measure, Analyze, Improve, Control) into consideration.

As already briefly mentioned, Zhang et al. (2011) also highlight five core elements of Six Sigma, which can be described as follows.

Customer Orientation – emphasizes the understanding of customer needs and is mainly used as a principle in order to select and prioritize projects.

Leadership Engagement – is based on the importance of strong management support, which ensures the appropriate selection of projects

Dedicated Organization Structure – is set up to improve the company´s structures by including roles of Green Belts, Black Belts, Master Black Belts and Champions.

S*tructured Method* – is strongly linked to application of DMAIC / DMADV, which provide a structured way of acting based on the analysis of root causes and the structural control of the process.

Metric Focus – ensures the clear definition of goals, which must be feasible and based on financial or customer related aspects.

The outlined views and core elements are used to define the scope of Six Sigma. There is a high risk of insufficiently applying these views and elements in practice, which often leads to the failure of Six Sigma projects (Eckes, 2000). Therefore, it is essential to review, plan and select the dimensions of a Six Sigma project conscientiously in order to achieve organizational feasibility, financial benefits and customer orientation (Kwak & Anbari, 2006).

Lean:

Lean is a popular practice to eliminate waste by reducing non value-added activities, which can be seen as activities the customer is not willing to pay for (Bacoup, et al., 2018). Lean facilitates the continuous improvement of quality as well as robustness of product and process (Bacoup, et al., 2018). Moreover, lean emphasizes the concept of Just-in-Time (JIT), which eliminates gratuitous work-in-process to be able to provide a continuous flow of products (Ohno, 1988). In addition, lean as a QM practice incorporates the concepts of “perfect quality”, visual management and human resources management to secure the efficiency of activities and processes within the company (Liker, 2004). Generally, all lean principles are customer value driven, which makes it applicable for various manufacturing and distribution scenarios, including the issue of deviations in production processes. According to Andersson et al. (2006) excess production, superfluous processing, delays, transport, inventory, defects and movement can be identified as key elements contributing to the elimination of non-value-added activities. Thereby, Value-Stream Mapping (VSM), Total Productive Maintenance (TPM), Kaizen, cost analyses, change management and document management are approaches which should be taken into consideration.

Quality Circles:
Blaga & Joszef (2014) outline Quality Circles as a practice, positively affecting the mindset of employees concerning product quality in processes. Thereby, every employee is responsible for quality in one´s own work, which leads to balanced ownership of quality among employees (Blaga & Joszef, 2012). In fact, every employee contributes and is accountable for the quality of the product. Juran & Godfrey (1999) point out, that Quality Circles are a problem-solving practice where quality teams are set up to solve cross-functional quality problems. In general, it can be said that Quality Circles are also focused on the development of the employees in addition to improving quality (Juran & Godfrey, 1999). Training and learning are key to develop employees (Patyal & Maddulety, 2015). Skill-improving training for employees as well as employee involvement within continuous improvement activities can guide the employees towards increased commitment to quality (Flynn, et al., 1995).

2.1.3 Quality Management Techniques

Quality Function Deployment (QFD):
QFD is used in product planning and development, customer needs are determined and product specifications are systematically evaluated conforming to customer needs (Ficalora & Cohen, 2010). QFD is beneficial in terms of communication and transparency between product development team and management (Ficalora & Cohen, 2010). Thus, through QFD the interests of both can be aligned by reviewing the plans and allocating the resources. According to Ficalora & Cohen (2010), QFD application may differ from company to company, but the key elements remain the same. This includes the assessment of customer needs and result in the so-called House of Quality (HoQ), a major matrix representing the Voice of Customer (VoC). Other matrices, focusing on technical performance measures, piece-part characteristics and process parameters are interrelated and provide a holistic view supporting deployment. Deployment here refers to the process of translation from (customer) needs to product decisions (Ficalora & Cohen, 2010). In practice, many companies only use the HoQ and miss out on the additional matrices, resulting in a lack of further planning of detailed decisions made throughout the product development phase.

PDCA (Plan-Do-Check-Act) Cycle:
The PDCA cycle (also called Deming cycle) is a sequence of activities with the goal of improvement designed to solve problems (e.g. quality issues) and present solutions (Jagusiak-Kocik, 2017). The PDCA as a technique can be adequately applied in almost every type of business and problem area due to its versatility and flexibility (Jagusiak-Kocik, 2017).

According to Jagusiak-Kocik (2017) the PDCA cycle includes four phases, which are:

Plan (P) –identification of potential changes and setting the goals for improvements

Do (D) –implementation of the planned changes

Check (C) – checking and testing activities in order to evaluate solutions

Act (A) – dependent on the outcome of the "check-phase". Verified solutions are applied and standardized. When solutions are ineffective, the cycle is repeated.

These four phases are repeated for continuous improvement. (Jagusiak-Kocik, 2017).

DMAIC:
According to Pyzdek (2003) the DMAIC technique is suitable, when the goal of a project can be achieved by improving an existing product, process or service. Thereby, a five steps methodology is followed. At first, the goals of the improvement activity must be defined (Define). Then, the existing processes or systems need to be measured (Measure) and analyzed by comparing the current with the desired state (Analyze). The last two steps of this approach include the improvement (Improve) of the system based on the analysis and the steady control of the improved system (Pyzdek, 2003). In addition, a similar approach can be used for Six Sigma projects regarding the development of new products or services. This approach is called DMADV and differs through the two last steps design (second D) and the verification (V) (Pyzdek, 2003).

7 Quality Control Tools:
Ishikawa (1986) outlines 7 Quality Control Tools (here same as techniques), which are widely used in professional contexts. These tools are the Cause Effect Diagram (also known as Ishikawa Diagram), Control Chart, Scatter Plot, Pareto Chart, Histogram, Check Sheet and Stratification. Most of these are based on statistical techniques, which incorporate, amongst others, Statistical Process Control (SPC), Pareto Charts and Histograms (Melsa, 2009). SPC is grounded on statistical approaches and was introduced by William Edwards Deming (Melsa, 2009). SPC is the most commonly used methodology of the statistical tools. SPC is applied to evaluate conformance of products to requirements in a process (Qiu, 2014). SPC is used to identify deviations in production processes. The application of statistics for managing quality issues in production processes is also the main basis for Six Sigma, which is further outlined as a QM practice in the previous chapter. In addition to the 7 Quality Control Tools focusing on

gathering quantitative data, there are 7 Management Tools namely Affinity Diagram, Interrelationship Diagraph, Tree Diagram, Matrix Data Analysis, Matrix Diagram, Problem Decision Chart and Activity Network Diagram, which are used to complement the quality tools with a management perspective incorporating qualitative data (Tari & Sabater, 2004).

Root Cause Analysis (RCA):
RCA is a popular problem-solving technique for general improvement of various issues concerning quality, productivity and safety (Sarkar, et al., 2013). In general, the RCA can be described as a process to identify the root-cause of a specific problem (Sarkar, et al., 2013). Within RCA various tools can be used for analysis. Common tools within RCA are the Cause-Effect diagram, the 5 Why´s and the Tree diagram. In addition, the RCA often follows the PDCA cycle (Sarkar, et al., 2013).

In general, there are many techniques for problem detection and solution in practice (Tari & Sabater, 2004). One that requires specific emphasis is Self-Assessment and Lessons Learned to be considered within QM.

Self-Assessment and Lessons Learned:
Self-Assessment is interrelated with the practice of Lessons Learned. Moreover, the technique of Self-Assessment can be identified as the basis for a successful Lessons Learned process (Michell & McKenzie, 2017). According to Mitchell & Mckenzie (2017) a Lessons Learned process can only be seen as a success if the learnings are implemented and result in improvements, e.g. quality improvements. Thereby, there must be an internalized reason to learn, which must include a determined potential benefit for the company (Michell & McKenzie, 2017).

2.2 Deviations in production processes

In literature the term deviation is used in different fields with various opportunities for application. Even though the origins of the word deviation can be linked to changes of course regarding ships sailing the unpredictable sea, the most common application of deviation can be identified in the subject of statistics. In this context, the standard deviation can be described as "*a measure of the degree to which sample data is spread about the mean of that data"* (Butterfield & Szymanski , 2018) and deviation can be seen as *"the difference between the observed value of a measurement and the true value"* (Butterfield & Szymanski , 2018).

These definitions can most likely be the basis for every other field of application. Therefore, this term can also be put into a production context, where *"the difference between the actual value and the desired value of a controlled variable"* (Atkins & Escudier, 2013) is of major interest. This definition is also the one, which will be referred to whenever the term deviation is used in this thesis. Deviations became increasingly prominent in a production context alongside the evolution of QM. In the phase of quality control and inspection, which mainly took place in the early 20th century, the focus laid on stabilizing and maintaining the production processes (Juran & Godfrey, 1999). Actions were taken when the actual performance did not correspond to the goals, which can also be described as reacting deviations in production processes (Juran & Godfrey, 1999).

By comparing literature in the area of production, it can also be recognized that deviation is not the only word used in this context. Names such as variability or variation of production processes are often used as synonyms. According to Andersson et al. (2006) the goal of QM principles and practices can be linked to reduction of deviations, cost savings and thus successfully meeting the production objectives. Moreover, high deviations in critical processes can result in many unwanted outcomes such as scrap, rework, customer dissatisfaction or even faulty operations in parts of the production (Asilahijani, et al., 2009). Hence, Asilahijani (2009) outlines, that reducing deviations is a major goal of improving production processes and their quality.

The reasons for such deviations in production processes are rather complex and manifold than simple and obvious. According to Asilahijani (2009) the roots of deviations must be related to process inputs which vary as the process operates. There are a lot of process inputs, which have to be taken into consideration in order to identify the reasons for the particular deviations. Fleischer et al. (2014) point out that by using new and innovative processes in combination with small batch sizes bigger deviations could occur within the production line due to uncertainties concerning the new processes. So, it can be concluded that the reason for deviations can also be linked to the implementation of new production processes as well as the introduction of new products within existing processes. Furthermore, Schweinoch et al. (2016) mention, that production impacts in combination with geometric changes concerning prototypes (new products) can also cause deviations. In this context, the interface management between product and production development can be indicated as a more general root cause for production deviations. Decisions taken during the earlier phases of technology development and product development have a direct influence on the performance of production processes and thus can end up in deviations (Säfsten, et al., 2014). According to Lindroos (2009) deviations in production processes can also be created by human errors as well as machine malfunctions. There are various human errors, generally those caused by lack of information, experiences and methods (Ahram & Karwowski, 2018). Ahram & Karwowski (2018) outline that the root cause for human errors in the production line are mainly based on the defined system design and training of employees in the development phase. According to Alsyouf (2007) machine malfunctions can have negative effects on the company´s quality of products, which can be translated to deviations in production processes. The main reasons for machine malfunctions can be linked to the improper maintenance (Alsyouf, 2007). Thereby, poor maintenance is often caused by absence of maintenance strategies and planning in many companies.

The interrelations between human, machine and system design can be linked to the Human-Technology-Organization (HTO) concept (Carayon, 2006). This concept focuses on the interdependencies of the three sub-systems within an overall dynamic system (Karltun, et al., 2017). The human sub-system describes impacts on individuals on a personal level, the organization sub-system relates to a collective staff level and the technology sub-system refers to the machines and technologies applied in the working environment (Karltun, et al., 2017). Thereby, it is important to consider all three parts equally because they are interdependent. Hollnagel (2014) mentions that the processes and activities within a company cannot be completely fulfilled without the support of human activities in prospect to the technology and organization.

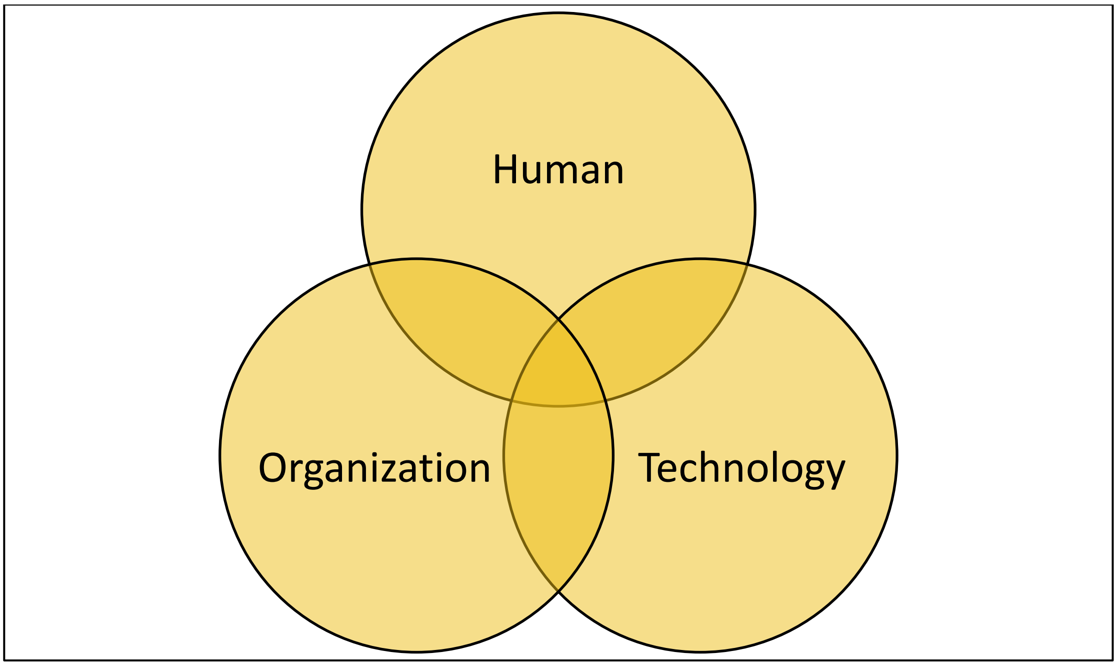

Figure 4: HTO model adapted from Carayon (2006)

All the operations within this system, such as worker, machine, planning and management activities are explained through the HTO concept, which is based on Carayon (2006). Figure 4 outlines the basic HTO model and its interfaces.

Another perspective on deviations in production processes is taking aspects of sustainability into consideration, which involve three levels or pillars, namely environmental, economic, social (Purvis, et al., 2018). According to the United Nations' Brundtland Commission (1987, p. 27) sustainability is generally defined as the *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*.
When this definition is applied to a production context, the term of sustainable manufacturing is often used in literature. Jayal et al. (2010) outline, that sustainable manufacturing incorporates the 6R approach, consisting of "reduce", "reuse", "recycle", "recover", "redesign", and "remanufacture". Deviations in production processes are mainly associated with the aspects of "reduce" (Jayal, et al., 2010). Thereby, "reduce" refers to a minimized usage of energy and materials as well as a reduction of scrap and rework activities within production processes. Moreover, Khidir & Zailani (2009) state, that companies focusing on sustainability in manufacturing processes generate a competitive advantage by reducing costs of manufacturing while also enhancing the level of quality.

In general, it has to be outlined that deviations in production processes mostly result in quality issues indicated by scrap and rework activities (Prashar, 2014). These activities directly affect the environmental and economic aspects of sustainability (Jayal, et al., 2010). Therefore, scrap and rework activities result in additional costs (economic factor) as well as extra use of energy and materials (environmental factor). In prospect to the outlined definition of sustainability, the goal of companies regarding sustainability in production processes must be to ensure the level of quality in production processes *that meets the needs of present without compromising the ability of future generations* by optimizing the usage of resources (Brundtland, 1987).

2.3 Quality Management approaches to control and reduce deviations

As outlined in chapter 2.1, there are various QM approaches, to control and reduce deviations in production processes. These approaches are further explored in the following section.

2.3.1 Lean Six Sigma application to handle deviations in production processes

Literature provides different cases on how to practically use Six Sigma and Lean to effectively handle deviations in production processes. Thereby, in most of the cases a combination of Lean and Six Sigma is proposed as the best solution. According to Smith (2003) companies within different industries combine Lean and Six Sigma as a "best practice" in order to reduce production deviations that lead to rework and scrap. Kumar et al. (2006) outline, that the integration of the two QM practices create better outcomes than either one of them can generate on their own. Lean strategies are crucial for eliminating waste, such as non-value adding activities, within the company. In addition to this, Six Sigma provides potential improvements for process capability and performance by incorporating statistical techniques (Kumar, et al., 2006). Kumar et al. (2006) provide a framework for the Lean Six Sigma implementation, which is based on a case study at an Indian small-medium sized company. The proposed framework, which is illustrated in the following figure, uses Lean techniques to complement the Six Sigma practices, following the DMAIC methodology.

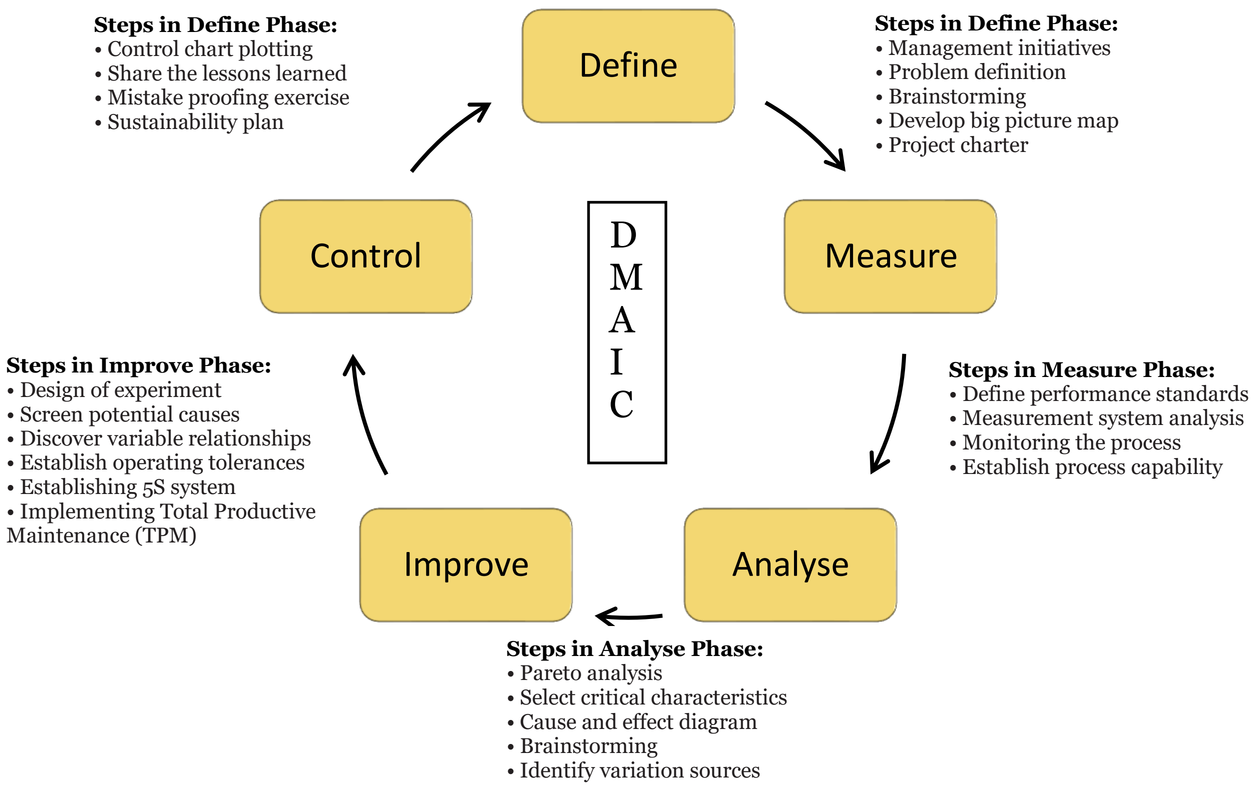

Figure 5: Framework Lean Six Sigma Implementation (Kumar, et al., 2006)

Another practical case example of implementing Lean Six Sigma is described by Anderson & Kovach (2014). The goal of this case study is outlined as reducing welding defects by using the Lean Six Sigma approach. The case company is introduced as an industry-leading turnaround, construction and fabrication services company situated in Houston, Texas. Anderson & Kovach (2014) follow a similar practical approach as outlined in the previous case example by also focusing on DMAIC as a basic methodology. Therefore, Anderson & Kovach (2014) also emphasize the use of Lean and Six Sigma techniques by following DMAIC as a road map. The only differences to Kumar et al. (2006) can be identified in the application of QM techniques, which are adjusted to the context, including resources, existing structures and employees. Therefore, it must be highlighted, that both case implementations of Lean Six Sigma resulted in improvements for deviations in production processes in the given scenarios.

2.3.2 TQM application to deal with deviations in production processes

In literature, the TQM application is linked to a broad spectrum by influencing business and operational performance within companies (Corredor & Goni, 2011). Therefore, TQM also supports the control and reduction of deviations in production processes. Rahman & Tannock (2005) outline three cases on implementing TQM in companies. All these companies are small-medium sized companies operating in manufacturing industry in Asia. Even though all case companies prioritized customer focus and process improvements, every company used a different approach for applying TQM and achieving their goals.

According to Rahman & Tannock (2005) 8 common success factors of implementing TQM can be identified.

These are named as follows (Rahman & Tannock, 2005):

- Top Management Commitment
- Policy and Planning aimed at Customer Satisfaction
- Effective Steering Committee
- Good Internal Communication
- Employee Involvement and Teamwork Development
- Reward and Recognition Systems
- Employee Training and Development
- Appropriate Problem-Solving Tools and Techniques

Moreover, Oakland (2003) provides another perspective on the application of TQM within companies. The case of the Philips Group, one of the largest electronics companies in the world, outlines the TQM implementation as the start to world-class performance. According to Oakland (2003) Philips focuses on business excellence through the elements of speed and teamwork. Thereby, the practical application of this TQM perspective follows the continuous PDCA cycle at a strategic and operational level.
This framework on the TQM application at Philips is illustrated in figure 6, based on Oakland (2003).

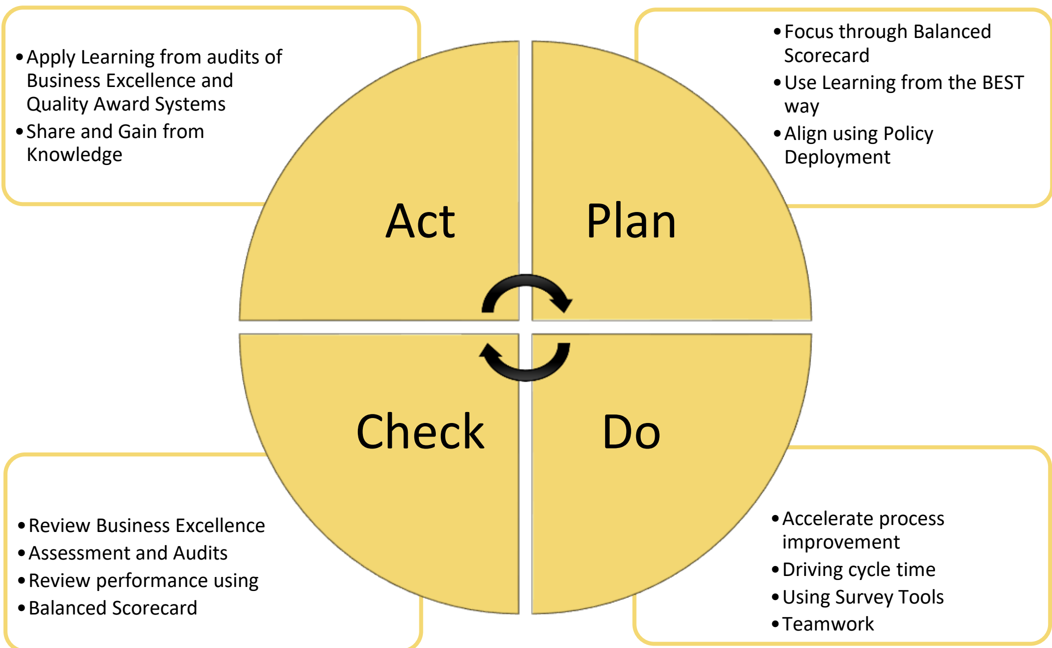

Figure 6: Philips´TQM implemantion following PDCA (Oakland, 2003).

Furthermore, Quality Circles as a practice are used to affect deviations in production processes (Vijayaram, et al., 2006). Vijayaram et al. (2006) emphasizes the introduction of Quality Circles by using a case example of foundry quality control in metal casting manufacturing industries. Thereby, the main steps are described as identifying, selecting and analyzing the problem, generating and choosing appropriate solutions, preparing an action plan, communicating and implementing the plan with management support (Vijayaram, et al., 2006).

It has to be considered, that not all quality approaches are implemented successfully and result in improvements. That is the reason why many researchers also express criticism about the different QM approaches (Patyal & Maddulety, 2015). According to Patyal & Maddulety (2015) many companies lack in knowledge of obstacles and risks as well as channeling the right information, which are key to successful application of QM.

2.4 Intelligent Quality Management

The roots of Intelligent Quality Management are traced back to the term Knowledge Management (Maier, 2007). Ansari et al. (2011) outline Knowledge Management (KM) as a function to translate information into actionable knowledge, enable lessons learned and promote knowledge sharing. Many KM approaches propose, that the more knowledge a company holds, the better it is for the company (Maier, 2007). According to Maier (2007) this simple preposition implies some shortcomings because it does not take the following conditions into consideration. First of all, not all gathered information or knowledge might be useful. In addition, the more information is generated, the more knowledge is needed to use the information adequately. As a consequence, the danger of information overload and insufficient use of knowledge has to be handled within this context. Therefore, the focus must be moved towards the filtration and determination concerning the optimal level of knowledge, which is presented in a knowledge seeking system (Maier, 2007). Wang (2009) mentions Knowledge Discovery Database (KDD) as the interdisciplinary field incorporating different concepts from machine learning, statistics, database query, and visualization. KDD is also associated with the overall process of discovering the suitable knowledge from a dataset, which contains the evaluation and analysis of patterns in order to make decisions based on facts. Within this process, data mining is of major importance for the knowledge discovery by using algorithms to find desired patterns in the collected data (Wang, 2009).

Wang (2009) outlines the concept of Intelligent Quality Management (IQM) as an approach to embrace data mining technology and knowledge discovery in databases. Thereby, the fundamental idea is to integrate the gathered information from quality control and QM practices to a primary database and implement an IQM system including assistant decision-making based on data mining. Moreover, Wang (2009) sees current QM practices, such as TQM, as the basis for IQM. These QM practices provide the primary data, producing and accumulating a lot of information regarding the allocation of resources and the status of production lines on a daily basis. But Wang (2009) also outlines the difficulty of using the right techniques within this field of application because there are many techniques quality engineers can choose from. Therefore, there is a need for more suitable techniques, which can support the analysis of distributed process data and streamline the integrated workflow within the company. This leads to aspects of machine learning, pattern recognition, techniques for large-scale databases and artificial intelligence, which develops into Quality Discovery in databases (QDD) as a technology convergence of KDD specifying on QM aspects. According to Wang (2009) QDD is created to obtain the distributed process data from various processes within the workflow and to convert the data into knowledge in terms of artificial intelligence. This form of knowledge discovery has direct impact on the product quality as well as providing access to information about all the processes. Köksal et al. (2011) outline a five-step process for KDD, which is also valid for QDD as a basis.

According to Köksal et al. (2011) the five steps are the following:

Data Preparation:
Firstly, sources of data are identified, evaluated and selected. These datasets are translated into a matrix format in which variables are organized in specific rows and columns. If the data set is very large, sampling techniques are used to gather more representative data.

Data Preprocessing:
Due to inconsistencies, redundancies and incompletion of retrieved data from various sources, data preprocessing is focused on improving the data quality. Thereby, reduction, cleaning and transformation of data helps to enhance the accuracy and reliability of the data mining functions.

Data Mining:
There are various data mining methods, which can be categorized according to different criteria. In general, it can be distinguished between descriptive and predictive data mining tasks. Descriptive data mining incorporates patterns and interrelations, which might exist within datasets. Predictive data mining performs prediction functions to estimate future values of datasets.

Evaluation and Interpretation:
At this stage, an iterative process must be conducted to come to a final decision about the data mining methods. The evaluation of these methods needs to involve a comparison of the result from the different methods computing several measures such as accuracy, time and resource necessities.

Implementation:
The last step involves the implementation of the results based on the evaluation and interpretation of quality improvement related decisions.

Based on these five steps, Wang (2009) proposes a generic architecture of a QDD system, which is illustrated in figure 7.

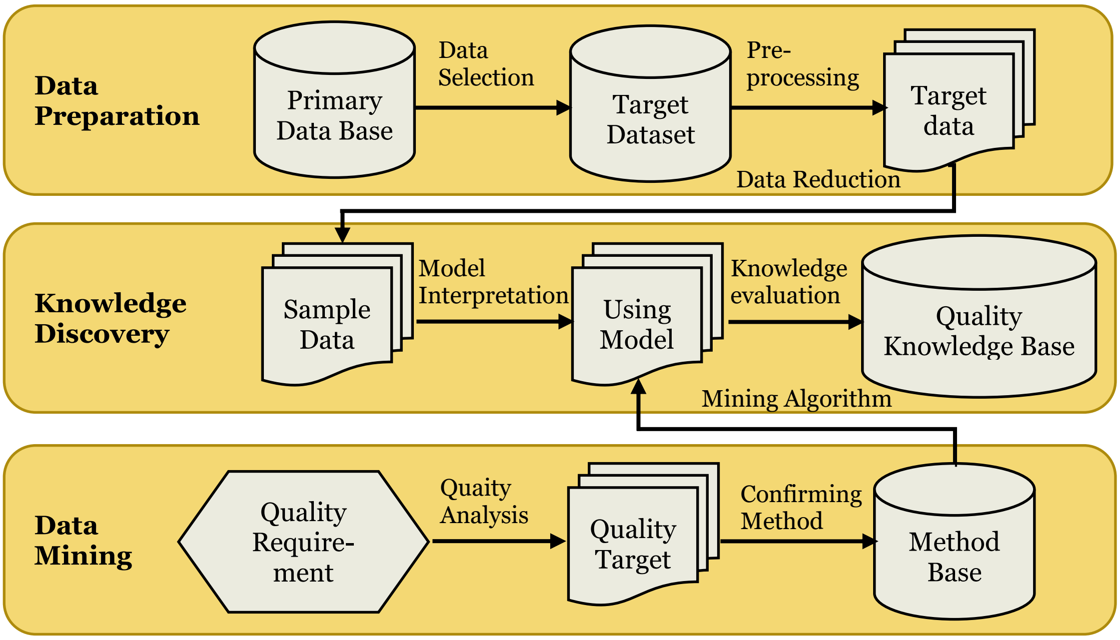

Figure 7: QDD system architecture, adapted from Wang (2009)

The QDD system contains three modules, which are called data preparation, knowledge discovery and data mining. This view on interconnected systems and digitalization within the field of production is a trend, which is often linked to Industry 4.0. This trend also reached the basic concept of QM, which results in the outlined application of IQM. According to Hermann et al. (2016) Industry 4.0 (also known as smart manufacturing) is a comprehensive term for technologies and concepts of companies, which monitor real-life processes and create a virtual copy as a foundation for decision-making. According to Rüßmann et al. (2015) Industry 4.0 consists of 9 pillars, namely Autonomous Robots, Simulation, Horizontal & Vertical System Integration; Industrial Internet of Things (IOT), Cyber Security, the Cloud, Additive Manufacturing, Augmented Reality, Big Data and Analytics.

Xu et al. (2018) outlines the evolution from Industry 1.0 to Industry 4.0, which is essential for understanding the progress and trends within the manufacturing industry. Industry 1.0 represents the “Age of Steam”, Industry 2.0 is called the Age of Electricity”, Industry 3.0 is defined as the “Age of Information” and Industry 4.0 is mainly described by the use of Cyber Physical Systems (CPS) (Xu, et al., 2018). CPS, one of the key elements of Industry 4.0, are engineered systems integrating computational algorithms and physical components (Xu, et al., 2018). Chen (2017) outlines that within CPS, physical and software elements are widely interlaced and cooperating with each other in many different scenarios. Industry 4.0 mainly applies CPS to facilitate an intelligent production system, which represents both the physical and virtual world (Zhou, et al., 2015). Therefore, CPS provides the basis for IoT and the use of the Cloud including Big Data by bridging virtual and physical realities, which also represents the interface with IQM (Wang, 2009) (Xu, et al., 2018).

Törngren et al. (2015) describe IoT as unique *things* which channel data via *Internet* with little or no human interaction. Moreover, IoT facilitates wireless communication abilities between physical *things* and software systems. Thereby, information on location, operational status and business aspects are shared and monitored (Törngren, et al., 2015). Generally, IoT systems can be seen as CPS systems, but CPS does not always need to include the internet. The Cloud technology is the software or platform where all the data retrieved from systems and operations via IoT is stored (Rüßmann, et al., 2015). Furthermore, the cloud is not dependent on facilities or other physical boundaries within a company. The cloud technology is closely intertwined with Big Data, which is the analytics of the large datasets. Therefore, Big Data is also the foundation for data mining and knowledge discovery methods, which are the key elements of IQM (Wang, 2009) (Törngren, et al., 2015).

3 Method and Implementation

Within this chapter the research methodology as well as the use of different techniques are outlined. Moreover, the generalizability, reliability and validity of the research approach is described.

3.1 Research approach – Case Study

In general, there are two different types of case studies, single case study design and multiple case study (Yin, 2009). The difference between these are, that a single case study only includes the perspective of one case as basis for the research, whereas the multiple case study design takes more than one case into consideration (Yin, 2009). According to Williamson (2002) the single case study is more applicable within an exploratory research process and the multiple case study is more suitable for an investigation of a specific occurrence in a variety of settings. But these approaches can also build on each other. For example, the single case study can be applied to investigate why a particular event occurs, which then creates the basis for a multiple case study to further elaborate and verify this event in other settings (Williamson, 2002).

With keeping these aspects in mind, an exploratory research approach has been indicated as being the most suitable design, since the aim of this thesis is to investigate why deviations occur and how to deal with them. This purpose is of explorative nature because the various reasons for the occurrence of deviations in production processes are events, which need to be qualitatively analyzed. Therefore, a single case study design is used to conduct the research in the scope of this study.

In the following, the case selection as well as the background to the case company is further explained.

Case Selection:
When selecting a case within a single case study approach, is it vital to make sure that the selected company will provide all the essential data in order for the study to meet the purpose and to be able to answer the research questions (Williamson, 2002). When selecting the case company for this thesis, the main criteria was to find a manufacturing company, that currently faces problems with deviations in their production processes and is focusing on fully-automated production systems with high production volumes. The automation of the production process involves decreased manual handling of products, which simplifies the differentiation between machine malfunction and human errors. Moreover, a higher level of automation provides the necessary basis for the concept of IQM. In addition, criteria like reputation, size and location of the company have been taken into consideration.

Case Company:
The selected case company is a large wooden furniture manufacturer located in the south of Sweden. The company is a subsidiary of one of the biggest global group, which is designing, producing and selling furniture and home accessories. The case company produces products for only one customer, which

is part of this global group. In order to preserve the corporate confidentiality, the case company will be referred to as company ALPHA.

APLPHA´s factory is 34000 m^2 and with a total of 270 employees, whereof 30 are white collar and 240 (30 maintenance) are blue collar. ALPHA is a company, which focuses on mass production and yearly produces millions of products in various variants, which differ in type, size and color. The production is fully automated, but the quality controls are still conducted manually. The company is currently tracking and reporting the production deviations at the end of the line. Because of the high production volumes and non-automated quality control, there is a risk of deviations to occur, which fulfills the criteria for this thesis.

3.2 Research Techniques

This chapter present the different research techniques that are used for this thesis work. Both authors of this study are involved in all data collection techniques.

3.2.1 Observation

Within this thesis observations will be executed, in order to collect necessary data from the case company. There are two different ways of organizing observations, which are following a structured or unstructured approach (Beck & Manuel, 2008). According to Beck & Manuel (2008) structured observations are useful when the knowledge about the observed problem is high. In contrast to this, the unstructured observation technique is commonly used in an exploratory way, in order for the observer to increase the knowledge within the observed problem area. During the observation there are four different approaches regarding the involvement of the observer, which are namely *active, not active, known and unknown* (Williamson, 2002). Williamson (2002) describes *active* as the active involvement of the observer during the observations, whereas *not active* is characterized by no involvement of the observer. Furthermore, *known and unknown* are specified whether or not the observer is introduced to the people within the focused setting.

Because of the wide range of reasons to why deviations occur and how to control them, the observations are performed in an unstructured way. Thereby, the observers follow the approach of known and not active (Patel & Davidsson, 2011). Following this approach, the observers do not interfere or interrupt the working procedures as well as being accepted in the present working environment. This leads to a data collection, which is as accurate to regular conditions as possible (Patel & Davidsson, 2011).

3.2.2 Interview

According to Wilson (2016) interviews can be structured in four different ways, *high level of standardization, low level of standardization, high level of structure and low level of structure*. The main difference between these types can be indicated by the extent of freedom the interviewer provides the respondent, regarding the order of the questions (standardization) and the "response spectrum" (structure) (Gorman & Clayton, 1997).

High level of standardization and structure limit the freedom of the respondent, whereas low level of standardization and structure will increase the freedom (Patel & Davidsson, 2011). Since the purpose of this thesis is to explore the reasons for deviations and reducing their reoccurrence, interviews with low level of standardization and structure will be conducted. This structure can also be called "Qualitative Interview" (Patel & Davidsson, 2011). This means, that the questions are being asked in an open-ended way in no particular order, which gives the respondents freedom of explaining and elaborating on their answers (Patel & Davidsson, 2011). These types of response provide essential perceptions to be able to answer the research questions of this study.

3.2.3 Document Study

Bowen (2009) describes document study as a systematic technique to evaluate and review documents. This includes both paper and electronical based materials. According to Bowen (2009) the analysis part of a document study requires finding, assessing, selecting and displaying data, comprising in documents. Therefore, this technique offers deeper insights into the company´s procedures and systems (Williamson, 2002). Within this thesis a document study is conducted, in order to gather information about the case company´s operative systems and documentation. The company´s reports of current and past deviations in the production processes regarding their number of occurrences and way of handling are analyzed. In order to provide a recent overview on how the company is dealing with deviations in their production processes and if there are any significant patterns of why the current deviations occur, retrieved information from documents are not older than two years. This also allows to outline the company´s development regarding improvements within this area in recent times.

3.3 Validity, Generalizability and Reliability

In this section, the trustworthiness of the research approach and the data collection techniques is evaluated by considering the aspects of validity, generalizability and reliability.

In general, validity is described as the capacity of accurately measuring what is supposed to be measured within a study (Williamson, 2002). Thereby, Williamson (2002) propose that a differentiation between internal and external validity has to be made. Internal validity is the certainty that the results are in hand of the researcher, and not caused by unknown variables. The external validity refers to the generalizability of the research results, which indicates to what extent the findings can be applied to other populations or settings. Moreover, Williamson (2002) defines the reliability of a study as the consistency of results when the same measurement is applied in a similar scenario. According to Patel & Davidsson (2011) reliability and validity are interrelated and it is not possible to exclude one and concentrate on the other. Therefore, three basic rules about this interrelation are outlined by Patel & Davidsson (2011). Firstly, high reliability is not a guarantee for high validity. Secondly, low reliability results in low validity. And finally, a high level of reliability is the foundation of a high level of validity. Therefore, it can be concluded, that it is vital to focus on all aspects of reliability and validity (internal and external) in order to be able guarantee trustworthy research results.

This thesis strives for a high degree of trustworthiness, which is be based on high levels of validity and reliability. In order to ensure a high reliability of the research results, two researchers are involved in the process, which means that all observations and interviews as well as the document study are conducted following a dual control (Patel & Davidsson, 2011). To be able to achieve a high internal validity, a triangulation of research techniques is applied. Figure 7, based on Williamson (2002), outlines the used techniques triangulation.

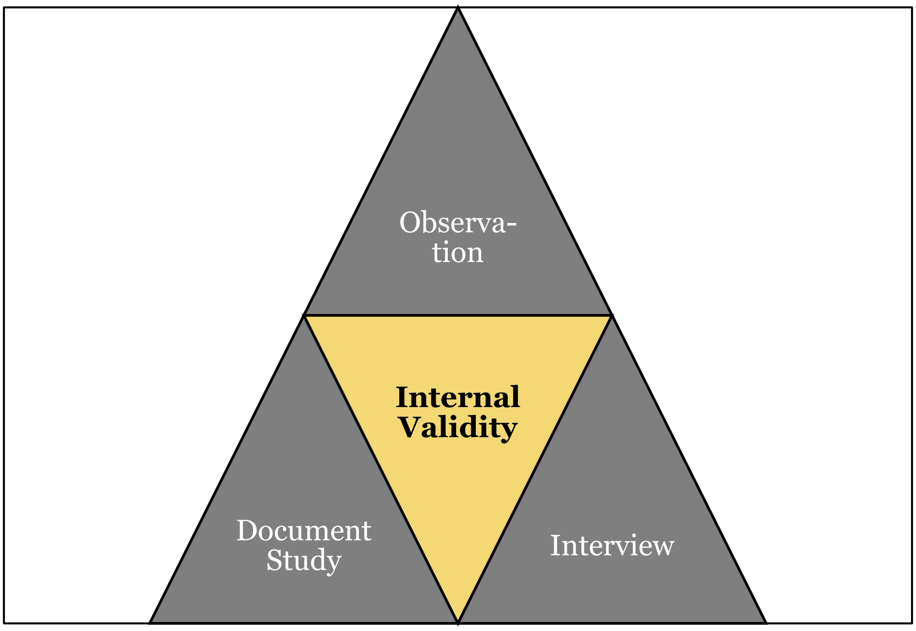

Figure 8: Technique Triangulation to enhance Internal Validity, based on Williamson (2002)

By using a minimum of three techniques within one research design a triangulation is conducted (Williamson, 2002). In this thesis, the case study design incorporates the document study, observations and interviews to answer the research questions. Yin (2009) outlines, that the external validity (generalizability) is often a shortcoming of the single-case study design. Since, this thesis also relies on a single case study design, there might be lack of generalizing the research results. However, the external validity may be improved through the extensive literature basis, which is provided in chapter 2 of this thesis. Moreover, the industrial sector of the case company also offers a possibility to generalize the results in regards to companies acting in the same industry.

3.4 Research Process

By outlining the research process in particular, the practical application of the described research design is transparently documented. This shall ensure a better understanding of the actual research steps taken by the authors of this study.

The beginning of this study´s research process is indicated by the execution of observations in order to get an overview on the present procedures and potential problems. The observations within this study are grounded on three pillars, which are the observation of the production process, the attendance of "production flow meetings" and the participation in "factory meetings". The observation of the production process has been facilitated through guided production tours and individual observations. Production flow meetings are held on a daily basis once every production shift, in order to get an update on activities and issues from previous shifts. Thereby, accidents and potential risks, quality shortcomings, scheduling and planning aspects are discussed with guidance of the shift leaders. Team leaders from each production area are participating in these flow meetings. If there are urgent and complex problems, which cannot be solved within the flow meeting, an escalation to the factory meeting takes place. Factory meetings are held once every day and managers from different departments (quality, lean/production, maintenance and logistics) as well as the shift leaders participate. Both meetings are always held in Swedish language.

The next step within the research process includes activities regarding the document study. The access to all corporate software programs has been established, in order to get essential insights into the application of software systems, which are closely interrelated with tracking deviations in production processes. To be able to understand how the software systems work the researchers got an introduction to these systems. Thereby it has to be mentioned, that the operating language of the software systems is Swedish. The information gathered from the document study and the observations provide an important foundation for the interviews. Prior knowledge on the processes and the systems are crucial to set up suitable interviews by discussing the right topics with the right respondents. Moreover, the semi-structured interviews could be adequately prepared and a fitting timeframe of maximum one hour determined.

Two managers from the Lean and Quality department and a total of seven shift and team leaders from different production areas have been interviewed. The interviewees are representatives of the whole production process by also taking the management as well as the operational perspective into consideration. The following table provides an overview on the characteristics of the conducted interviews.

Interview Number	Department/Area	Role	Interview Time
1	Quality and Lean department	Quality engineer	30 min
2	Quality and Lean department	Lean and Quality manager	35 min
3	Painting/Lacquering line	Team leader	45 min
4	Production Flow 1	Shift leader	40 min
5	Packaging line	Team leader	30 min
6	CNC	Team leader	30 min
7	“Frames” line	Team leader	20 min
8	Painting/Lacquering line	Team leader	30 min
9	Packaging line	Team leader	25 min

Table 1: Interview Characteristics

The interviews have been conducted on three different working days in order to be able to stay focused and process the received information between the interviews. This also reduced the time pressure and stress level during and between the interviews, which enhances the quality of the interviews. In order to grasp all the information during the interviews, one researcher was always taking notes whereas the other one was fully focused on conducting the interview. The role of the researchers changed after every interview. Moreover, every interview has been recorded with the permission of the interviewees. During the semi-structured interview, the concept of IQM has been briefly explained in order to be able to ask the respondents about the role IQM can play regarding the control and reduction of deviations in production processes. Thereby, it had to be ensured, that everyone has the same understanding of the IQM concept to minimize the bias for this topic due to a knowledge gap.

4 Findings

Within this chapter the findings of the observations, interviews and document study are presented.

4.1 Findings from Observations

4.1.1 Production tour

The findings, which are based on the production tours around the facility, are mainly observations referring to the physical production process. Alpha´s production processes generally consists of five steps, as illustrated in figure 9.

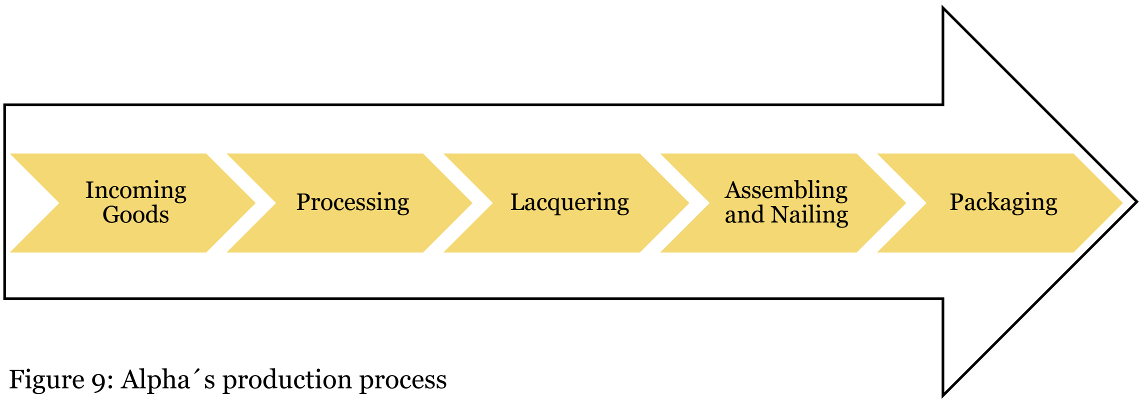

Figure 9: Alpha´s production process

The production process starts with receiving, checking and storing incoming goods. The goods are sorted into batch sizes for the next steps. They are identified according to the two different production flows, depending on the size of the product variants (one for bigger dimensions and one for smaller dimensions). The goods are processed by cutting the pieces in dimensions, burning the edges and adding the characteristics (holes and threads for upcoming assembly) to the pieces. For some variants, cutting is not applicable because they are already pre-cut by the supplier. The pieces are then lacquered, painted and dried. The edges are separately spray-painted. The next step is assembling and nailing, which depends on the product variant. For some variants there is no nailing involved, whereas other variants need thorough nailing procedures to attach the glass frames. Before the packaging of the finished products, a visual inspection is done where products are then segregated into scrap, rework and accepted goods.

4.1.2 Meetings

There were two types of meetings, for which further observations were conducted. The flow meetings are held by the shift leaders, who highlight the problems with planning, maintenance, quality and deviations for each production flow. Charts are used to visualize and track the status of the production flows. In addition, a screen that monitors the machine activities including up and downtimes, is set up at the meeting location. The factory meeting, consisting of Alpha´s management level, is based on the status report from the flow meetings and mainly focuses on the escalated problems. The discussions about these problems, which are mostly about production deviations, are focused on finding solutions and avoiding reoccurrences.

4.2 Findings from Document Study

The findings from the document study are based on two software programs, which are further referred to as program A and program B.

Program A reports the quality-related issues for the production processes, the total number of rejects, consisting of scrap and rework. The causes of scrap and rework (rejected products) are divided into 28 predetermined categories. In the last two years, the five scrap and rework categories (translated from Swedish to English) are “corner edge damage”, “bumps”, “dents”, “dirty or scratched surface” and “color smudging edge”, as seen in figure 10.

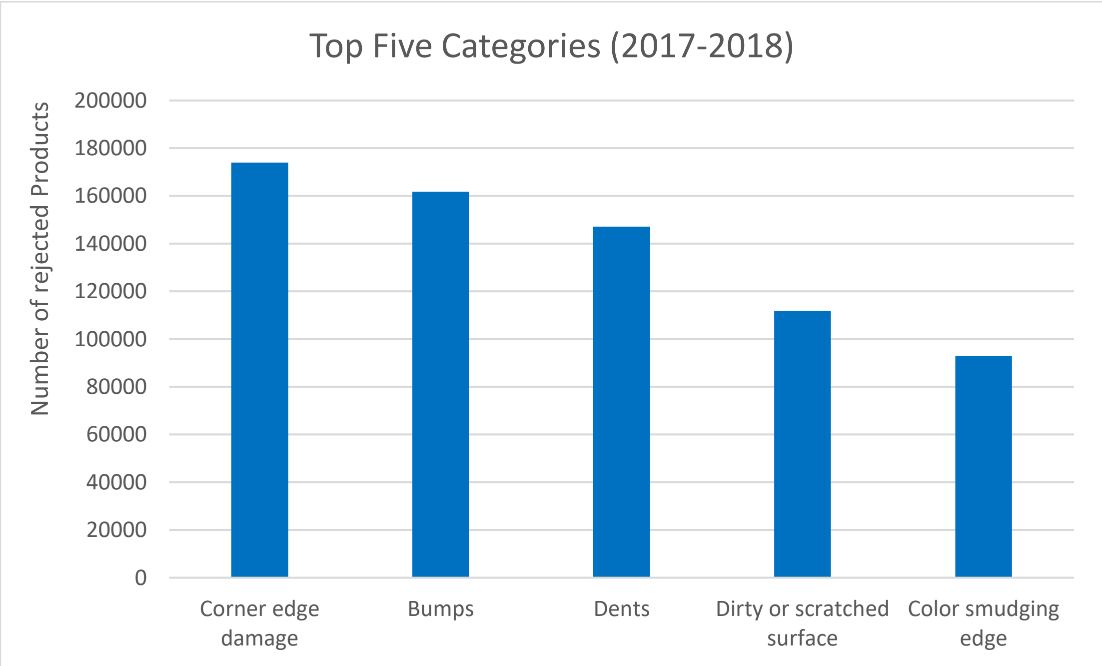

Figure 10: Top five categories of rejected products at ALPHA

The total number of rejects at ALPHA in the years 2017 and 2018 is 1,284,276 products (out of approximately 15,000,000 produced products), which are assigned to all the 28 existing categories in program A.

Furthermore, it is possible to filter the data according to dates (year and weeks), product groups, article numbers, order numbers, machines and materials in order to get an overview on specific issues within the production processes.

The weekly reject rate is shown in a chart where 7.5% reject is set as the key performance indicator for monitoring purposes. Program A also shows the total reject rate (rejected products divided by the total amount created products).

Figure 11 below, illustrates the reject rate per week for 2 years.

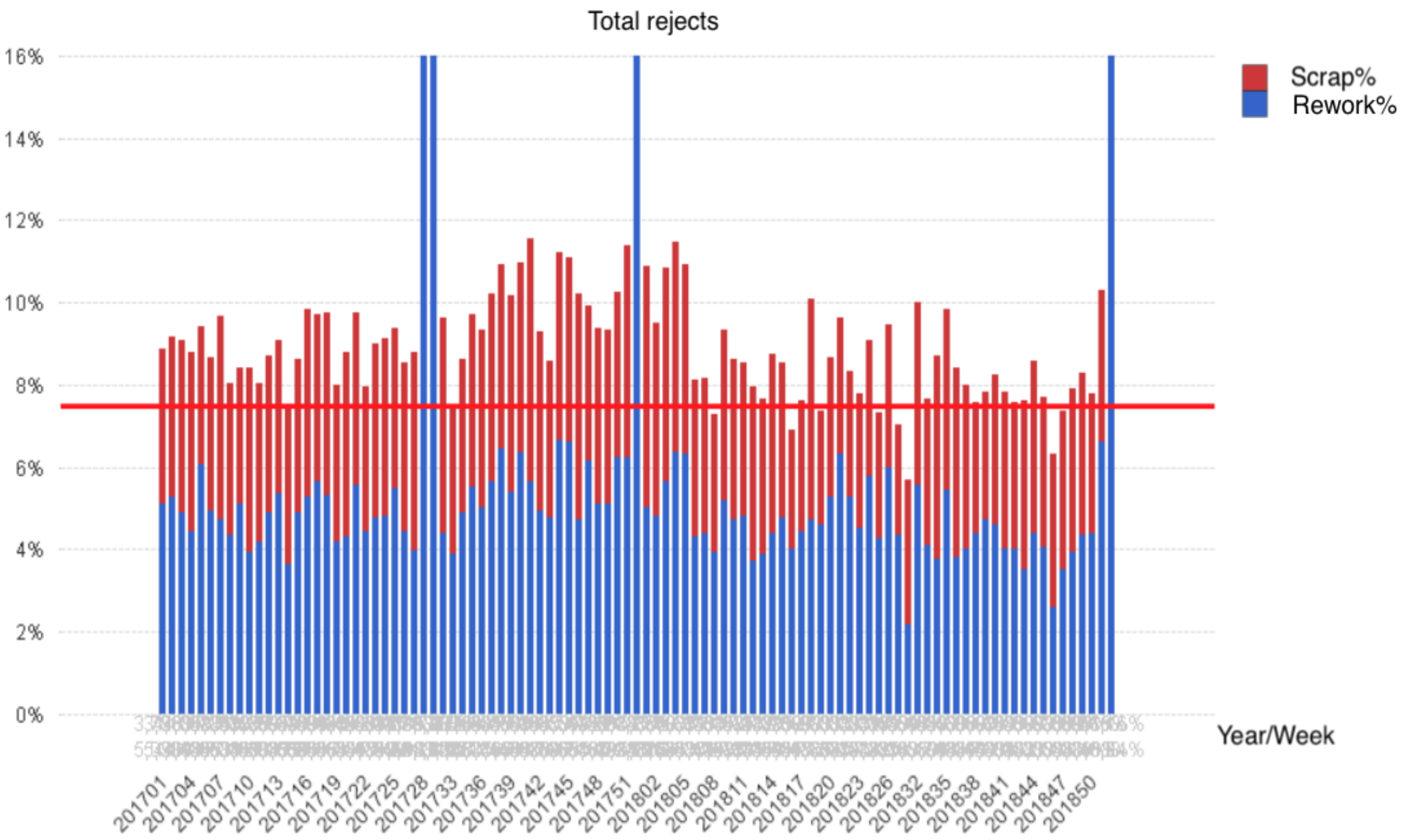

Figure 11: Total rejects at ALPHA from 2017-01-01 until 2018-12-31

The blue bars represent the rework rate and the red bars the scrap rate. The sum of rework and scrap rate result in the total reject rate of the said week´s production. Referring to figure 11, the weeks showing 16% was caused by production stops due to high number of reworks, or none or low production volume. In general, a deviation report is created every time 200 deviations per batch is recorded. The deviation reports are created and handled in the software program B.

Program B provides a user-interface for describing all the report characteristics regarding the deviation’s occurrence, as outlined in figure 12.

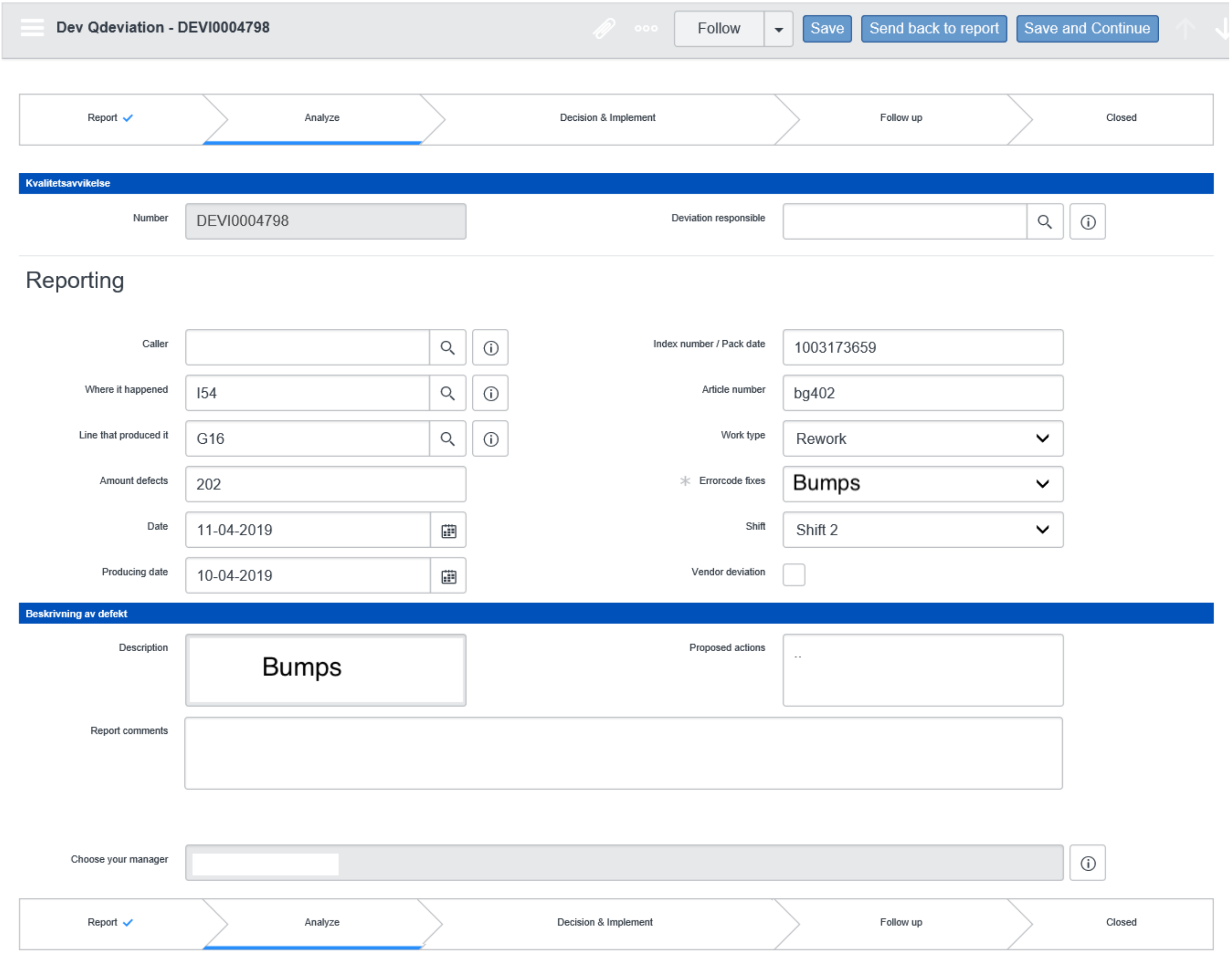

Figure 12: Deviation report system interface at ALPHA

The report contains information of the person who reports the deviation, the area of detection, number and type of defects, date detected, category of deviation as well as the work shift where the deviation is detected. Furthermore, a description of the defect is outlined. Four-phases are identified on the deviation report, general information, analyze, decision & implementation, and follow-up. The deviation report is then distributed to the responsible personnel as well as actions are suggested based on the reason for the deviation. The responsible people are then required to report the progress of the deviations, which could either result in closing the case or reviewing it as a follow-up. Another finding within this document study is the observation, that most of the deviations are described and followed-up without using all the determined prescription fields. In addition, some of the descriptions are not precisely formulated or just consisting of two or three words.

4.3 Findings from Interviews

The findings from the semi-structured interviews are based on the answers of nine respondents responsible for various sections of ALPHA´s production process.

The reasons for deviations in the production processes are outlined by the respondents with different focuses. The main reasons for deviations are quality defects of raw materials, machine malfunctions, unstable processes, and human errors. The respondents acknowledge the root-causes of the production deviations as lack of adherence to standards, lack of employee training, lack of (preventive) maintenance, and lack of thorough quality inspections. All respondents outline, that the main detection of the deviations is at the end of the line (packaging area), where the final quality check (visual inspection) takes place. According to the respondents from the packaging area, the employees are trained to adequately sort the products. Hence, the process of visually controlling the products is assessed through a Measurement System Analysis (MSA), which is used to evaluate the accuracy of the performed inspection.

Minor quality inspections in the production line are conducted, which differ timewise depending on the machine characteristics (e.g. different processing times), the process step and the operators. This is why two respondents especially highlighted, that these quality checks are conducted in varying extents with a lack of standardization, which means there is no comprehensive schedule for these quality inspections. Detecting deviations during high production volume is difficult due to time constraint. The "Standard Problem Solving" (SPS) is currently used as a technique to deal with deviations. All the respondents describe the problem-solving process as short-term actions or as "firefighting". A team leader working in the lacquering area emphasized: *"Smaller problems cause the bigger problems, which are then deviations"*. In this context, "smaller problems" refer to everyday problems, which are often not solved with long-term focus. This leads to "bigger problems", as an accumulated result of the smaller ones in a long-term perspective. Mostly the deviations are not dealt with due to the mindset of the employees that the problem will be looked at and fixed by the operation that comes next.

The data concerning deviations is collected manually through the operators by putting the information into the software systems. There is no automatic or machine-based data collection in Alpha´s production processes. Thereby, the deviations are then passed on to the responsible person or department to be handled. Based on the type of defects, the shift leaders decide on the area of the production which could have possibly caused the deviation, and hand over accordingly to the area responsible. From that point, that area or person is in charge of handling the deviation and taking actions. The communication between the different areas is often through emails, where hyperlinks to specific deviations in the program are attached. Hence, if a deviation report is modified or closed a notification is sent to the people involved via e-mail. A clear cause of the deviation is hard to identify due to late detections (often the defect products have passed the entire production process already), which also makes it difficult to determine the responsible production area of the deviations.

The respondents identified a number of solutions for the current problems in handling deviations during the interviews, such as:

- A transparent road map on how to conduct the problem-solving process
- Adopt an approach for long term solutions.
- Support for the responsible people in problem-solving (additional resources)
- (Re-)implementing overarching meetings with involvement of the whole flow and the support departments
- A better application of Key Performance Indicators (KPIs) and an improvement in quality performance measurements.

Even though, respondents were unfamiliar with IQM at the beginning of the interviews, the reaction to the concept of IQM, upon clarification by the thesis workers, were solely positive with regards to production deviations.

The quality engineer stated: *"Visualizing and understanding information is the future"*. Whereas, the shift leader of production flow 1 stated: *"Deviations are caused by assumptions and guesses, IQM will allow you to base your decisions on facts"*.

The popular opinion on the role of IQM in handling deviations was the creation of a higher degree of transparency regarding the information flow and knowledge management, which would lead to solving problems in shorter time and fact-based decision making. Further, a better understanding of the connection between the deviation and its root-cause could be created through the intelligent use of data, which could make the maintenance activities and the work preparation easier to perform.

In addition, all of the respondents agreed that IQM could be applicable at ALPHA´s production line. Some of the respondents also explained that ALPHA had used cameras for automation of the quality inspections a couple of years ago, but it was not successful. The cameras were too sensitive and therefore could not differentiate between a tolerable and a major deviation.

5 Analysis

Within this chapter, the findings of the study are analyzed in order to provide the basis for the discussion.

Between January 2017 and December 2018, the KPI of 7,5% reject rate was not achieved. A high fluctuation within the production performance, which is visible in figure 11, was identified as a result. This shows that ALPHA is currently dealing with significant reoccurrences of deviations which require further investigation.

By linking the HTO model, based on Carayon (2006) to the findings of the data collection, an overview on the reasons for deviations in production processes is outlined in figure 12. This represents the basis for analyzing the gathered data as well as describing the interrelations of the various reasons for deviations.

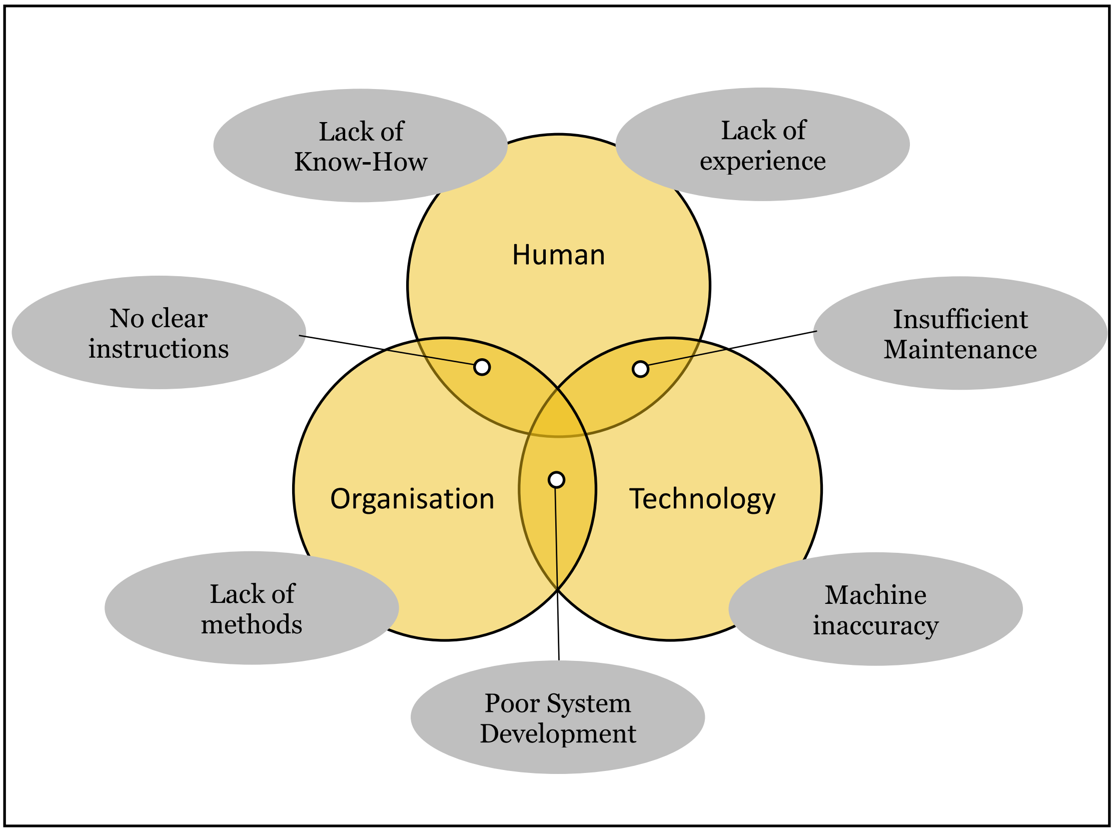

Figure 13: HTO concept with reasons for deviations, based on Carayon (2006)

Based on the observations, the document study and the interviews, the reasons for deviations in production processes can be found in the segments of the HTO concept and within its interfaces.

Human (H):
The deviations in production processes, caused by human actions or errors are mainly associated with *lack of know-how* and *lack of experience*. At ALPHA, it

is found, that the possible root-causes of human errors were due to insufficient training and lack of clear instructions. It was clear among most of the responses, that the knowledge of the respondents was solely linked to their work area. Questions on previous or follow-up processes could only be poorly answered. Consequently, the employees do not have a good holistic understanding on the whole production processes. This leads to shortcomings regarding interfaces between the production areas, which facilitate the (re-)occurrences of deviations in production processes.

Technology (T):
Many deviations were directly caused by machines due to malfunctions. These malfunctions are often triggered by *insufficient maintenance*. Machines are repaired as they break down, instead of preventing the breakdowns. Hence, fluctuating machine performances (re-)occur causing deviations in the processes.

Organization (O):
The interviews also underlined a lack of adherence to *standards and methods* among the employees. As it was found that most deviations are dealt with short-term solutions or large extents of firefighting activities, the root-cause analysis and problem-solving process is not standardized and effectively communicated among the employees. It was found that there exists an urgent need to improve the existing KPI´s and to create performance measurements. This indicates a lack of long-term organizational planning. Furthermore, there are no significant continuous improvement activities in place to handle the deviations in production processes over the past years. This can be linked to *poor system development*, which lacks a long-term improvement strategy. Due to the organizational structure of ALPHA within the global group, which is producing for a single customer, who belongs to the same enterprise, there is less competition and lack of requirements from said customer.

Interfaces:
By analyzing the three segments of the HTO approach, it becomes clear that the reasons for deviations in production processes cannot solely be categorized through focusing on one segment at a time. Every segment is dependent on the other, therefore it is crucial to take the interfaces between these segments into consideration. In the interviews, the respondents named different reasons for deviations in the production processes, which emphasizes the importance of the HTO interfaces. Consequently, the combination of at least two segments are often the actual root-cause of deviations in ALPHA`s production processes.
The information and knowledge flow represent the overarching connection between all the segments. If there is a shortcoming concerning the necessary information or required knowledge within interfaces, deviations are most likely to (re-)occur.

Based on the interview data, quality practices and tools, which are used at ALPHA are either not clearly communicated or not entirely implemented. It was noticeable that there was no clear response on Quality Management approaches are adopted for controlling the deviations.

Some rudimentary parts of Six Sigma tools that are implemented could be identified, for example, MSA, Control Charts and SPS. In addition, the PDCA cycle is used to keep track of the status of the problem-solving process (used in the software systems as well as on the quality charts).

The subject of IQM was perceived as positive and promising, based on the description of IQM provided by the interviewers. Based on the responses from the interviews, IQM could facilitate the distribution of information and knowledge, which could also support the problem-solving and decision-making process. Furthermore, it can be outlined, that the current focus of the employees is more on the physical processes and products rather than on support programs and software systems. With IQM as a concept of channeling information and discovering knowledge, the use of software systems might be eased and the employee´s mindset might also move towards an understanding of the digital data.

6 Discussion

Within this chapter the analyzed findings are discussed and evaluated in prospect to the purpose and the research questions of this study. The purpose of this thesis is to explore the concept of IQM in connection with ways to control and reduce deviations within production processes

6.1 What are the reasons for deviations within production processes?

Asilahijani (2009) emphasizes the roots of deviations as a relation to process inputs which fluctuate as the process operates. Hence, it is crucial to take the input factors and influences on the processes into consideration in order to be able to outline the reasons for deviations in production processes. The main impacts on ALPHA´s production processes have been found and highlighted in figure 12, where the three segments and interfaces of the HTO model based on Carayon (2006) are incorporated. Lindroos (2009) also argues for the direct correlation of human errors and machine malfunctions with the (re-) occurrences of deviations in production processes. Moreover, Ahram & Karwowski (2018) relate human errors to a lack of information, experience, methods and training provided for the employees acting in the predetermined production system design. These shortcomings, that consequently lead to human errors have also been found at ALPHA, which might be directly correlated to the high total reject rate of products in ALPHA´s production processes over the past years. In addition, machine malfunctions caused by poor maintenance are identified as another reason for the (re-)occurring deviations in ALPHA´s production processes. Alsyouf (2007) also highlights the interrelation of machine malfunctions and poor maintenance. Furthermore, Alsyouf (2007) defines poor maintenance as the absence of maintenance planning and strategies, which is in line with ALPHA´s insufficient application of preventive maintenance.

Additionally, literature provides other perspectives regarding the reasons for deviations in production processes. Fleischer et al. (2014) mention new and innovative processes as a trigger for uncertainties, which as a consequence could result in occurrences of deviations in production processes. Furthermore, Schweinoch et al. (2016) point out that deviations in production processes could also be caused by the introduction of new products or geometric changes for existing products. Generally, it can be said that decisions taken in earlier development stages (product and processes) are substantial factors regarding the occurrence of deviations in production processes.

These perspectives on reasons for deviations in production processes haven´t been encountered during the data collection at ALPHA. This does not necessarily mean, that these factors do not exist at ALPHA. The reasons for deviations in production processes are very complex and often a combination of various factors. Therefore, the occurrence of deviations in production processes always needs to be evaluated based on company characteristics such as size, grade of automation, available resources as well as the specific production inputs. Hence, the reasons for deviations in ALPHA´s production processes can be used as a practical example for other companies. Moreover, the understanding of the HTO model can provide a solid basis for specifically investigating and comprehending the complex interrelations of the possible reasons for deviations in production processes. Therefore, it is vital to get a holistic overview on the production processes and potential root-causes for deviations. By having an understanding of where deviations in production processes are caused, actions on controlling and reducing of deviations are easier to plan and execute.

6.2 How can deviations in production processes be reduced and controlled?

Many decades of research in QM provide an extensive literature on how to ensure product and process quality. This also includes principles, practices and techniques according to Dean & Bowen (1994), which can be applied to handle deviations in production processes. An overview on the most important QM principles, practices and techniques has been outlined in figure 2.

The QM principles, which are based on ISO 9000 (2015), represent the foundation of all quality-related activities. During the data collection at ALPHA some of these principles could be identified, but are either missing crucial elements or are insufficiently applied. Relationship management, top management commitment and process approach are principles, which are adopted to ALPHA´s corporate culture. The relationship management is facilitated through the connections between the subsidiaries of the whole ALPHA group. The top management commitment has been indicated as gradually improving due to the fact, that a lot of projects have been initiated by the management to enhance the production performance. Thereby, a process approach is mostly followed, which enables ALPHA to optimize the system and its performance based on the knowledge on how outcomes are created by the existing production system. Customer focus, continuous improvement, employee involvement and fact-based decision-making are principles, which are poorly implemented at ALPHA. The customer focus needs to be evaluated by following an internal approach in this case, since ALPHA´s customer is in the same group. Moreover, the consecutive production areas can be seen as internal customers with regards to the previous ones. A lack of the necessary customer focus has been found through the interviews. The mindset of the employees within the different production areas is often limited to their responsible areas and not considering the next production steps (internal customers). This can also be linked to a shortcoming of employee involvement and integration. Moreover, a lack of continuous improvement and fact-based decisions was also evident. Instead of adopting continuous improvement strategies, long-term focus and fact-based decisions, ALPHA often falls into patterns of “firefighting”. In order to be able to reduce and control deviations in production processes the QM principles need to be effectively implemented and sustained as a basis for the application of QM practices and techniques (Dean & Bowen, 1994).

To a certain extent, the adoption of QM practices and techniques has been found at ALPHA, in order to deal with (re-)occurring deviations in their production processes. But it could be said, that no practice is completely integrated within ALPHA´s processes. Parts of Six Sigma or ideas related to Quality Circles and TQM have been discovered within ALPHA´s procedures. MSA, Control Charts and SPS are techniques, which are applied at ALPHA in the scope of Six Sigma. According to Zhang et al. (2011) Six Sigma is an improvement practice for deviations in processes, where five views and five core elements can be differentiated. ALPHA is clearly focusing on the metric measurements such as process capabilities and control charts with prospect to the goal of a maximum 7,5% reject rate. But shortcomings regarding the application of sufficient techniques, project management activities and the dedicated Six Sigma organizational structure are detected. Consequently, ALPHA has no concrete Six Sigma implementation, which is seen in the lack of Green, Black and Master Belt projects. Furthermore, DMAIC is not applied, which is the basic technique used in a Six Sigma framework. Additionally, no patterns of Lean or Lean Six Sigma, as a combination of the two QM practices, has been explicitly indicated at ALPHA. Smith (2003) outlines Lean and Lean Six Sigma as a potential "best practice" (if efficiently implemented) for reducing deviations, leading to rework and scrap in production processes.

Moreover, thoughts on Quality Circles can be seen within ALPHA´s operational structures. Blaga & Joszef (2014) describe Quality Circles as a practice, where the ownership of quality is distributed among the employees. ALPHA distributes the accountability for deviations to the responsible production area. Hence, the employees of the production area where the deviations are caused are responsible for the problem-solving process. Juran & Godfrey (1999) see Quality Circles as a problem-solving practice where cross-functional quality issues are solved with the support of specifically formed quality teams. These quality teams need to be developed, which involves training and learning (Juran & Godfrey, 1999). According to Patyal & Maddulety (2015) training and learning is key to developing employees, which positively affects the operational performance and therewith the process quality. Moreover, Flynn et al. (1995) emphasize skill-improving training for employees within the scope of continuous improvement as a guide towards a higher commitment for quality among the employees. ALPHA is lacking in these aspects of training and in generating a mindset of continuous improvement with a commitment to quality practices and techniques.

Rudimentary parts of TQM could also be identified in ALPHA´s procedures. Especially the application of the PDCA cycle, which is according to Jagusiak-Kocik (2017) an often-used technique for continuous improvement within a TQM framework, has been frequently found in ALPHA´s operational processes. There are a lot of different ways to apply TQM within a company. The most suitable and practical TQM solution is always dependent on the characteristics and the goals of the focal company (Oakland, 2003). This context dependency is valid for all the QM approaches due to uniqueness of every company. Hence, production deviations can be controlled and reduced by conducting different approaches because there is no generic solution.

Taking all of this into consideration it can be stated, that ALPHA is currently working with some of the QM practices and techniques. But ALPHA is lacking in the thorough adoption of most of these practices and techniques, which might be the reason for the reoccurrences of deviations in their production processes. This does not mean that the QM practices and techniques do not have an impact on controlling deviations, but rather haphazard implementation does not work. Time and commitment are needed in order to fully implement the required practices and techniques. Therefore, to be able to control and reduce deviations in production processes, the appropriate QM practices and techniques must be effectively implemented for a and lasting effect in the company.

There are various reasons why it is crucial to effectively control and reduce deviations in production processes. Thereby, a connection to the subject of sustainability has to be drawn. ALPHA´s deviations mainly result in high scrap and rework rates. According to Jayal et al. (2010) scrap and rework are unwanted activities contributing negatively to environmental and economic sustainability. Scrap and rework lead to additional costs due to extra usage concerning resources, additional machine utilization and energy input. The environment is negatively impacted with the additional use of energy and materials as well as through the waste creation of scrap products. As a consequence, the scrap products must be disposed, which is often done by burning rather than recycling and especially results in air pollution. Khidir & Zailani (2009) outline, that companies focusing on sustainability in production processes, which includes environmental, economic and social aspects, generate a competitive advantage by reducing the costs of production as well as improving the level of quality. Therefore, researchers emphasize the implementation of sustainable production concepts, which often involve the 6R approach (Jayal, et al., 2010). The different aspects of sustainability always need to conscientiously be taken into consideration when focusing on deviations in production processes. Thereby, a corporate culture must be facilitated, where the level of quality in processes is ensured while also "*meeting the current needs without compromising the ability of future generations by optimizing the usage of resources"* (Brundtland, 1987).

6.3 What role does the concept of Intelligent Quality Management play in handling and reducing deviations in production processes?

As discussed earlier, it is vital to sufficiently handle deviations in production processes for numerous reasons. The manufacturing industry is continuously developing, which can be seen through the evolution from Industry 1.0 to Industry 4.0 over the past centuries (Xu, et al., 2018). Therefore, it is necessary to also take new concepts and approaches into consideration. IQM is one such new concept which could be developed from the existing QM systems in order to effectively control deviations in production processes.

Wang (2009) mainly describes IQM as an approach of integrating information from quality control and QM practices to a database. Data mining and knowledge discovery techniques are applied in this database in order to facilitate fact-based decision making on quality-related issues. Moreover, Wang (2009) emphasizes current QM practices, especially TQM, as the foundation of IQM. Here, it can be realized, that there are many QM practices and techniques, which could be useful for the implementation of IQM. The practices and techniques could differ from company to company, depending on the different corporate characteristics and existing systems. Positive reactions towards IQM found in this study, although favorable, could also indicate that it is common for practitioners to express enthusiasm for a new and structured system. Referring to ALPHA´s unsuccessful attempt at automation of inspection with use of cameras, the role of IQM can be exemplified. IQM can only work with automated inspection, which means the implementation of cameras or comparable sensor systems is essential for the concept of IQM. Consequently, IQM could have facilitated the channeling and filtering of the information, which could have helped the system to adopt to the camera introduction. A general suggestion for ALPHA could be to comprehensively take the elements of Industry 4.0 into consideration, which could also enable the implementation of cameras or sensors and in consequence the concept of IQM. Following a more holistic approach by considering more elements of Industry 4.0 could lead to a more successful next attempt regarding automated inspection.

Fleischer et al. (2014) outline, that new and innovative processes can lead to bigger deviations due to uncertainties and lack of knowledge regarding the new processes, which might have also been the problem with the camera introduction at ALPHA. Furthermore, IQM as a new concept entails potential risks as well. Hence, IQM could not only positively influence the existing processes, but might also create new sources of deviations. When discussing the applicability of IQM at ALPHA, there are two perspectives to consider. On one hand, ALPHA´s production line is fully-automated and there are existing software structures in place, which could facilitate the implementation of IQM. But on the other hand, all quality checks involved visual inspection and a previous trial of installing cameras as a quality control system failed due to camera sensitivity. Therefore, creating an interconnected and smart production system for automatic data collection for an intelligent software system involves obstacles.

Besides the outlined risks and obstacles, IQM involves many valuable elements and potentials to deal with deviations in production processes. The interviews have outlined, that IQM might support the problem-solving and decision-making process, which could consequently reduce the reoccurrences of deviations. Moreover, necessary information and knowledge could be provided and channeled more efficiently, which would save time and would support distributing the right information to the responsible people. Hence, minor mistakes can be avoided, which could have elsewise resulted in deviations. Based on the findings of this study, a framework for the application of IQM is visualized. This framework is based on the implementation of QM practices, and incorporating suitable QM techniques. The IQM perspective is added through data mining in the software systems, programs A and B, and the effective interconnection of the physical and virtual world. Thereby, essential aspects of Industry 4.0 such as CPS, IoT and Big Data shall be integrated in order to connect the existing practices and techniques with the concept of IQM.

The framework for the application of IQM is illustrated in the figure 14.

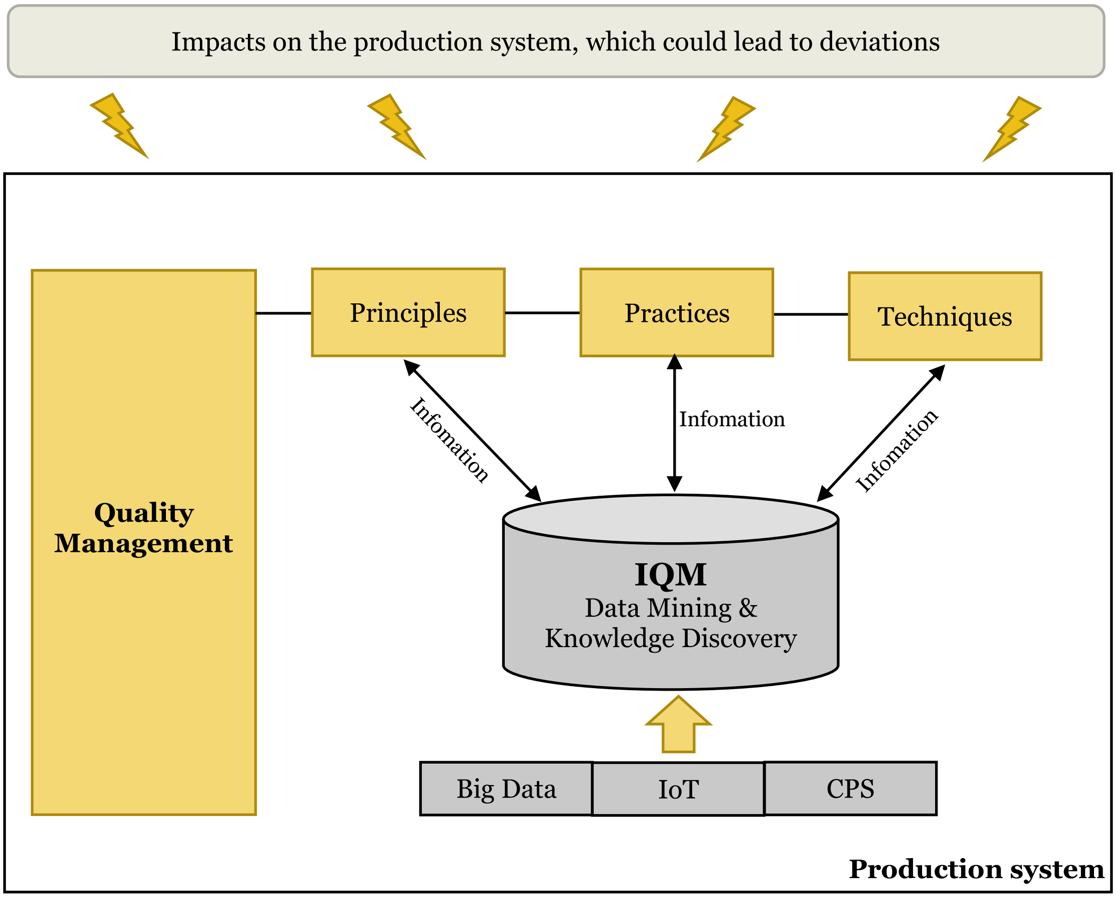

Figure 14: Framework of IQM´s role in dealing with deviations

Deviations occur and affect the production system and its processes. QM, as in the principles, practices and techniques, are applied to deal with deviations. The evolution of QM, which includes the elements of Industry 4.0, leads to a new perspective on how to effectively handle deviations in production processes, in which IQM can be integrated in the existing QM systems. Therefore, there is a strong interdependency between IQM and the QM principles, practices and techniques, which determines the characteristics of the modified QM system.

Generally, this framework is based on the understanding, that IQM is interconnected to all QM activities of a company. This connection might differ depending on the focal company. That is why the requirements of the IQM system have to be designed according to the company´s characteristics, resources and corporate goals. It is important to keep in mind, that the framework provides a basis and shows the direction, but do not offer an overall solution. If the framework is poorly implemented, the results could be even worse than before the implementation. It can be summarized, that with an adequate application of the outlined framework, IQM can play an important role in controlling and reducing deviations in production processes.

7 Conclusion

The purpose of this thesis is to explore the concept of IQM in connection with ways to control and reduce deviations within production processes. Thereby, a framework on IQM´s role with regards to handling deviations within production processes has been created.

Deviations in production processes (re-)occur due to human, technological and organizational shortcomings. Moreover, the interfaces between these three segments need to be taken into consideration because the deviations are often caused by a combination of at least two segments. It is crucial to get an understanding of the root-causes of deviations in production processes in order to be able to take adequate actions. The HTO approach can be used to identify the root-causes, which facilitates the adoption of appropriate QM principles, practices and techniques in order to control and reduce deviation in production processes.

The concept of IQM can be integrated into existing QM systems by adopting vital elements of Industry 4.0. IQM can support the control and reduction of deviations in production processes, but also entails a risk of causing more deviations if it is poorly implemented. The created framework can provide an understanding on what role IQM could play in this context and how IQM must be connected to the QM principles, practices and techniques.

This thesis provides a good foundation for future research concerning the concept of IQM. Thereby, the research goal must be to conduct multiple case studies in order to verify the obtained results in different settings. Moreover, the implementation of IQM to a company´s operative system, which was not part of this thesis, has to be executed and evaluated to be able to make conclusions on the practicability of IQM. In addition, IQM is a concept, which could include more potentials beyond the impact on deviations in production processes. These potentials need to be further investigated.

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Appendix

Interview questions of the semi structured interview

1. What are the main reasons for deviations in your production process?

2. Where do you detect the deviations?

3. How do you control your deviations today?
   Use of Quality tools/practices?

4. Are you focusing on short term or long-term solutions, regarding deviations?
   Continuous improvement?

5. How do you collect the data on deviations?
   Manual or Automatic?

6. How do you follow up on the collected data?
   Software systems?

7. Where do you see the potentials for improvements in dealing with deviations?

8. Are you aware of new concepts within Quality Management?

Short introduction to Intelligent Quality Management (IQM):
IQM is an approach to embrace data mining technology and knowledge discovery in databases. Thereby, the fundamental idea is to integrate the gathered information from quality control and quality management practices to a primary database and implement an IQM system including assistant decision-making based on data mining.

According to Wang (2009)

9. What role do you think the concept of IQM can play in controlling and reducing deviations?