UNIVERSITY OF VAASA

SCHOOL OF TECHNOLOGY AND INNOVATION

INDUSTRIAL SYSTEMS ANALYTICS

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IMPROVING SUB-ASSEMBLY PRODUCTIVITY, EFFICIENCY AND QUALITY WITH LEAN SIX SIGMA TOOLS

A case study

Master's thesis for the degree of Master of Science in Technology

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VAASA 2019

ACKNOWLEDGEMENTS

This thesis has been done in cooperation with several people. First, I want to thank the company and the General Manager or providing me this opportunity a long time ago and willingly accepting our request to do another case study for another course at the University. That cooperation brought on this possibility later on. I want also to thank my instructor, who has shown interest in my work and steadily guided me during this process and challenged me in a positive way. From the company. I'd also like to thank the General Manager for Innovation Deployment, who have shown his support by encouraging me. I'd also like to thank the University of Vaasa and the personnel who has helped me with arranging my studies, which did not go according to the initial plan, so to say. My supervisors Jussi Kantola and Ari Sivula also deserve a recognition for their work. I'll express my gratitude especially to Ari, who have inspired me during my master's studies with energetic and educational courses.

This Master's thesis is the pinnacle of a long story, in which there have been countless of persons supporting me during my life and responding to my curiosity. Of these people I'm especially grateful for my family, who have always been genuinely encouraging in everything I've pursued. But most of all, I'm overwhelmed by the uncompromising support that my wife has showed me during this process – in good and bad times.

Leo

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SYMBOLS AND ABBREVIATIONS

BB – Persons with the Six Sigma Black Belt competence

CTP – Critical to Process factor

CTQ – Critical To Quality

LCL – Lower Control Limit

Routing time – Assembly time consisting of preparations and assembly + 12% for breaks

MES – Manufacturing Execution System

UCL – Upper Control Limit

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School of Technology and Innovations
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Topic of the Thesis: Improving sub-assembly productivity, efficiency and quality with Lean Six Sigma tools.
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Degree: Master of Science in Technology
Major: Industrial Systems Analytics
Year of entering the University: 2014
Year of completing the Thesis: 2019 **Pages:** 84

ABSTRACT

This thesis is written for the company as a case study for improving the productivity, efficiency and quality of a module assembly. The main objective of the study was to investigate the current situation of the assembly process, so that necessary improvements could be done. In parallel with this objective, a project called Andon 2.0 was done. The purpose of this project was to implement a system, which would make it more convenient for the operators to report progress and deviations in the process.

The methodology used in this case study is based on the DMAIC cycle used in Lean Six Sigma. Prior to the cycle, a theoretical background about the current situation, terminology and methodology is given.

In the Define phase the framework with the objectives and limitations for the study were formed. The cycle continued with the measure phase, in which the data from the internal ERP system was sourced. The results chapter contains the Analysis phase where the process is analyzed statistically with the Pareto principle and by multiple regression analysis. The assembly process is also monitored directly. The Improve phase contained improvement proposals for all three aspects considered in this study. The last phase was customized for including the motivation, evaluation and design of the Andon 2.0 pilot version.

The process contains currently many flaws, of which the inconsistency for notifying logistic personnel of a deviation due to logistical errors conveys inefficiency. This issue was dealt with by proposing a design for the Andon 2.0 pilot version, which reduces the response time and provides process developers more accurate date for future improvements.

KEYWORDS: Smart manufacturing, Lean Six Sigma, DMAIC, cellular manufacturing, Andon.

INTRODUCTION

“The only thing that is constant is change”, is a famous quote by the Greek philosopher Heraclitus. Since he stated this conclusion it has been re-quoted thousands of times. One of those who understood the significance of this insight was the Director of Digitalization for the company (Source 1. 2018). In that text, he concluded that the technology in both the both sectors are rapidly evolving, and we are in the middle of a technological revolution. The Director of Digitalization clearly spelled the situation with the shift towards digitalization, but this insight applies on all segments of technology today.

Technology corporations are facing ferocious competition in the current global market. The customers constantly raise the expectations on both quality, fast delivery and price. Meanwhile the global warming is an inevitable factor that affects all fields in one way or another. This is why the words of Heraclitus are a necessity to apprehend, in order to be able to survive in this challenging environment.

The company has demonstrated a capability to be in a continuous mode of change, by investing heavily in both product and process development. We see frequently new innovative products and solutions which are presented by the company. The initiation of the new innovation factory is also a leap in the same direction. But one should not either forget the smaller improvements that are achieved inside the current facilities and production methods. At the present there is done smaller, but not necessarily less significant steps forward, which together have a significance on the possibility for the company to stay ahead of the game.

By addressing the productivity, efficiency and quality in the module assembly, this thesis is a microscopic fragment of the whole picture and will hopefully lead to better competitiveness for the company.

1.1 Research background

The factory is currently undergoing a serious shift towards smart manufacturing due to the recent investment in the same city, a new innovation factory This change will entail changes in the current ways of assembling products in the manufacturing. Constant monitoring and optimization of the processes will be an even more self-evident part of the manufacturing in the future.

In 2015 the company introduced a revolutionizing new product – the product, a platform that the company has high expectations on. These expectations are not unwarranted, because the product is the most efficient product type ever and has shown impressive performance in several other aspects (Source 2. 2015). The product family will be preliminary manufactured in the same city, which require a workable and effective production. Currently the product manufacturing faces multiple challenges and a lot of work is still to be done before the product type can be manufactured in the same or bigger quantities as the older products are manufactured today. Thus, it is reasonable to focus on the manufacturing processes of the product.

A key part of the product is the module, which supports the product and enables a higher overall performance. To assemble a module takes currently several weeks and it is a challenging project in many aspects. In order to respond to the need from the market with several hundreds of new products in the future – we need to radically improve the efficiency of the module manufacturing. Currently the company has acted against this challenge by initiating a second assembly cell for the module. So far, all the manufactured modules has been assembled in an older product pilot assembly. In this new assembly manufacturing cell only modules are to be assembled. (Source 3. 2019.)

The assembly process of to this point manufactured modules is recorded and documented to the internal ERP-system MES. Therefore, a satisfying amount of data is available and will be assessed by utilizing the LSS DMAIC procedure. This dissection should provide deeper understanding of the underlying challenges in module assembly. (Source 3. 2019.)

At the company there is currently an ongoing project called a system for data integration. Which aims to address all the information that is measured and collected from the company's manufacturing units to one single pool. From this pool it would be possible to source out desired data and present it in a comprehensible way. As a part of this significant project a so-called Andon 2.0 is introduced, where the vision is to create a tool that the mechanics could use in the manufacturing, which would ultimately replace the need to insert data to the MES via a PC. A desirable goal would be to only utilize this system in the innovation factory, and thereby enhance smart manufacturing and increase productivity without cutting down on the amount of collected data. (Source 3. 2019.)

In this thesis the target is to increase productivity, efficiency and quality. In order to strive for this target, we will design a simple pilot version of the software, which will collect and redirect the information to the MES, the system for data integration and finally to the general display, where it then will be displayed in a comprehensible manner. The focus will be on designing the functionality, so that it is usable for the mechanics, minimalistic, but makes it possible to source the required information. In our study we will also evaluate different options for sending a notification for a specific deviation. The extent of the functionalities of the Andon will not be as broad as the functionalities in MES, instead the focus will be on designing an executable pilot version, which is possible to configurate to the module and to get the mechanics and logistics personnel used to the procedure. A separate team is working on the the system for data integration itself, which will be able to provide support in both planning the functionalities as in coding the program itself.

1.2 Problem statement

The product has passed the piloting phase and several contracts are signed where the products should be manufactured and tested during 2019. The product is an platform, which can be built in multiple configurations and mainly in three different types: The type 1, the type and the type 3. (Source 3. 2019.)

The sector 1 is estimated to create the highest demand for the product in the next years. Thus, the product type 1 is the product predicted to see highest increase in demand. (Source 3. 2019.)

The manufacturing of the module was previously carried out in a cell assembly with two units close to the pilot assembly. Due to the increased manufacturing volumes the product will also be manufactured on the assembly line, which is in a separate building. These changes lead to the creation of two new cell assembly units in the same building as the assembly lines. This arrangement would increase the capacity of the module assembly and decrease the need to arrange challenging transfers between the two buildings. (Source 4. 2019.)

According to the Source 4 (2019) the assembly of the one module has a routing time on 166,79 hours, which will be regarded as a benchmark in this the present state analysis. Beyond the routing time, the time that the module is in the cell is the time that has the highest negative impact on the productivity of the assembly unit. For the module this time has been between 12 and 75 days according to internal measurements. In the data derived from MES, the average assembly time is notably higher. These findings are analyzed later in chapter 3, in the present state analysis.

With the current assembly pace of the module it is not possible to achieve the set target volumes for product manufacturing for 2020. Therefore, the assembly process requires improvements in order to increase productivity. By assessing the manufacturing process considering improved productivity, it is reasonable to aim for increased efficiency and quality as well. (Source 3. 2019.)

The system for data integration project was initiated during 2018. The target is to collect data from multiple sources to one pool, from where it can be sourced and displayed on the general display. As a part of the system for data integration project a team has been working in collaboration with the factory 2 on a module, driven by a Raspberry Pi, that would enable the mechanics to call for support in forms of quality inspectors or logistics personnel when needed. This module is called Andon 2.0 because it will partially work as a successor to another production improvement tool called Andon. (Source 5. 2019.)

The exact functionalities and applications of Andon 2.0 are unclear to some extent but progressing. One proto version of the module is installed in the pilot assembly, where it will be tested to request the quality inspector and logistics personnel. The Andon 2.0 interface has not been adopted to suit the needs of the module assembly cell yet. Nor does it have the functionalities to initiate and end activities of the assembly process. (Source 5. 2019.)

1.3 Objectives and research questions

This thesis has essentially two different objectives. Of which the first one is the to assess the module assembly process, so that the increased product delivery volumes can be met by the factory unit. The assembly is targeted from three different perspectives: Productivity, efficiency and quality. This is done by monitoring the process and by addressing the MES-data utilizing LSS methodology, which makes it possible to define the problematic activities and phases of the assembly process. By combining those insights with the deviation data, it should be possible to generate a perception about the severity of the deviations. By having a better understanding of the crucial deviations, it is apparent to do corrective actions, which will increase the quality of the product and reduce waste from the process. Non-corrupt data is a condition in order to achieve factual conclusions that would provide value. Therefore, the data will be validated by comparing it to the research the process developer carried out. (Source 6. 2019.)

The second objective of this thesis is to research if Andon 2.0 is suitable for the product assembly process. This objective is achieved by designing a simple interface for the module that enables the proper data to be obtained from the mechanics during the assembly process. The target is to use the Andon 2.0 from start to end during the assembly of a module. The long-term goal is that the module would displace the need to insert data into the MES via a PC. If it is found that it is technically or practically too challenging to create program which collects the data and forwards it to the system for data integration, then the focus will be on optimizing the remaining functions of the Andon 2.0. The meta-target for the second objective is to determine if the Andon 2.0 is suitable for this particular use in the assembly process.

These objectives are assigned in our research by finding answers to the following research questions:

1. Which measures can be done in order to increase productivity, efficiency and quality of the module assembly by doing a Lean Six Sigma DMAIC-cycle?

2. How could the Andon 2.0 be implemented in module assembly in the factory in such a manner that it would increase the possibilities to monitor the assembly process?

1.4 Structure of the thesis

This thesis is structured mainly in the chronological order of the research, which is presented in the figure 1 visualizing the research design. It follows the classical structure of a thesis with an introduction, theoretical framework, methodology, analysis and discussions & conclusions. This framework was suitable for the purpose of answering the research questions with a certain amount of adaptation to this specific case study. The thesis consists of five chapters: An introduction to the topic and the research, The theoretical framework regarding the issue and tools used, A chapter describing the methodology which contains the Define and Measure phases, A Results chapter containing the Analyze, Improve and Control phases and the last chapter with the results, discussions and proposals for future studies.

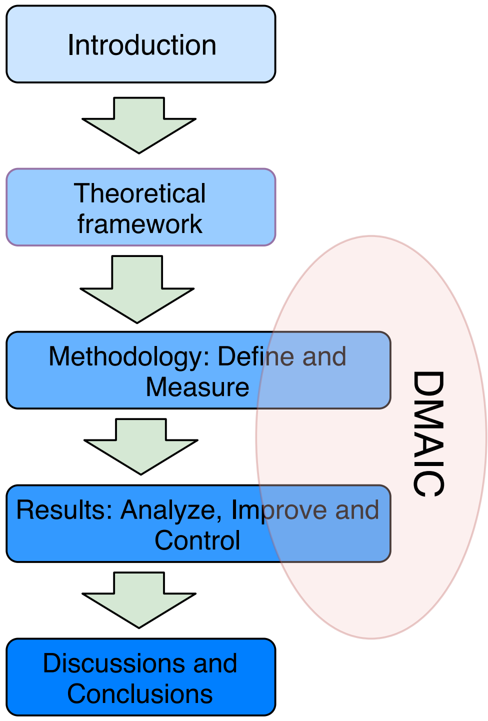

Figure 1. The structure of this thesis based on the headings.

Due to the sensitive nature of the processes assessed in this study, some concepts in this research are replaced, censored and some are numbers hidden. These explanations and complete figures are found in the background material, which is a separate document.

1.5 Research design

The design of this research is constructed with a base in the LSS DMAIC cycle, where the Analyze, Improve and Control phases generate the results. The practicalities following a case study for a specific business has shaped the framework of this study and due to the circumstances with a business case and a research as a part of a masters' thesis preparations and other measures were carried out in order to get a uniform and full research. The structure of this research is presented in figure 2. These phases were completed chronologically but with minor iterations due to new problems emerging whilst the research was done, in order to generate the valuable results. These phases presented in the figure cannot be regarded as even in terms of length or work, but they were still independent steps with a specific purpose, and where therefore regarded as independent steps.

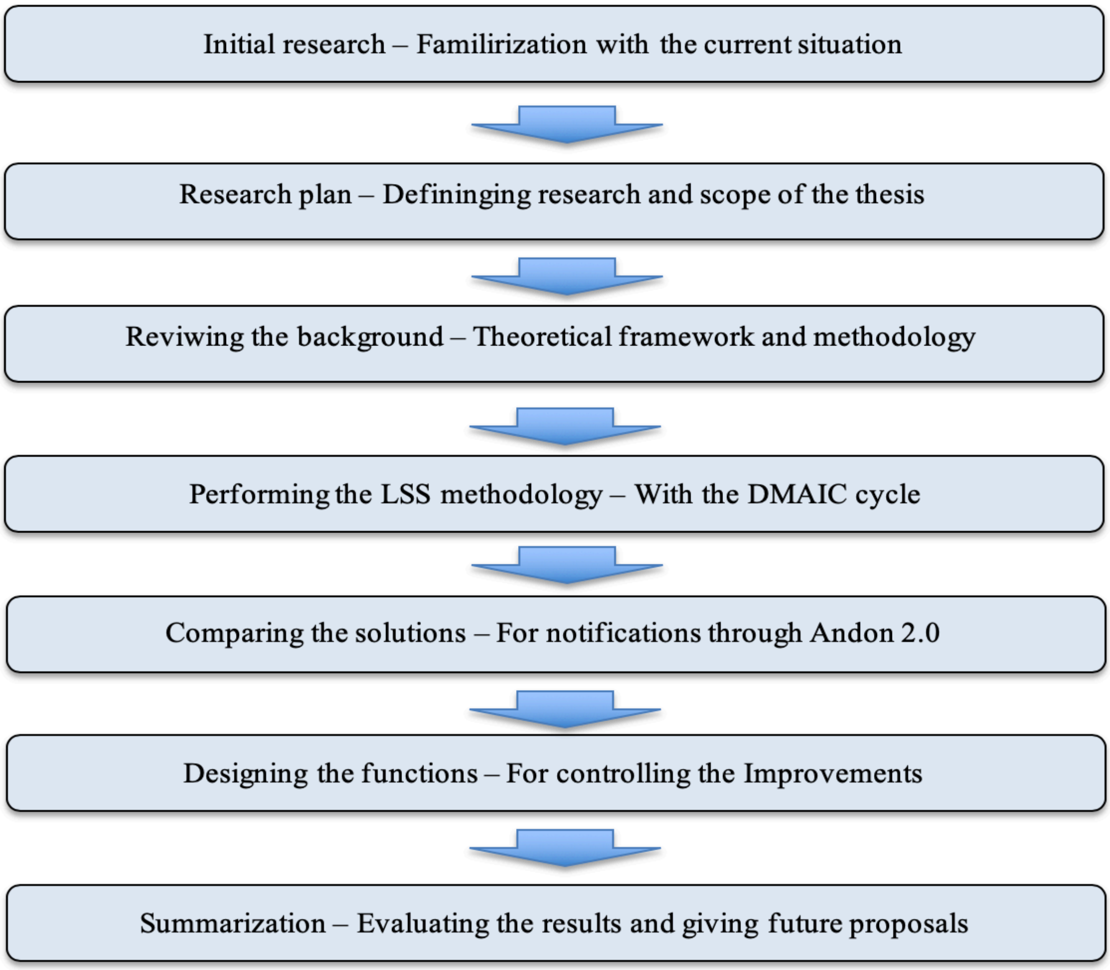

Figure 2. The research is divided into sections with different purposes. These sections are completed chronologically.

2 BACKGROUND / THEORETICAL FRAMEWORK

2.1 Case company

The company has its roots in a sawmill founded in 19^{th} century in the eastern parts of Finland in a small village. In 1851 the company started manufacturing also ironworks, from then on, the focus shifted towards steel industry. In the 1920s the surplus in the steel industry led to severe economic difficulties for the company. The company survived the challenges and acquired multiple other finish companies in the decades to come. One of those was the machine shop in western Finland. After the second world war the finish government had to pay a substantial war reparation. The company had at that time become a multi-industry corporation and its contributions in manufacturing these products that worked as the payment was considerable. (Source 3. 2019.)

Later on, the focus shifted towards the naval industry and the company operated several finish shipyards. The type 1 products to these vessels were manufactured in western Finland. In the 1980s the shipyard industry shrunk in Finland due to the increasing competition from Asian shipyards. The fall of the Soviet Union was the final element in the equation that resulted in a bankruptcy for several finish shipyards. Therefore, the shrunken company enterprise had to find a new direction (Herlin 2003: 157). In the 1990s the previously affiliated company an older product was set as the base for the new vision. The company and the products evolved, and company started also manufacturing products for the sector 1 market. The company also evolved into a system integrator and started to provide power source and propulsion systems for the maritime market. This development happened also on the sector 1 division, where more and more ‘key in hand’ projects were delivered. Instead of producing only products, the company turned into being provider of lifecycle solutions and supported this redirection by acquiring multiple companies both in the sector 1 and as well in the sector 2 market. The service division of the company also experienced a rapid growth. (Source 3. 2019.)

Today the company is completely different than it was when it was established. Its position in the current market is described in the following manipulated quote:

”The company is a global leader in smart technologies and complete lifecycle solutions for the sector 2 and sector 1 markets. By emphasizing sustainable innovation, total efficiency and data analytics, the company maximizes the environmental and economic performance of the solutions in sector 2 and solutions in sector 1 of its customers. In 2018, the company's net sales totaled EUR XX billion with approximately XXXXX employees. The company has operations in over XX locations in more than XX countries around the world. The company is stock enlisted.” (Source 7. 2019.)

The company has also recently invested XX million in western Finland by building a Innovation factory. This factory is built on a spot close to the Port. It will function as a center for research product development and production. The company will move its operations in western Finland to these new facilities in 2020. The total investment will be around XXX million euros. (Source 8. 2019.)

2.2 Lean six sigma in manufacturing

According to Voehl et al. (2014: 67-68) Lean manufacturing can be described as a management philosophy, not a distinct manufacturing technique. The goal of the philosophy is to minimize waste generating activities in a specific process. This waste can take form of time, cost, materials, storing, actions, personnel etc. In other words, slimming the production so that the manufacturer only performs actions that are generating value to the customer. This philosophy emerged from the Toyota factories that became state of the art in the 1980's.

Six Sigma is a concept also developed in 1980's but in a different context and with a different purpose than the Lean philosophy. Six Sigma emerged within Motorola as a concept for eliminating waste, improving quality and productivity. The term Six Sigma is derived from statistics, where a Sigma represents one standard deviation and describes the dispersion of a distribution. Consequently, Six Sigma indicates six standard deviations of defects in the process, which can be described as the level of quality in the process. By decreasing the deviations, the quality is improved, which of course boosts the value generated for the customer. (Ang Boon Sin 2015: 105-117.)

As a consequence of globalization and increased competition corporations and industries need to continuously search for ways of improving their manufacturing units and profitability, in order to retain or gain comparative advantage. This progress has led to a new philosophy which blends Six Sigma into the Lean philosophy. The purpose of this incorporation is to use the statistical models in Six Sigma for achieving goals that Lean normally is used for (Skalle & Hahn 2016).

2.3 DMAIC

Problem solving is an important aspect of improvement. Problem solving itself is often about finding the most optimal solution or solutions for the problem itself. Often problem solving remains on the level of solving the symptoms instead of focusing on the core problem that is causing the symptoms. The distinction between the root cause and the symptoms is crucial to make, in order to be able to achieve real improvement that creates value. Therefore, it is required to have a deep understanding in the process, in order to enable a sustainable solution. (Sörqvist & Höglund 2009: 71-73.)

A desideratum for an advancement in a process, is a harmonized way of working for all stakeholders. The significance of a harmonized way of working increases, as the scale of the project increases, especially when the number of stakeholders involved increases. This finding has forged several systematized ways of working with process improvements. (Sörqvist & Höglund 2009: 71-72.)

A well-recognized way of improving processes is the DMAIC-model, which was originally developed by Motorola in the 1980's. Later on, it was refined by Allied Signals. Today the model is well recognized and is used in many other fields than industry and manufacturing. DMAIC is a model that consists of five independent elements that can overlap to some extent. The word DMAIC is so established that it is recognized in industrial management. The five phases that the model consists functions as an acronym, these phases are: Define, Measure, Analyze, Improve and Control. The model is also chronological, and in order to work, the elements has to be performed in a specific order but can be iterated if it is favorable for the improvement. (Sörqvist & Höglund 2009: 73; Sokovic, Pavletic & Pipan 2010.)

2.3.1 Define

A good understanding of the complete process is a requirement for being able to address the problem itself. Otherwise the risk for only resolving the symptoms is high. Another aspect of the importance of a good understanding of the problem is the importance of a broad understanding for everyone involved in the process of improvement. It is not a necessity that each member of the team shares same knowledge, nor the same expertise. But it will significantly improve the possibilities for a sustainable solution if all members have knowledge about the process and the problems that the team will address. A good understanding of the process also supports the communication between the stakeholders. (Sörqvist & Höglund 2009: 74-75.)

The targeted problem needs to be defined. Otherwise it is probable that the team won't be able to target the exact root cause that is causing the symptoms. A common way of defining the problem is to formulate it in text. When writing the problem statement the focus should be on clearness and understandability, which are often achieved by answering the questions: Why, where, when and who? Another common challenge is that the problem as presented is too broad and challenging to address. This may lead to challenging communication and a slow improvement process which is challenging to keep within the budget- and timeframes. Thus, it is recommended to scale of the problem as much as possible, and if not, then it is reasonable to consider splitting the problem into smaller components, which are more graspable and convenient to deal with. (Sörqvist & Höglund 2009: 74-75.)

During the Define phase the problem should also be addressed from a macro perspective, where the existing problem is connected to a bigger picture, which often is value creation by customer satisfaction and how that will be increased by resolving this problem. By defining this connection in this phase, it will be easier to receive the required resources for completing the project and the bigger picture will be clear for all stakeholders. (Sörqvist & Höglund 2009: 75.)

2.3.2 Measure phase

A productive solution that refines the process and corrects the existing process is dependent on reliable data and information. This data has to be factual and represent the state of the process. If the improvement process continues to the next step without reliable data from the process, then it is inevitable that the proposed solutions are based often on biased subjective perceptions about the current state. (Sörqvist & Höglund 2009: 79-80.)

Before measurements are initiated it is crucial to reflect and decide specifically what to measure, so that the data will reflect the problem state as effectively as possible. This will also save the team from unnecessary work of measuring metrics that are not necessary for the analysis phase. If the needed metrices are not specified, then the risk increases to measure what is convenient but not needed. A well formulated problem statement will help to create critical to quality (CTQ) parameters that are to be measured. (Sörqvist & Höglund 2009: 80.)

The aim with the measure phase is to quantitively or qualitatively obtain a perception about the current state of the process that reflects the reality. Thus, the sample data has to be in such a scale, that it is possible to approve the null hypothesis and conclude that the sample represents the population, in this case, the real process. It is also possible to carry out the measure phase by utilizing the existing data, which is usually collected by information systems that are used in the process. This form of data is called secondary data and has to be validated that it is reliable and sufficient. (Sörqvist & Höglund 2009: 80-81.)

2.3.3 Analyze phase

The target in the analyze phase is to achieve an understanding about the factors that are causing the problem which is to be solved. As the basis for this phase functions the data derived in the measure phase. The analysis phase in Six Sigma methodologies is derived from the perception that the problem is existing because of inputs that cause deviations in the process. These deviations can be quantitatively measured with statistical methods which enables the LSS-team to determine which inputs are causing these observed deviations and to find other possible correlations or causalities, which can be further investigated. (Sörqvist & Höglund 2009: 82-84.)

Problems in the process can be caused by a malfunction in the system or by human factors. There are multiple ways of examining the process in order to find the root cause. It is possible to carry out innovative problem solving or a method of qualitative problem solving. The most objective and unbiased way to work is a quantitative with statistical models. The three statistical tools that are most common in the analysis phase are:

- Hypothesis testing
- Correlation and regression
- Analysis of Variation (ANOVA)

These tools can be utilized separately or combined, depending on the situation and the results gained from the use of one tool. The purpose of these statistical models is to find the input factors which are causing the undesired output, or which are affecting the undesired output to some extent. (Sörqvist & Höglund 2009: 82-84; Shankar 2009: 41.)

2.3.4 Improve

After the analysis has been carried out and the input factors that are causing deviations in the process are mapped, then it is time to continue with the next phase of the DMAIC improvement cycle. During this phase the solution or solutions that ought to repair the process are introduced. (Sörqvist & Höglund 2009: 92.)

One challenge in the Improve phase is the multitude of solutions that may function for resolving one particular issue. The possible solutions are seldom identical, they will vary in terms of resources they consume when they are implemented, timeframe of the implementation, probability to succeed, chances to be acknowledged by the workers and in the extent that they will correct the fault in the process. The possible solutions for the process are not equal in terms of complexity. One solution can be astonishingly axiomatic, but challenging to discover, while other solutions may be hard to shape and does not necessarily generate the same results. Because of this, it is always reasoned to generate several solutions that are to be compared and ranked. There is no precise way how to compare the generated solutions, it can be done by a subjective comparisons, different experiments and pilot versions, studies, benchmarking or by testing and measuring the solutions. (Sörqvist & Höglund 2009: 88-89.)

The implementation of the solution is a critical step of the improve phase. The highest risks to fail is during the implementation. A failure will result in no progress and waste of resources. Thus, an effort should be made in order to ensure a proper implementation of the solution. One way to boost the possibilities for a proper implementation is to regard the implementation as an independent project, which requires effort to accomplish. The most significant risks are the people affected by the improvement and their attitudes towards a new solution, which may imply transformed ways of working. This factor can be managed, and the risk reduced by sufficient communication and an implementation plan, where the scope and frame of the implementation described. (Sörqvist & Höglund 2009: 90-91.)

2.3.5 Control

The last phase of the DMAIC improvement cycle is the control phase, where the objective is to control and sustain the improvements made in the previous phase. This phase is often undervalued and neglecting this phase can therefore jeopardize the success of the whole project, because it may be convenient for the employees to return to the old habits and ways of working. During this phase the solutions are finally validated by inspecting the results on a longer timeframe. (Sörqvist & Höglund 2009: 92-93.)

Shankar recommends (2009: 95-97) that the validation of the performance for the implemented solution is carried out in a similar manner as the measure phase is completed, by establishing a statistical process control (SPC). By utilizing this tool, it is possible to have a detailed follow up of the stability of the process and ensure that the symptoms that originally initiated the DMAIC cycle, are reduced or removed completely.

The whole project should finally be put into a context, even though the DMAIC cycle is an independent project, with a beginning and an end. This means that after verification of the successful implementation of the solution is done, there remains some tasks that are not crucial for the success of this particular improvement but will generate value for the owner. Firstly, a cost-analysis where the savings are compared to the costs of the improvement are compared, is to be carried out and reported to the higher management. These calculations can be included in the final report, which is handed over after the project is closed. A profitable action from a long-term perspective is to share experiences with other units, which may not be affected by the improvement. This way they can get useful information about utilizing Lean Six Sigma methodologies when assailing a problem. Insights such as the progressivity of the workers and organization and attitudes towards changed working procedures can be hard to map directly, but will often be evaluated when carrying out a LSS improvement. (Sörqvist & Höglund 2009: 92-95.)

2.4 Cell assembly

Cellular manufacturing is a concept of manufacturing which is controlled by the pull production process. To be disciplined by the pull production is still not the particular characteristics of cellular manufacturing. The describing attribute of cellular manufacturing is the focus of activities to a specific previously defined place. (Nicholas 2018: 283.)

Another typical attribute of the workcell is the significance of the workers, which usually have to move around and handle several actions. Workcells usually are also usually set up for several assembly workers, which increase the productivity. The assembly process in the workcells are prolonged to line assembly stations. Nicholas (2018: 285-288) emphasizes that there are mainly two categories of workcells: Machining cells and assembly cells. A characteristic for assembly cells is the amount of work carried out manually. The author points out that workcells are mainly used for manufacturing not too complex products, but the workcell system is adaptable for assembling more complex products consisting of numerous activities. According to Nicholas (2018: 285) Constraining factors for complex products are the ability for assembly workers to reliably conduct the tasks, dealing with inefficiency generated with more tools or components available and unnecessary moving inside the workcell.

> Job shops and flow lines cannot meet today's production requirements where manufacturing systems are often required to be reconfigured to respond to changes in product design and demand. As a result, cellular manufacturing (CM) (…) has emerged as a promising alternative manufacturing system.

As Mungwattana (2000) describes in the previous quote, the traditional system of line assembly is not feasible for all applications. This is something Nicholas (2018: 285) and Quinn et al. (1997) also points out when they describe the possibility to manufacture different products within the same product category in one workcell. The company has a wide product portfolio which makes cellular manufacturing beneficial for achieving a certain productivity when the market demands different solutions.

2.5 Improvement concepts

Figure 3. The relation between the three concepts of productivity, efficiency and quality and how LSS is relevant to these concepts, displayed with a Venn-diagram.

Before setting the targets for our study, we have to ask us a valid question: Why should measure and improve these specific concepts? And is it a legitimate assumption that value will be created if these concepts are improved? To these questions Fried and Lowell (2008) answers as following.

> First, only by measuring efficiency and productivity, and by separating their effects from those of the operating environment so as to level the playing field, can we explore the explore the hypotheses concerning the efficiency and productivity differentials. Identification and separation of controllable and uncontrollable sources of performance variation are essential to the institution of private practices and public policies designed to improve performance. (…) Third, efficiency and productivity measures are success indicators performance metrics, by which producers are evaluated.

By defining the concepts of productivity, efficiency and quality, we can set the goals for this study, and the goal will be aligned with the targets of the company.

These three concepts are regarded as independent concepts and are thus assigned individually by utilizing tools and methodologies from the Leans Six Sigma philosophy (LSS). As it is visible from figure 3, we can conclude that LSS is applicable to all three concepts and efficiency can be regarded as partially dependent on the concept of productivity.

2.5.1 Productivity

A classic approach to productivity is that productivity is the output during a specific time period. With higher productivity per month, more units are manufactured. Contrary to this interpretation Lee & Johnson (2012) suggests that in its simplest form productivity can be described as the ratio between the level of output compared to the level of inputs in the process. In this interpretation the output is limited to the deliverables to the customers. Which means value added to the provider in form of experience or enhanced production methods cannot be considered as an output and thereby not as increasing productivity. This interpretation of productivity will be challenging to distinguish from efficiency, while there is a strict difference, which is how waste is accounted for.

In our study productivity will still be considered from the classical point of view, when efficiency is the metric describing the relation between the output and the input, which indicates that the difference is nonvalue adding waste. The output factor when considering productivity this way is time, contrary to efficiency, which considers other factors also.

2.5.2 Efficiency

Efficiency is not a homogenous term that has a uniform description. The perception about the term is clear but disagreements exists on which metrices are the most suitable for measuring efficiency in industrial contexts. A general finding of the theories and metrices for efficiency is the use of input factors as the crucial component in the descriptions or calculations. (Färe 1985: 6-7.)

Contrary to productivity which focus on the desired product or outcome of the process, the focus of efficiency is on the undesired outcome from the process. This is a perception Lee & Johnson (2012) uses, who further specifies efficiency as the relation between current levels of productivity compared to the optimal level of productivity, which functions as a benchmark. According to MBN (2019) efficiency can be described as following.

> Simply, efficiency is the ability – often measurable – to avoid wasting energy, money, efforts, materials and time in doing something or in producing a desired result. The ability to do things flawlessly and without waste – the ability to do them well.

This definition places efficiency as a sub-category compared to productivity, which focuses on the complete output, instead of what is happening within the process. This is also the definition utilized in our study.

2.5.3 Quality

Quality is a term which may have a different meaning depending who you are talking to. Therefore, quality has to be defined, before it can be assessed or improved. Both business customers and consumers want high quality products for different reasons. It can be due to increased safety, the wish to decrease the environmental impact, increased reliability and life-span or enhanced brand image. Quality can always be achieved but it comes with a price, thus efficiency and productivity are also attributes included in our study (Gupta, Acharya & Pathwardhan 2011).

According to Smith (2019) the word quality originates from Latin and means “that type”, which implies that quality is referring to a standard of some sort. He claims that the discipline of quality can consider measurements, specifications or methods as standards for quality. From the point of view of the manufacturer quality refers to fulfilling the purpose according to the specifications consistently. Furthermore, these specifications are always the needs of the customer. This interpretation of quality is used in our research, which means that high quality is when the product is corresponding to the specifications, without deviations and low quality is when components or the whole product is deviating from the specifications.

Wilkinson (1995) is contrary to these previous definitions clear with the necessity to define and avoid complexity when discussing and surveilling quality. He is pointing out that quality is simply conforming to previously set frameworks, which can be standards or specifications. This view is confirmed by Crosby (1979).

3 METHODOLOGY

3.1 A case study

The use of case study methods as a tool for conducting research has been increasing according to Yin (2003: 2). He summarizes a case study as a methodology with two key attributes. The attributes are described as following:

> Investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident. (Yin 2003:13).

Yin continues by describing three conditions required for a successful case study. The first condition is associated with the nature of the research questions that requires an answer. If the research questions are “what” and “how” questions, then one can conclude that a case study is the appropriate method conducting a study.

The second condition for a case study that Yin (2003: 7-8) addresses in his book has to do with the influence over the actions, or “Extent of control over behavioral events”. This condition requires no attachment between the studied events and the researcher. By having this position, it is not possible to affect the events in any way, and the researcher is totally dependent on data and documents derived from these events.

The third condition Yin (2003: 8-9) points out is the possibility to carry out a case study in circumstances contrary to the ones where an experiment is suitable. E.g. in an environment where the researcher can directly stimulate the parameters is not feasible for a case study.

The first research question is not directly formulated as a "how" question, but when evaluating the meaning of the question, it is clear that it answers how the process can be improved, in a distinct manner. The second question is also a "how" question. Regarding the conditions 2 & 3, it is clear from our case, that we are not able in any way to manipulate events that have already taken place. Hence, the questions and the current layout of the problem does support the use of a case study methodology.

3.2 Lean Six Sigma in a case study

Lean Six Sigma has two main methodologies which function as the framework for the improvement project. Both of these frameworks consist of five steps, which are chronological but can be iterated if needed. These two cycles are DMAIC and DMADV, of which the former is suited for improving current processes whilst the latter is suited for establishing new efficient processes.

The International Organization for Standardization has established a specific standard for the DMAIC methodology where the cycle is defined and the conditions for a DMAIC project are defined. ISO 13053:2011 is the specific standard and according to (ISO 2011: Introduction) it describes the core prerequisite as following:

> A difference, from what may have gone before with quality initiatives, is every project, before it can begin, must have a sound business case. Six Sigma speaks the language of business (value measurement throughout the project), and its philosophy is to improve customer satisfaction by the elimination and prevention of defects and, as a result, to increase business profitability.

As the ISO-standard states, we need to have a sound business case before the methodology can be implemented. This requirement is regarded as project scoping in the context which Lynch et al. (2003) presents. Without a clear scope of the project it is difficult to maintain a focus and achieve the set goal for the project, or to even deliver anything of value for the project sponsors. If the scope is not set, risks for exceeding the timeframe, budget and the powers of the LSS experts is increasing. The elements that the project should contain is later on described and answered in this same chapter in the Define phase.

3.3 Define

The first phase in the DMAIC cycle is the called Define. The purpose of this phase is not to generate any value in itself, instead the focus is to define the scope of the project, in order to enable the four remaining phases to be executed inside the framework defined in this phase. If the Define phase is eradicated from the DMAIC cycle, then the it is probable, that the project is not completed in time, within the budget or in a manner that it provides value for the organization, hence the importance of this phase should not be reduced. (GoLeanSixSigma 2019).

3.3.1 Defining the limits

In our case study the framework for the DMAIC cycle, and consequently the Define phase, is the research questions formulated in the introduction. The first question establishes the framework and the focus of the problem. Our study is limited to our case company only and more specifically to the module assembly, which is located at the factory. In this assembly we are only considering the assembly of the products. Our focus is to increase value for the organization and to the customer, by improving the productivity, efficiency and quality of this assembly. These three attributes have been defined specifically in advance. These attributes do not have a set priority, but they are dealt with according to the possibilities for them to be improved.

The resources available for this project are the following: The student doing this research, the supervisor at the University, the instructor at the company, a team working with the Andon 2.0 project, a process developer, supervisors at the factory and the data from the ERP. The only person doing this fulltime is the student who is responsible for conducting and managing this project, who is a certified LSS Green Belt. The project sponsor is the instructor.

The second research question targets the Andon 2.0 project. This is a separate project which will be linked to the improvement of the assembly. This project is of a magnitude, that its scope is far bigger than this case study, but parts of it will be included in this research. The focus with it will be set a starting point, from which that project could be developed further according to the suggestions delivered in this study. In other words, the purpose of this study is to assess the options in which way the Andon 2.0 could be implemented for achieving the target of improved smart manufacturing. The Andon 2.0 will also not be assessed to its full functionalities or potential, instead it will be targeted from one point of view, which is the one that would provide the maximum value for effort.

3.3.2 Specified attributes of the project

According to Lynch (2003) the demand for resources in organizations willing to improve their processes, entails that the focus, of a DMAIC cycle which is to be executed, should be specified according to the attributes presented in table 1, in order to provide the maximum value for the organization.

Table 1. Attributes of a project which should be defined according to Lynch (2013).

Problem	The project should address an organizational performance problem that has an unknown solution.	Answering increased demand effectively requires increased efficiency and productively.
Goals	The project should have clear numerical goals directly tied to a well-defined set of metrics that correspond to the opportunity.	The preliminary goal is to design a system and process that will bring increased productivity, efficiency and quality to the current process. The secondary goal is to find practical independent points for improvement.
Project tracking	Progress should be tracked through the metrics.	The project is preliminarily tracked by continuous follow up of the project. The improvement is later on tracked by establishing metrics customized for the process.
Business benefits	The project should culminate in a measurable cost, schedule or quality benefit.	Increased comparative advantage by reduced costs and increased quality. Additional gained experience of executing similar improvement projects.
Implementation schedule	The project benefit must be realized in a reasonable period, typically three to six months.	During the time of this thesis, from 06/19-11/19.
Process	The project should follow the DMAIC process for problem solving.	Conducting a DMAIC cycle as a case study for answering the research questions.
Tools	Six Sigma tools should be used when following the DMAIC methodology.	Statistical analysis of the data gathered during the past year from the internal ERP, as a part of the DMAIC cycle.
Capability and Confidence	The project should serve to increase the self-confidence of the BB and project team in utilizing the DMAIC	Increase confidence in LSS by carrying out the project and displaying the possibilities and gained benefits.

	methodology. Simultaneously, successful results increase corporate confidence in the Six Sigma effort.	
Process orientation	The project should be viewed from the orientation of improving a process, not necessarily addressing a resultant issue.	The process which is to be improved is preliminarily the assembly of the module, later if the results are confirmed, the solutions can be exported to other units also.

3.4 Measure

Reliable quantitative data functions as the starting point for an examination of a process. Bertels (2019) emphasizes the importance of having the right information at hand when doing decisions. In our case these decisions in a DMAIC cycle are decisions for improvement and control. These decisions will be flawed if the data that works as a foundations is both valid and reliable. Bertels (2019) also points out that these metrices needs to continuously be evaluated against the goals of the organization, in order to enable correct decisions to be made. To get hands on this type of data it is possible to proceed in three ways:

1. Establish and define a metric, which is measured.

2. Start measuring an already defined and used metric.

3. Utilize existing measured data, which will be further processed.

Each course of action has its own advantages, therefore the approach utilized in the DMAIC process should be evaluated to the targets of the project and to the feasibility of metrics which are to be used. In this research the target is increasing productivity and quality. Regarding productivity the core metric is throughput time of the modules assembled in the workcell. In terms of increased quality deviations affecting the quality of the product is a defining metric. In our case both of these metrices are already measured by the internal ERP system called MES. Therefore, the measure phase of our DMAIC cycle will preliminary focus on sourcing this data. According to Sörqvist & Höglund (2009:

81) the reliability of the data is crucial for the success of the improvement with DMAIC. Thus, the reliability and validity of this source data will be evaluated in this measure phase.

3.4.1 Data filtering for activities data

A data package was sourced from the internal ERP system by the help of a software expert. It was extracted as an excel file. The package contained every submitted activity within the timeframe of the past year, from 3/7/2018 to 3/7/2019. From these activities it was possible to count the assembly durations, which can be regarded as a CTP-factor. The package was processed in order to be usable for the analysis. Following list are the described actions which were carried out in Microsoft excel.

1. Filter off all activities except product type activities
2. Filter off all activities except module assembly activities
3. Delete columns:
    a. *Activity revision*
    b. *Group*
    c. *Activity type*
4. Synchronization of WBS-number with product type
5. Convert dates from dates from DD/MM/YYYY to integer
6. Calculate columns:
    a. *Activity_duration*

b. *Order_start before activity_start*

c. *Order_start before activity_end*

d. *Order_complete after activity_start*

e. *Order_complete before after activity_end*

By subjecting the raw package to this procedure, we were able to create a more compressed package that was set to function as the base for the analysis, which was named Data package 1.

3.4.2 Data validation for activities data

Before it is reasonable to carry out an analysis of the Data package 1, we have to validate the data by comparing it to a fixed and reliable source. An extensive report was available and utilized for this purpose. The report was a research that a process developer did during the late spring of 2019 (Source 6. 2019).

The research consisted of a manual follow up of the assembly routing time by following each step of each activity of the module assembly and clocking the assembly time manually. This research is found the record called in Document 1.

The hypothesis was that there exists a strong positive correlation between the two durations. That would indicate that the length of the activities in the Data package 1 are real durations and measured from the same process. In the hypothesis the duration lengths of the two arrays could not be regarded as exactly the same, for the simple reason that the durations from the Document 1 are durations that are clocked and represents the routing time of the duration, while the data from Data package 1 is non-normalized assembly times, which include the time when no-one has been working on the activity. These are nights, holidays and weekends for example. A small deviation between the data was also expected due to human error in the process of inserting the durations for the Data package 1 in MES.

The activities from the Data package 1were synchronized with the activities from Document 1, by the following procedure:

1. Inserting product numbers into the Document 1.

2. Sourcing completed MES activities from the Data package 1 for:

   i) *CENSORED*

   ii) *CENSORED*

   iii) *CENSORED*

3. Matching the activity times from the Data package with the times from the Document 1.

4. Removing blank activities, that were not clocked

5. Calculating the assembly time per activity from the clocked time per action and discard the times normalized regarding the workforce.

6. Compile the activity times from three tables to one with all the clocked activities.

Due to practical reasons the activities measured in the Document 1. had to be clocked on three different modules. These activities consisted also of several actions, which functioned as the base unit in the research and were clocked. Further on the assembly times for the actions belonging to an activity were summed, normalized with assigned workforce and then composed the assembly time. In 6 out of 24 activities, the actions were not all from one single module. Thus, those specific assembly times for the activities could not be regarded reliable and coherent with the assembly times from the data package and were therefore discarded from the synchronization. The clocked times in the comparison were not normalized according to the workforce, as in the report from the Document 1.

Because the MES-data does not take into account the amount of assigned workforce assembling the module during a specific activity.

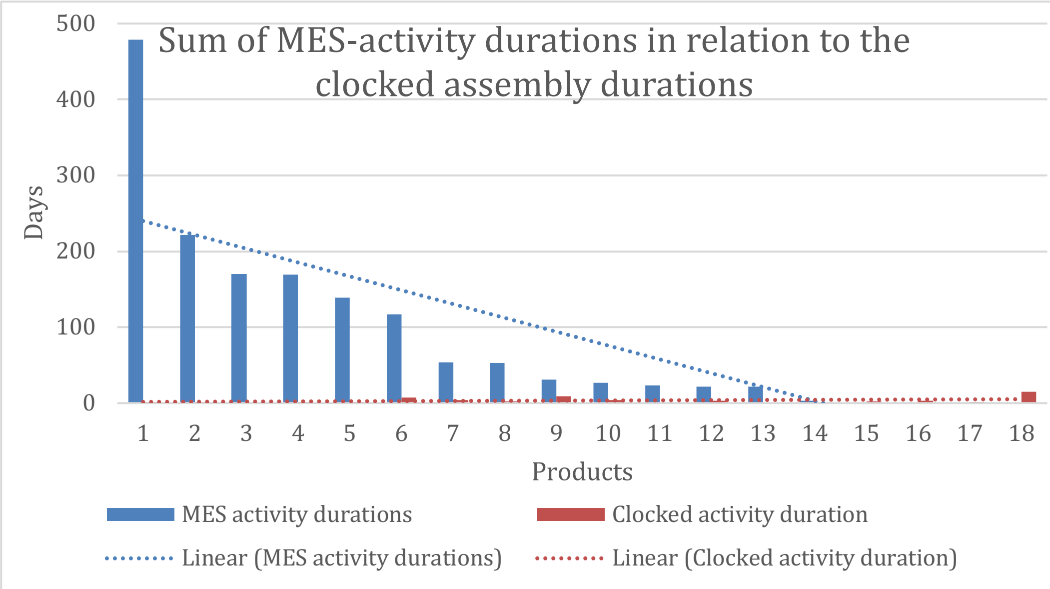

Figure 4. The clocked activities from the module which was measured in Document 1. In the x-axis are the activities starting from the longest duration to the smallest duration according to the MES activities.

This validation test showed to be necessary before any further analysis was carried out on the activities data. The purpose of the validation was to evaluate the reliability of the durations of the activities in the data. According to the hypothesis it was expected that the durations would have had a positive correlation and that the trends in figure 4 would follow each other. The relation of the trends would indicate that we are handling the same process and that the data from the MES is reliable. These data sets showed to have a correlation of -0,239, which is the opposite of the hypothesis. The non-conformity of the relation can be visually determined from the figure 4. But with a negative correlation we can assuredly conclude that the data from Data package 1. cannot be regarded as reliable to any extent regarding the durations of the activities. Hence, we are not able to correlate specific activities with amount of deviations, which would have been ideal for finding the root causes for the low productivity and efficiency. This was set to be one way for answering the research questions. Instead, other tools and methods have to be used. In the future, a correlation analysis gives a solid starting point for doing more accurate improvements and will therefore be suggested in the conclusions.

3.4.3 Sourcing and size reduction of deviations in the module assembly

In a process with input variables, it is natural, but not desired to have deviating input factors. Reasons for deviations can be everything from weather and human factors to changed codes of conducts and a flat tire. These factors do seldom directly affect the production as they are, but they can often be the contributor to some form of a deviation occurring in the assembly process.

The data package with the deviations for the time period 05/07/2018 to 05/07/2019 was sourced from the Internal data storage with a data mining tool. The data is sent to the internal data storage from the internal ERP Aprison by Microsoft. It was sourced by using the following SQL code:

```
select m1.mat_id, m1.mat_name, m.* from wbr_ods.v_Tf_mes_de-
viations

left join wbr_ods.v_td_material m1 on m1.mat_key=m.mat_key

where to_char(m.created_Date, 'YYYYMMDD')>'20180704'

order by m.created_Date asc
```

After compiling the deviations into an excel file by utilizing this code a package consisting of 49 823 deviations in rows with 67 attributes each. The package contained both deviations from other product types than the product as well as deviations which could not be regarded as reliable information and where therefore filtered later. For that reason, some attributes were discarded for practical reasons. The attributes that were deleted and later on used in the analysis are revealed in table 2.

Table 2. Attributes in the data package. The blue attributes were added by calculations for the purpose of the analysis.

Removed	Used and added attributes
DEVIATION_TYPE	MAT_ID
TYPETEXT_FINNISH	MAT_NAME
TYPETEXT_ENGLISH	MAT_KEY
DEVIATION_STATUS_ID	ID
DEVIATION_STATUS	DEVIATION_NO
STATUSTEXT_FINNISH	DEVIATION_SEVERITY
STATUSTEXT_ENGLISH	SEVERITY_TEXT_FINNISH
FACILITY	SEVERITY_TEXT_ENGLISH
PRODUCTION_ORDER_TYPE	REASON_CLASS
LATEST_CHANGED_DATE	DEVIATION_REASON_CODE_ID
LATEST_CHANGED_BY	DEVIATION_REASON_CODE
WORKSHOP	ROOTCAUSE_REASON_CODE_ID
RESPONSIBLE_WORKSHOP	ROOTCAUSE_REASON_CODE
DEVIATION_CLOSED_DATE	PRODUCTION_ORDER_NO
DEVIATION_CLOSED_BY	PRODUCTION_ORDER_SAPJOIN
DEVIATION_CANCELLED_DATE	MATERIAL_NO
DEVIATION_CANCELLED_BY	MATERIAL_DESCRIPTION
ROOTCAUSE_REASONCODE_ID_4	COMMENT_TEXT
ROOTCAUSE_REASONCODE_ID_5	DEVIATION_OPERATION
ROOTCAUSE_REASONCODE_4	DEVIATION_ACTIVITY
ROOTCAUSE_REASONCODE_5	DEVIATION_ACTIVITY_DESCRIPTION
URL	CREATED_DATE
REPLACEMENT_PART_NEEDED	CREATED_DATE_MOD
SAP_NOTIFICATION_NR	Duration_1_days
MET_BUSINESS_DT	Duration_1_hrs
MET_LOAD_TIMESTAMP	Duration_1_Norm_hrs
MET_CRT_BY_PRCS	CREATED_BY
CREATED_DATE_JOIN	*PRODUCT*_NUMBER
	WBS_ELEMENT
	Product type
	DEVIATION_STARTEDDATE
	DEVIATION_STARTEDDATE_MOD

	Duration_2_days
	Duration_2_hrs
	Duration_2_Norm_hrs
	DEVIATION_STARTEDBY
	DEVIATION_RESOLVED_DATE
	Add
	Duration_3_days
	Duration_3_hrs
	Duration_3_Norm_hrs
	DEVIATION_RESOLVED_BY
	DEVIATION_CLOSED_DATE
	DEVIATION_CLOSED_DATE_MOD
	ROOTCAUSE_REASONCODE_ID_1
	ROOTCAUSE_REASONCODE_ID_2
	ROOTCAUSE_REASONCODE_ID_3
	ROOTCAUSE_REASONCODE_1
	ROOTCAUSE_REASONCODE_2
	ROOTCAUSE_REASONCODE_3
	COMMENT_STARTED
	COMMENT_RESOLVED
	COMMENT_CLOSED
	PROJECT_NAME

3.4.4 Value filtering of deviations of module assembly

Out of the 49 823 deviations 767 deviations remained after removing deviations from other workshops and deviations for other product types than those to be considered in this analysis, which are presented in table 3.

Table 3. The filtering proceeded by removing not applicable types.

Attribute	Removed	Used
CREATED_BY	System	Residuals
WORKSHOP	Residuals	344

*PRO-DUCT*_TYPE	*CENSORED*	*CENSORED*
	CENSORED	*CENSORED*
	CENSORED	*CENSORED*
	CENSORED	*CENSORED*
	CENSORED	*CENSORED*
	CENSORED	*CENSORED*
	CENSORED	*CENSORED*
	CENSORED	*CENSORED*
	CENSORED	*CENSORED*
	CENSORED	
	CENSORED	
	CENSORED	
	CENSORED	
	CENSORED	
	CENSORED	
	CENSORED	

This package consisting of 767 independent deviations was regarded as the main source, from which it was possible to perform further analysis. It was named *Filter_general* as a sheet in the *Source.xlsx* file and formatted as table for purposes of usability in following actions.

The analysis was performed on three main sources by doing comparable selections. The *duration 3* was not considered in this analysis, because it is not a key performance indicator and does not therefore provide any insights for immediate improvement in the manufacturing.

The selections of critical variables were done by using the Pivot-table function in excel, with the aim to find as much significant and valuable relationships as possible for these different variables. The selections were further generated as smaller independent pivot-tables, that were presented on a different sheet. One sheet for surveilling relationships mainly according to the operations, in the x-axis. And other variables in the y-axis, with different values calculated as SUM, AVERAGE or STANDARD DEVIATION, as the function of the variables in the x- and y-axis. These calculations were done as interactive pivot tables, which are possible to modify in the main Pivot tool and focus on specific cases by using slicers in excel. Thus, the target of creating a dynamic tool which can utilize new sources, was achieved.

3.4.5 Value filtering for durations of the deviations

For each deviation three times were saved. The first time is when the deviation is opened, which theoretically should be directly after that the deviation is encountered, regardless of the time it takes to solve. It should be created always when something is deviating from the standard procedure. In the raw file *deviations.xlsx* this moment is called CREATED_DATE, but includes the exact time when it is created.

When the deviation is cleared up and the work may proceed, a new moment is saved for that specific deviation. In the raw file *deviations.xlsx* this moment is called DEVIATION_RESOLVED_DATE.

The time between these two moments for a deviation is interfering with the continuous flow of the process and is a no-value adding activity, which can be considered as waste. According to Voehl et al. (2014: 83-86) these forms of waste and no-value adding activities should not be decreased only because they hinder the process, but also because they may convey more no-value adding activities, which in the end will be draining the company from their resources and comparative advantage. Therefore, this time is considered in our analysis and defined as DEVIATION_RESOLVED_DATE subtracted by CREATED_DATE, as seen from figure 5. This time is further on normalized with the weight 0,476.

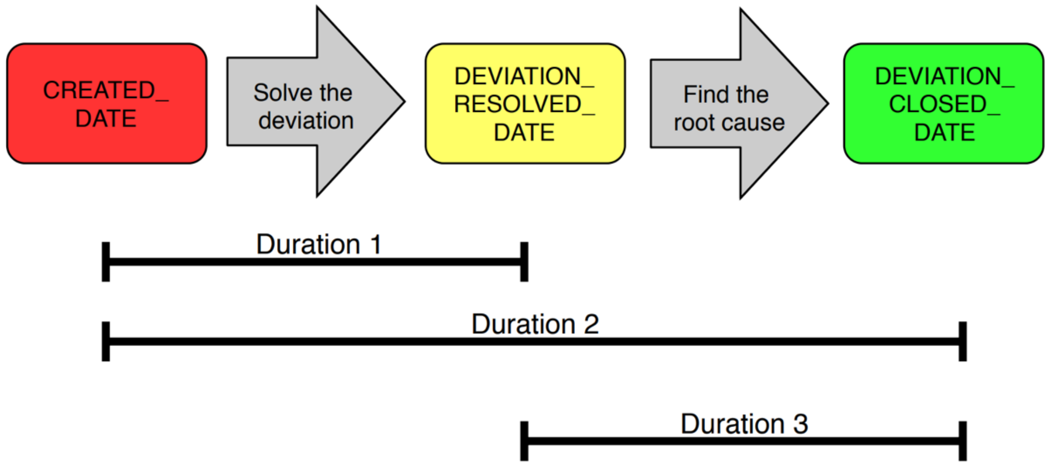

Figure 5. The defined durations from the three saved times of a deviation in MES.

When evaluating these times, a remarkable variation was found, with almost non-existing durations and durations as long as several months. Thus, value filtering was motivated. The LCL was set to be 5 seconds of normalized time and the UCL was set to be a week. When this filter was adopted the sample, size was reduced to 617 deviations.

In a similar manner the *duration 2* was counted as shown in figure 5. This duration represents the complete process from the first creation of a deviation to the closing after the root cause has been settled. According to Voehl et al. (2014: 108-109) the time of finding and settling the root cause can be regarded as a No-Value-Adding activity, because it does not directly contribute to the needs of the customers. Therefore, it is in the highest interest of the company to reduce the length of these durations as much as possible and eliminate these deviations in full.

Similarly, as for *duration 1*, we found a giant variation in length of *duration 2* also. Therefore, a comparable filter was applied with the LCL set to 1 minute of normalized duration and the UCL to four weeks. After this filter was applied a total 352 deviations out of 767 remained. This loss of non-credible deviations indicates that something is structurally wrong in the process of solving and assessing the root cause.

Duration 3 was counted but not considered in this analysis, because it is not a key performance indicator and does not therefore provide any immediate improvement for the production.

4 RESULTS

The results from the study are presented in three different sections, which all are based on steps from the DMAIC-cycle. The first chapter consider the analysis based on the data retrieved and described in the previous chapter. Secondly this analysis enables us to do understand the process in order to carry out accurate and effective improvement proposals, which are presented in the second part. The last chapter is about controlling the improvement proposals by selecting a sufficient solution for the Andon 2.0. The functionalities of this solution are also briefly presented in the control phase.

4.1 Analyze

According to Mandal (2014) a strategy for the analyze phase should be structured before the analysis itself can take place. Thus, the structure is defined before the analysis is carried in order to get the analysis phase to deliver the knowledge and understanding of the process, so that necessary steps for improvement can be made that enhances the quality and productivity of the module assembly.

The analysis was done with two separate methods of which the first one is a purely quantitative analysis based on the data sourced and filtered as described in the measure phase. This data was processed in MS excel in a table format suitable for utilizing the Pivot tool with slicers as seen in figure 6. The source for the tool varied based on the purpose for a specific insight. Sources used in the analysis were tables of:

1. All 767 deviations with the necessary columns for the analysis.

2. The deviations filtered for Duration 1.

3. The deviations filtered for Duration 2.

4. MES activities for all 25 manufactured modules during the past year.

The second approach for the analysis was a practical inspection of the module assembly process together with a process developer. This face was carried out after the qualitative analysis was done, which gave a better insight in the challenges occurring according to the MES deviations.

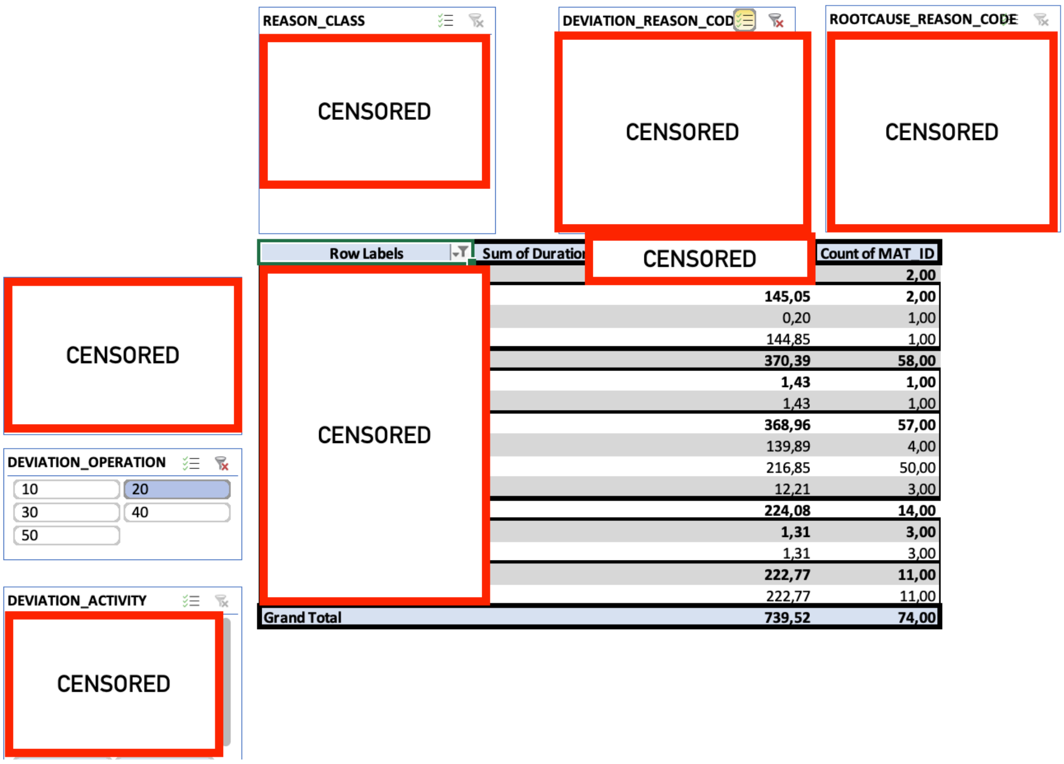

Figure 6. The pivoting tool created from the table of MES deviations. Slicers are used to combine parameters in order to demonstrate significant overrepresentation or negative trends.

4.1.1 Duration for the assembly process

A total of 25 modules were assembled in the factory during the time period 03/7/2018 to 3/7/2019, from which the data was sourced. In the measure phase this particular data was stated to be corrupt and unreliable with respect to the durations of the activities.

The management of the module assembly keeps manually track of the manufactured modules in their unit. These modules are noted in a separate Excel sheet, where the date for starting the assembly and the date when the assembly is completed, is entered. From that table it is possible to get time for the assembly with an accuracy of one day. This accuracy can, and will be regarded as accurate enough in the following comparison

Although the MES data was demonstrated to be corrupt in the measure phase. It is possible to validate this finding by carrying out a comparison relatively to the data from the internal excel sheet. This comparison was done by subtracting the moment when the first activity is initiated from the moment when the last activity is closed. This is the time that the activities are open in MES and should reflect the time that the module is under assemblance. Or in other words, the normalized time when value is added. The results from this comparison is visible in figure 8. From the figure we can discover that the times are not correctly matching, and in almost all, except three cases, the MES duration exceeds the real duration. The lines do follow each other and there is a correlation of 0,42 between the arrays. This correlation cannot by any means be deemed as significant. But we can clearly determine that we are handling the same process in this comparison.

It is also worth noting that out of 25 modules only three have both data points within the timeframe of one day. Thus, we once more can conclude that the MES data cannot be regarded as reliable, but it is still more reliable when considering bigger entities, as in this case compared to the comparison carried out in the previous chapter where there was absolutely no relation when comparing the durations of separate activities.

By sorting the assembly times according to the product types, it was possible to do the following statement. As seen from figure 8, a notable finding was that the assembly durations of the module of product type 2, did not take significantly longer than the assembly of modules for smaller products. This was particularly true for the product type 1, of which we had four sampling units with an average duration of 28 days, compared to the total average of 30 days. The module for the product type 2 had an assembly duration of 49 days, which is far above the average. But it is not possible to draw any conclusions, due to the small sample of only one module being manufactured during the time period of one year. This finding was not expected, because the product type 2 module is a more complex unit with more components and thus, requires more work.

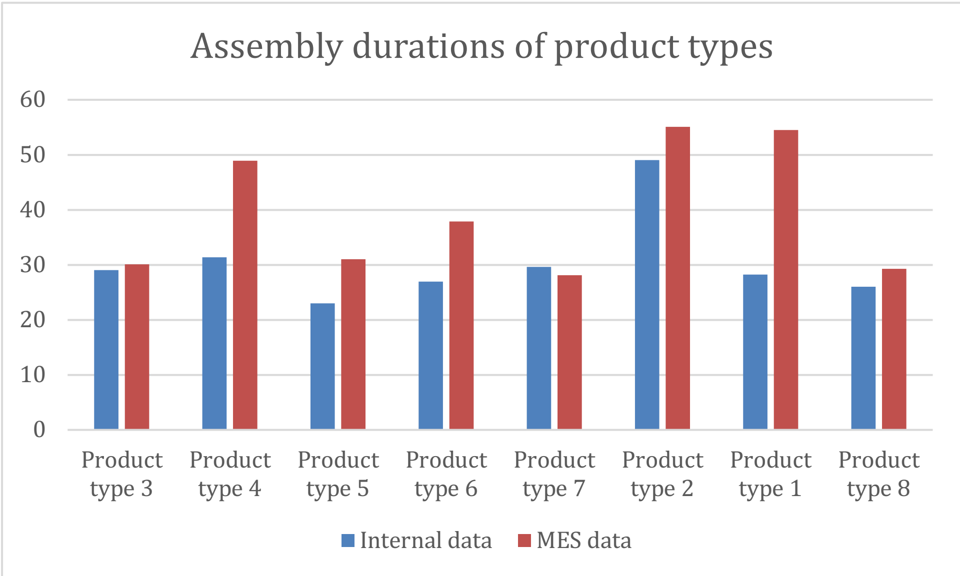

Figure 7. Average durations for the module assembly for different product types.

4.1.2 Benchmark for the module assembly

Currently there exists no stated target duration for the module assembly. Reasons for this lack are several, but mainly because the process is new and has not previously been audited. Therefore, there was no theoretical minimum time for the process. But according to Source 9 (2019), the research that was carried during this summer can be used as a benchmark and target.

The benchmarking was is done with two internal standards, which is an easy way to conduct a benchmarking and does not include any problems with confidential information. The first standard is a benchmark to a similar module assembled in the same module factory, with the same tools, comparable personnel and similar support systems. Thus, we can consider this benchmark as a direct target for future levels of performance. The second benchmark was set to be a static calculated value from the research that was presented by Source 6 (2019). This value was calculated and set to be the theoretical goal.

But this benchmark is excluding design differences between modules and should not be considered as the final standard for all product modules (Voehl et al. 2014: 220-221).

The duration from the study by Source 6 (2019) is measured by clocking independent activities and can thus be seen as the frame for the time that the assembly requires when it is performed with the current tools and procedures. This duration is not normalized, so in order for it to be comparable with the durations from MES, it was normalized with the following calculation:

$$Time_{Normalized} = \frac{clocked\ time}{\frac{Working\ hours\ in\ a\ day}{24\ hours} \times \frac{Workdays\ in\ a\ week}{7\ days}}$$

This calculation gives each activity as a normalized duration with a coefficient of 0,476 compared to the clocked times, which was 148,92 hours or 6,21 days. With the premise that only one mechanic is working on the module at once.

By using a benchmark, we are better able to analyze the constituents of the assembly and to find out how well we are doing and where the improvement requirements are. By splitting the benchmark into smaller units and being precise for each individual activity. The study Source 6 (2019) carried out, can be utilized for benchmarking independent activities. This comparison was not possible to carry out in this state, due to the lack of reliable MES data of independent activities.

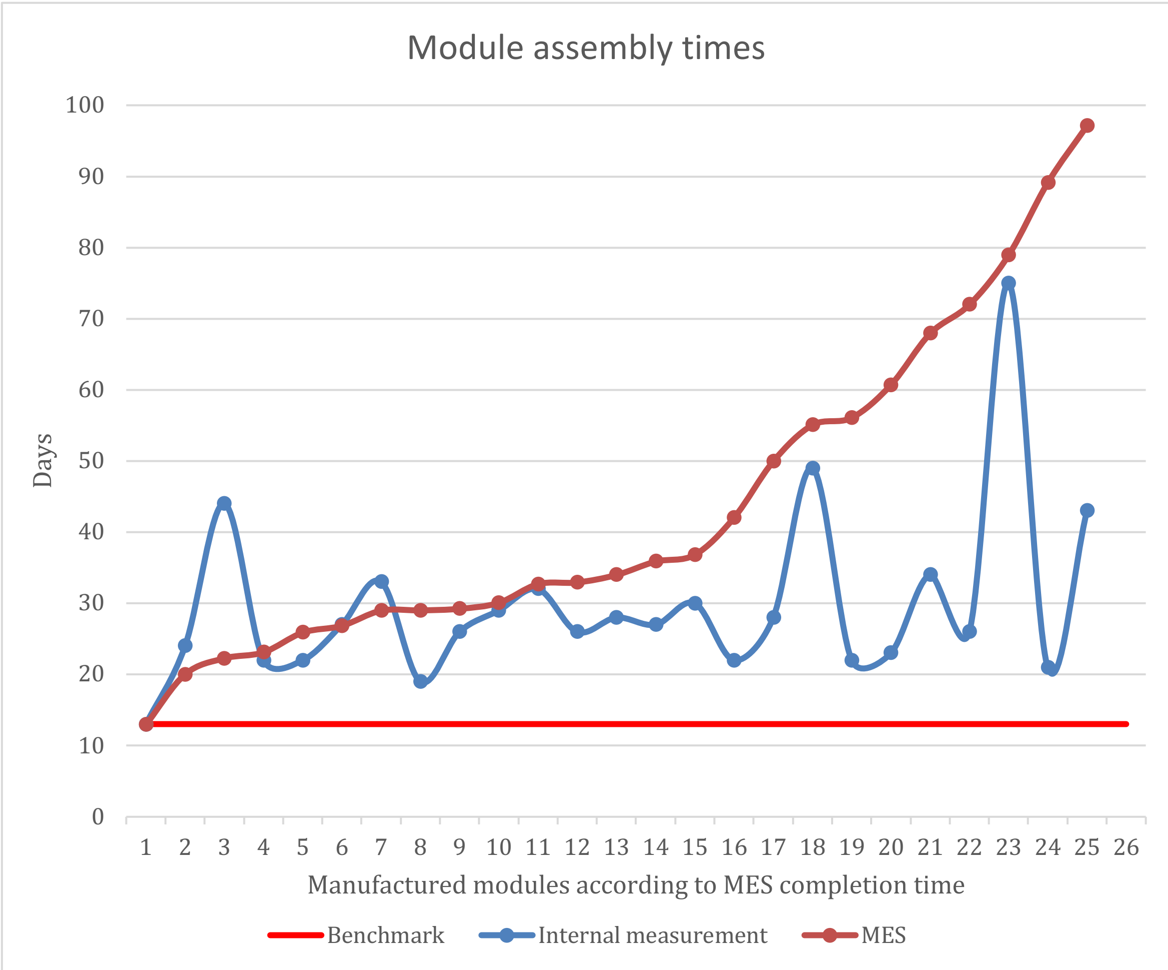

Figure 8. The benchmarks presented for 25 manufactured modules over the last year.

As seen from figure 8. only one module was able to achieve the benchmarked assembly duration of 6,2 days according both to the internal data used as the second benchmark and to the evaluated MES data. All durations in the figure are normalized, and therefore comparable. The median assembly duration was 33,5 days, which is almost four weeks longer than the internal benchmark. This significant difference between the median assembly time and the static benchmark provides space for further research and optimization of the manufacturing and functions thus as a motivator for our research.

4.1.3 Flow efficiency

The clocked times were measured only during continuous assembly and work. In other words, it reflects the time when value is added to the product. According to Modig and Åhlström (2012: 13-15) when knowing both time for value adding activity and throughput time, then the flow efficiency is calculable. The throughput time used in the comparison is the duration it takes for an independent product to pass through the assembly according to the internal follow-up. And as value-adding time the normalized clocked time for the assembly was used. This calculation gives a perception of the current state of the assembly process and how far the process is from being optimal and achieving a complete flow efficiency. This calculation was carried out and the result is presented in figure 9, from which we can conclude that the flow efficiency is relatively stable over all product types. But the modules for type 1 seem to have the lowest flow efficiency.

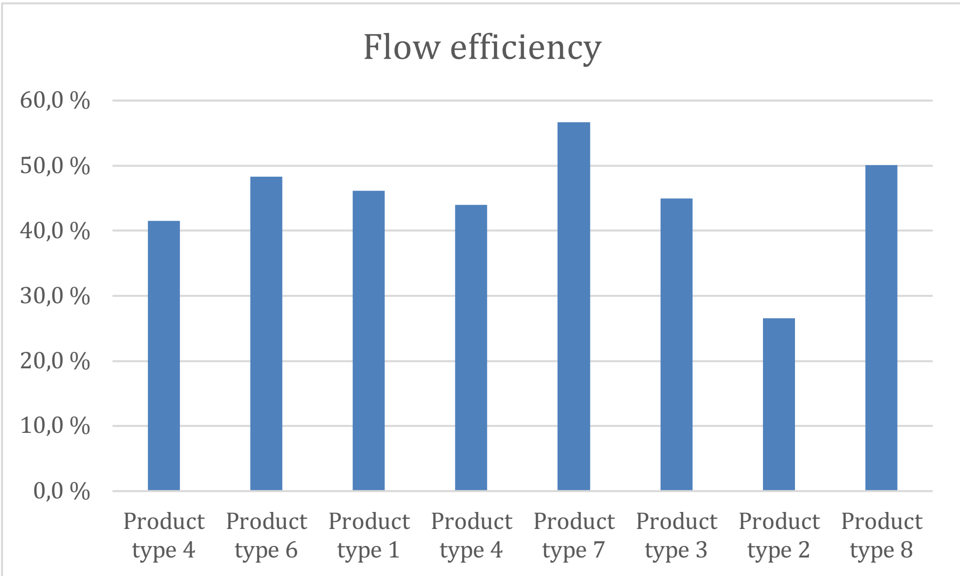

Figure 9. Flow efficiency rate for all product types for the time period of one year in the module assembly. The products to the left are measured with the biggest sample and the four last products to the right are manufactured only in one unit. Thus, the results for the last four should not be regarded as a starting point for further analysis.

4.1.4 General analysis of all deviations

Before detailed analysis based on the Pareto principle is carried out, a general analysis was done in order to achieve a perception of the current state of the distributions of the deviations between different parameters, such as product type, reason class for the deviation on phase of the assembly.

Firstly, we considered deviations distributed per product type. These deviations had to be normalized according to the amount manufactured. This was done by inserting a weight for the deviation according to the product type the deviations had occurred for. The weight was calculated by dividing the amount of manufactured products for that specific product type by the total amount manufactured during the same period. The results from this calculation is presented in figure 10. We are clearly able to conclude that the *Reason class* which has the highest representation is Reason_class_1. But this does not give possibilities in this phase to draw any further conclusions for the reason class, due to the normalized weight utilized in the calculation. Instead the focus is on the product type which is overrepresented. From the same figure we can see that the product type 3 has an average of 15 Reason_class_1, which is three times the average for the residual products. The figure also gives a perception of the amount of deviations for each *Reason class* each module encounters during a regular assembly.

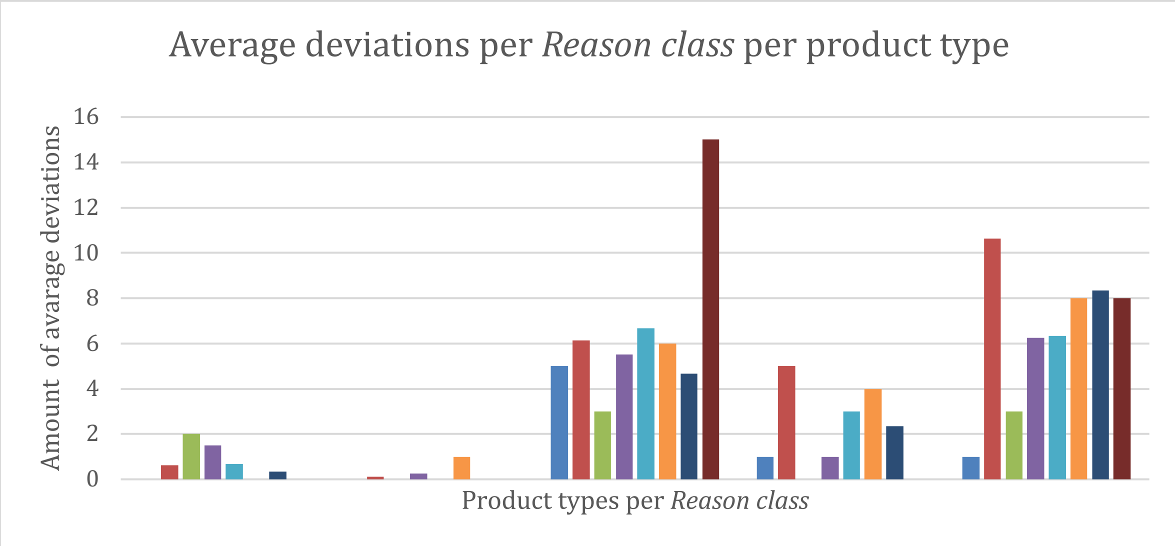

Figure 10. Distribution of average deviations per *Reason class* per product type. The figure with accurate units is found as appendix 7.

When further examining the distribution of different *Rootcause reason codes* for the phases of the assembly, we can clearly find differences, which demonstrate the differences between these five independent phases. These differences in the nature of the deviations entails different root causes, which further requires different actions for them to be solved. By inspecting figure 11 these *Rootcause reason codes* for the phases are shown. We can clearly see that the dominating *Rootcause reason codes* throughout the assembly process is Rootcause_reason_code_1 and Rootcause_reason_code_2 with an exception for phase 3, where Rootcause_reason_code_3 and Rootcause_reason_code_4 have been the most common deviations. Any direct conclusions for where to focus the improvement should not be made based on this figure and this examination. The reason is that figure 11 only shows the relative percentage of the *Rootcause reason codes* compared to all deviations in the same phase, not the absolute over all phases. Therefore, we can't focus only on the *Rootcause reason code* with the biggest share of deviations in one phase, because we have not yet considered the total amount of deviations per phase yet. This will be done in the next chapter where the Pareto principle is used.

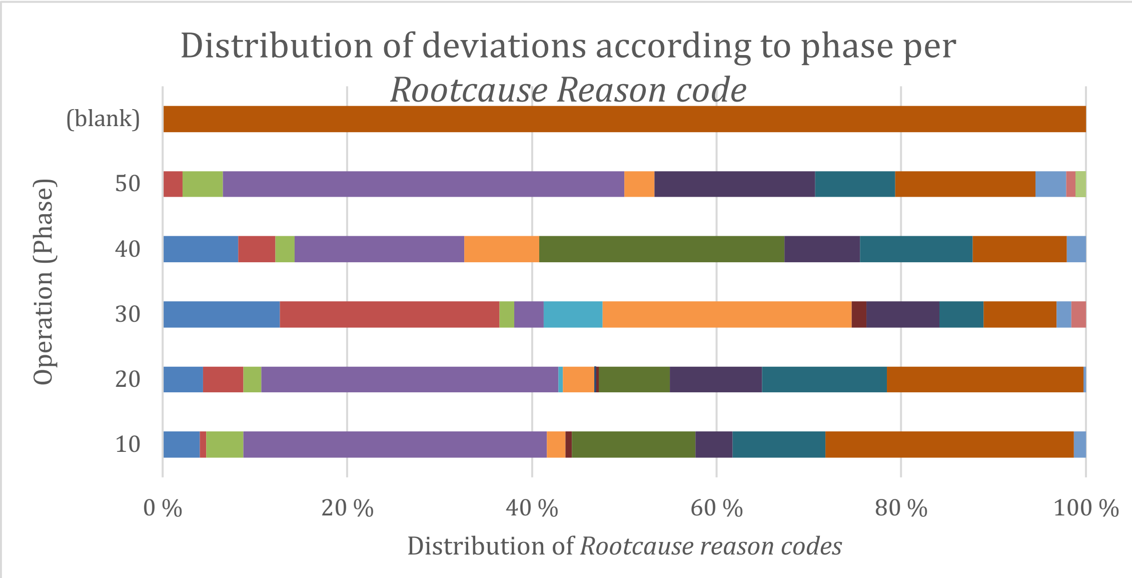

Figure 11. The distribution of deviations based on their *Rootcause reason codes* amongst the phases. The figure with accurate units is found as appendix 8.

4.1.5 Pareto analysis of the deviations

The Pareto principle is a universal principle which seems to exist in almost every field. According to Barry (2015) it can explain socio-economic, scientific, geographic or engineering phenomena. The principle is also called the vital few and the trivial many, which means that a small proportion of the sample is responsible for a large proportion of the outcome. In the initial phases of the principle in the 18^{th}-century the relation was often considered as 80-20, meaning that 20 percent are responsible for 80 percent of the outcome and vice versa. The use of this principle has expanded to multiple fields and is also a useful tool of Lean Six Sigma.

According to Voehl et al. (2014: 280) the Pareto diagram is useful for demonstrating graphically the few significant problems which are responsible for a wide majority of outcomes. The other way around a majority of the problems are responsible for a minority of the outcomes. This relation can be visualized conveniently in graphs where the factors which have the highest impact are piled as bars to the left and factors with less impact are following after. Normally also a trend is used in the same chart for displaying the proportion which different factors are responsible of the total sample.

Voehl et al. (2014: 280-281) emphasizes that these visual and statistic tools can be used to establishing priorities by finding major causes. This principle was found useful for our analysis and functioned as the basis for the search for the critical factors and root causes in our process. This was done iteratively by drawing several times a Pareto distribution of different factors and in the end finding the most significant factors that are leading to deviations and reduced quality and performance.

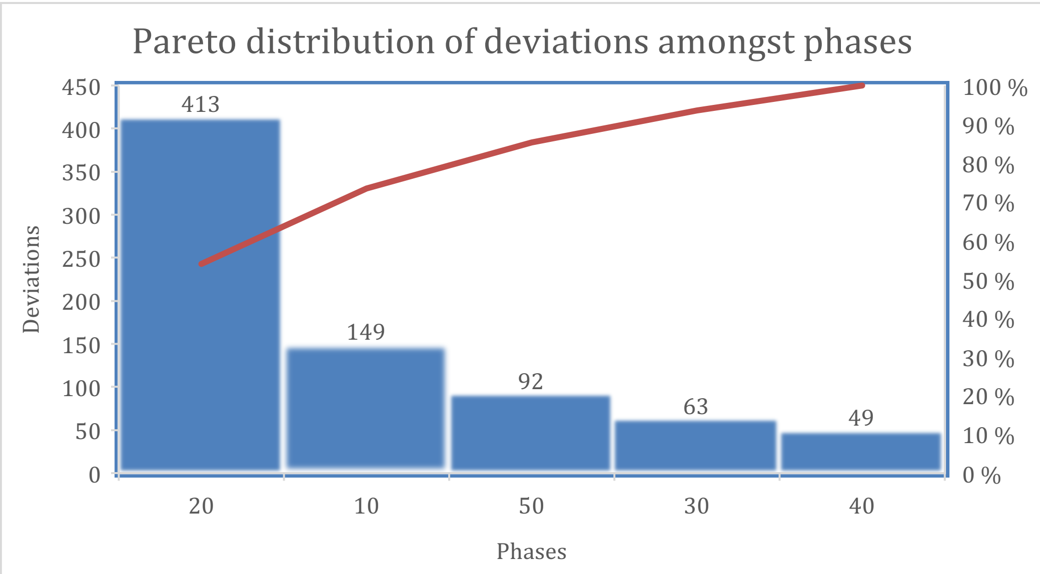

Figure 12. The Pareto distribution of deviations amongst phases.

By doing the Pareto analysis for the distribution of deviations per phases we can conclude that 53% of the deviations are occurring in phase 2, which is shown in figure 12. A total of 73 % of the deviations happen in phase 1 and 2, therefore we are proceeding by only analyzing the deviations in these two phases as George et al. (2005: 144) suggests when finding a pareto effect. We selected the *Rootcause reason code* and displayed its deviations distributed in a Pareto chart, which is shown in Figure 13. From this Pareto chart we are able to find that Rootcause_reason_code_1 and Rootcause_reason_code_2 are responsible for 54 percent of these deviations. If the following four *Rootcause reason codes* are involved, then the 80% mark is reached. In this analysis it is in our interest to find the most crucial factors, and thus, the procedure was continued by examine which components are overrepresented in the *Rootcause reason code* segment Rootcause_reason_code_1.

George et al. (2005: 144) suggests implementing a comparison between two pareto charts, in order to validate the real impact of the specific appearing categories. The second pareto beyond the pareto of occurrence, would be a pareto chart showing the impact or any other metric. When comparing these it would be possible to validate the result from the first pareto. This procedure was not possible for us in our situation, because the other data that would be *duration 1* and *duration* 2, were deemed to not be reliable enough if the sample is too small. Instead the results were validated by interviewing personnel involved in the assembly process and supervisors. After these discussions were held, we could conclude that the Pareto chart did show us the problematic groups of deviations. Hence, we concluded that the Pareto analysis was valid.

We proceeded in a similar manner by selecting the most common Rootcause_reason_code_1 and listing them according to their recurrence during the time period which was used in the analysis. This list is found as Appendix 1. and from that table the distribution amongst the phases is also visible. The list is sorted according to the occurrence of the deviations due to these specific components.

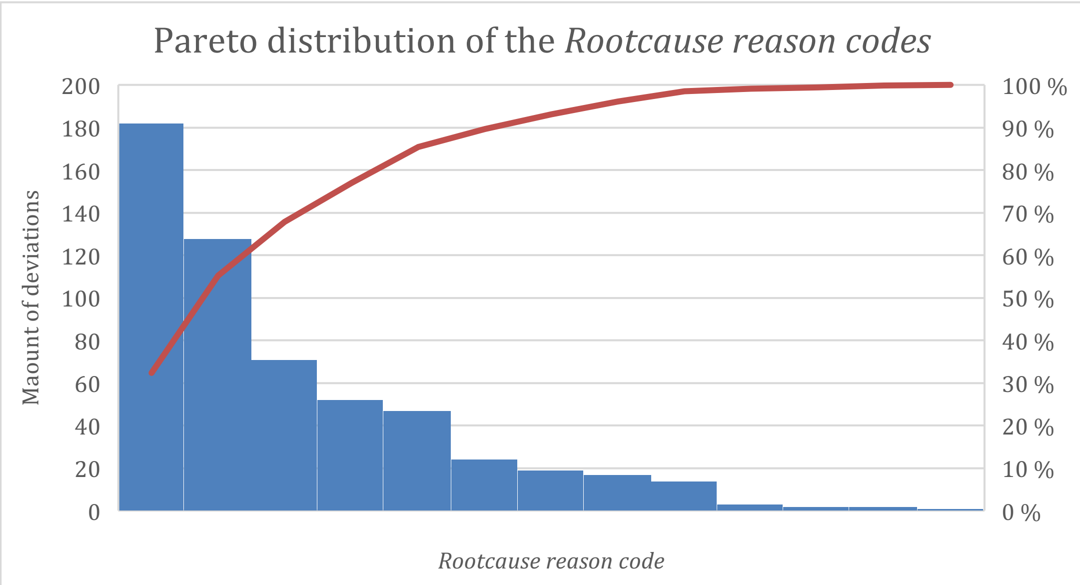

Figure 13. A Pareto distribution of deviations categorized based on their *Rootcause reason codes* in phases 1 and 2. The figure with accurate units is found as appendix 9.

4.1.6 Time analysis of the deviations

The first data source used was the filtered list with a total of 767 samples. These deviations were considered to be real and valid, but not necessarily reflecting the real durations calculated. One general finding was the reduction of the non-filtered *duration 2* over the timeframe used in this analysis. These data points are presented in figure 14.

Following the interpretation of Binu (2014) the R-squared or also called the coefficient of determination, which is an index showing the relation between the trend and the data points. In regression analysis the aim is to determine the impact the variable X has on variably Y. Here the R-squared is a useful tool to describe the dependence between these variables, and thus, it is used in our analysis. Interestingly the R squared value for the regression line of the data points is 3,73 percent, which reflects the amount of variable variation that can be explained by the linear model. This particular R squared is low, but it is higher than the R squared of the filtered values of duration 2, which is 1,32%.

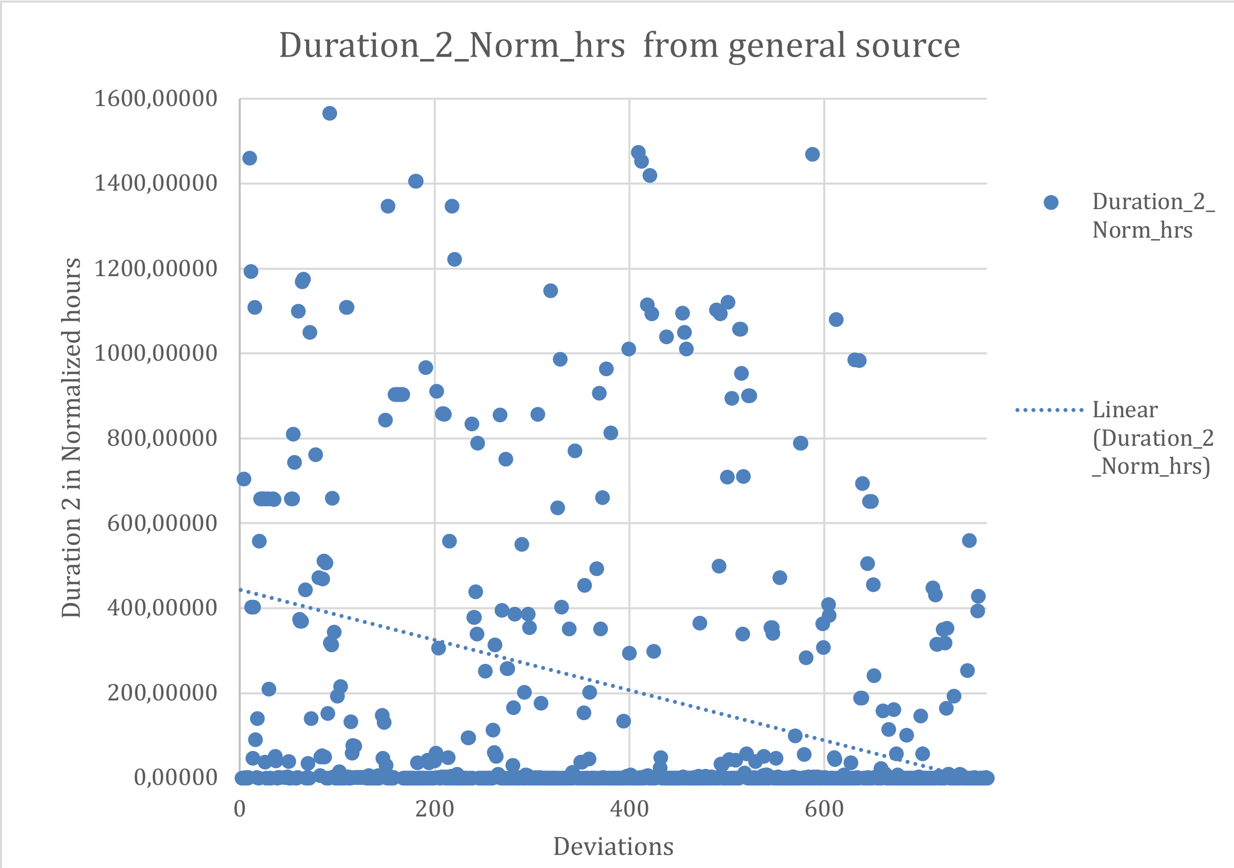

Figure 14. Duration 2 from the data set with all 767 deviations. The linear regression line is heavily negative, which indicates that the resolving time of a deviation has decreased during the time period considered.

Regression analysis can be used to predict future performance or for finding relationships between parameters called X-values affecting a chose Y-value in simple linear regression models. A regression model was established in the excel-tool that was created for the purpose of this research. The tool enabled us to select parameters and look for parameters which are generating a noticeable correlation. This correlation is measured as the R-squared and describes how attributable the Y is for the gained X. (George et al. 2015: 166-167).

The regression model was used when comparing the durations as presented earlier, but also in a second analysis, due to the issue with the previously stated unreliable nature of the durations. In the second analysis all the deviations were grouped according to their creation dates in two months of the time period. For the purpose of convenience and possibility to conduct an analysis these months were assumed to have equally many working days, hours and workload on the module assembly cells. The used timeframe of one year included 13 months where deviations occurred. But for the first and the last months 7/2018 and 7/2019 were not measured completely and were therefore excluded from the comparison.

When doing the analysis for every deviation the regression model was y = 1,68x + 58, with a R-squared of 3,6%. It is noticeable that the Trend is positive, but the regression cannot be stated to be clear due to the low R-squared. By looking into *Reason classes* and *Rootcause reason codes*, some specific deviations appeared to have a noticeable impact on the progression of the amount of deviations. Positive trends were found for issues related to quality, which were displayed by a negative trend and a high R-squared. For example, the monthly amounts of Deviation_reason_code_1*,* had a negative trend which was calculated to be y = -3,1x + 25,667, with the highest found R-squared of 64,8%. Other issues related to quality showed a similar trend. Issues regarding methods were not significant in terms of quantity or regression. But the issues related to logistics showed to be causing real harm to the process. The category of Reason_class_1had a positive trend with a slope of 1,8. The R-squared was 27%. This regression model is visualized in figure 15.

This obvious complication of a bad trend with the deviations regarding logistics was analyzed further. The *Deviation Reason Code* withhold two groups, of which Deviation_reason_code_2 had a negative trendline, but Deviation_reason_code_3 an even higher slope than all Reason_class_1. When going into the last attribute for the deviation, which is the *Rootcause Reason Code,* then it was found that every single *Rootcause Reason Code* had a negative trend, except Rootcause_reason_code_5. This *Rootcause Reason Code* had a regression model of y = 1,93 x + 5,29 and a significant R-squared of 31,6%.

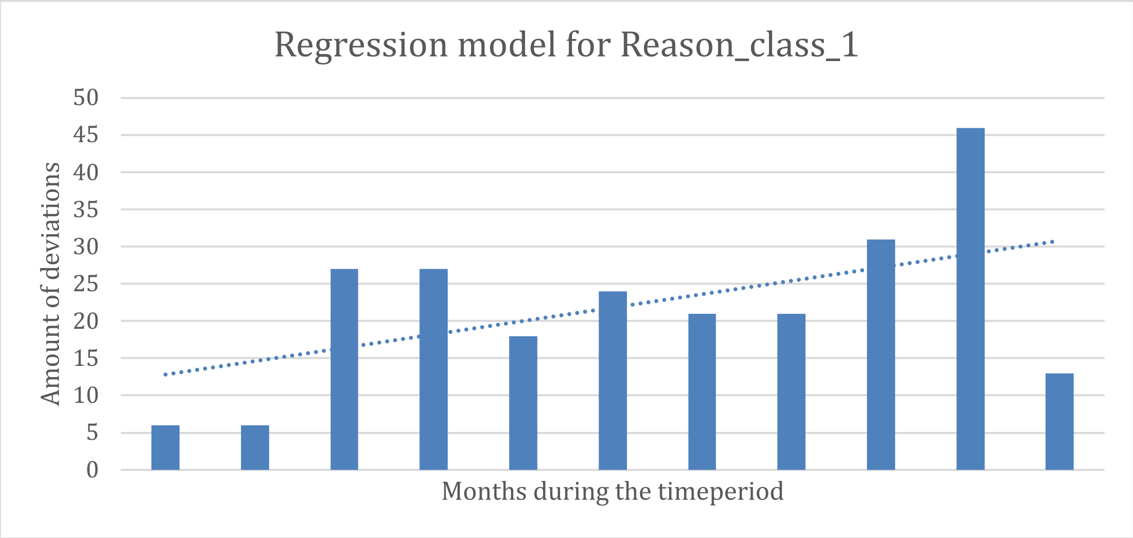

Figure 15. The regression model of the *Reason Class* Reason_class_1, with a positive trend displayed.

When the regression model of the Reason_class_1 is compared to the quality related deviations, which are the second biggest *Reason class,* then the importance of focusing on the Reason_class_1 is obvious. Simply because the development with these deviations has a far less poor trend. The weight of the model is 0,13 and the R-squared 2%, which makes the interpretation of the model challenging. This is shown in figure 16.

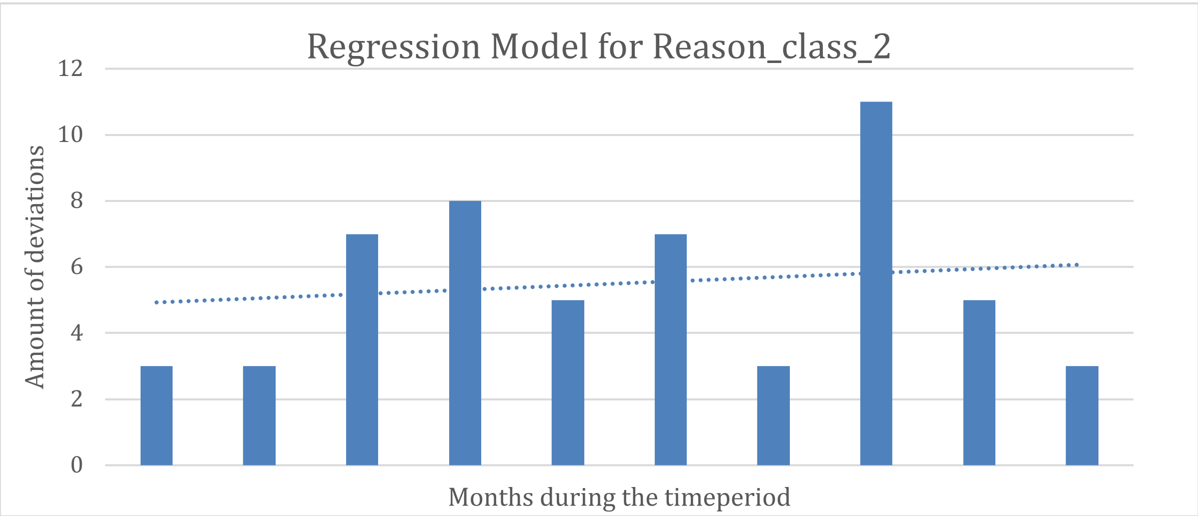

Figure 16. The development of the quality related deviations has not seen any progress, but compared to the Reason_class_1, the trend is not equally problematic.

4.1.7 Examination of the assembly process

The module assembly process is an independent assembly process of the assembly of the complete solution which is to be delivered to the customers. This process can still be regarded as an autonomous process, which can be surveilled and improved separately. Beyond the statistical analysis carried out in this phase, a direct examination of the assembly process for one module was carried out whilst this study was done. The purpose of this examination was to get a complete understanding of the assembly process itself and the practical challenges, which may be causing the problems which are revealed in the statistical part of the analysis. By having an understanding of the realities and the context, we are able to further make improvement proposals which are not interfering with other structures of the process (WhatIsSixSigma.net 2019).

Cellular manufacturing can generate significant savings compared to job shop manufacturing according to a case study Collect & Spicer (1995: 71-75) executed. Cellular manufacturing gives many advantages in terms of reduced waste in form of time, work and tools. Cellular manufacturing is especially well suited for manufacturing of products which are not completely standardized. This makes cellular manufacturing a well-suited production method for the products, which are not yet produced in as big volumes as the modules for the older products.

The assembly process of the module in the cellular workshop consists of five independent phases, which are similar to their actions. These phases are further categorized in activities, which are dependent on the type of module that is to be assembled. In our research we familiarized with the assembly of a product type 1, which has 25 activities in the complete assembly process. This process is described in brief in in Appendix 2 with the most crucial activities mentioned. Every activity conducted on a product type 1 module is shown in Appendix 3.

4.2 Improve

The purpose of the improve phase is to develop, select and implement the solutions with the lowest possible controlled risk for achieving the target of the cycle. (Opex Resources 2015). Our Improve-phase is based on the understanding attained from the statistical analysis and other parts of the analysis phase. The improvement phase approaches the improvement from the three perspectives of the research: Improving productivity, efficiency and quality.

4.2.1 Improvement based on the statistical analysis

The tool that was made for the statistical analysis gave us insights in the process of the module assembly for the time period of the past eleven months. The data was concluded to reflect the situation accurately and was therefore sufficient for usage in the analysis. In this analysis we are able to engender lists of priorities. These priorities were based on the assumption is, that all deviations, have a negative impact on all three researched aspects of the process. By spotlighting distinct groups and parameters, that are especially deleterious, we are able to efficiently improve all three aspects of the process. For this, we used two different approaches.

The first approach in the analysis phase is the pareto principle which was interpreted for finding the deviations which have the most significant impact on the process. We were able to find the most common deviation by step by step selecting the types of deviations, that are overrepresented. Results from this give us a strong indications that the improvements should be done in phase 2, for *Reason class* Reason_class_1 and for *Rootcause reason code* Rootcause_reason_code_5. From these categories one activity had many deviations regarding logistical issues: Activity 1. The same phase had also an overrepresentation of deviations regarding the quality of the components.

The second approach was the regression analysis conducted for both the *duration 2* and the monthly amount of deviations. This analysis gave us an understanding of the direction of the nature of the issues in the assembly. The results showed that there is a general positive trend for the duration 2, which is declining. No conclusions leading to decisions affecting the process should be made based on this finding, due to the unreliability of the data regarding the durations. But as a general conclusion, it can be stated that the work that has been done for reducing the durations inserted to the MES seem to bring results. The second aspect in the regression analysis showed the amount of deviations for different deviation classes. The general finding for all deviations were that a small increase has happened, thus we the causes were investigated and clearly the worst progress has happened regarding logistic issues such as Deviation_reason_code_3 in phases 2 and 5. Here in the *Rootcause reason code* Rootcause_reason_code_6 and Rootcause_reason_code_7 are showing a solid negative trend. Therefore, the most problematic segment is Rootcause_reason_code_5, especially for phase 2.

When having conducted the pareto-analysis and the regression analysis of the evolution of the amount of deviations for different segments and finding overrepresentation of some specific *Root Cause Reasons* for specific activities, we are able to address specific issues by adopting preventive actions for these common issues. This list is found as appendix 4. This was done by informing the supervisors and process developers of the module assembly. The excel tool for finding the right focus points for control was handed over to these persons as well.

4.2.2 Improving productivity and efficiency

Productivity can be described as to which rate a task is being completed or product manufactured. Productivity does not consider input variables, only the output. In our case increased productivity is achieved by manufacturing more units in with the same prerequisites. Productivity can naturally be increased by addressing more resources to the process, which would increase the productivity. In our case, this is still not the option we are preliminary looking for. Efficiency on the contrary takes also the amount of waste in the process into account. This waste can be physical waste, waste of resources or waste of time (Great People Inside 2017).

Productivity can be increased directly by assigning more resources. According to the experiences gained from the examination of the assembly, increased workforce would directly increase productivity and would be straightforward solution. But with a certain delay, due to the learning process of the new characteristics and methods of assembly for the relatively new product.

According to the statistical analysis, an apparent problem in the assembly is regarding the installation of the Components_1, which is done in activities Activity 2, Activity 3 and Activity 1. These Components_1 have to be fitted exactly according to the drawings, in order to fit. The complication in these activities is the lack of proper drawings, which would show the mechanics how the Components_1 are supposed to be installed. Currently only 2D drawings are available, from which it is impossible to directly see in which order the Components_1 should be installed. This entails nonvalue adding work, in form of time for the mechanics trying and pondering how the Components_1 should sit. This issue can be assumed to diminish with time when the mechanics get more experience with the procedures. But such an assumption will not directly increase productivity and therefore we are proposing the following action for fixing this issue. By composing instructions from which the sequence of the installation would appear, the mechanics could focus on the installation itself and the efficiency of the assembly process would increase considerably. These instructions should favorably come in form of 3D drawings or pictures of 3D drawings of the Components_1 presented in a power point where the sequence of the installation is presented.

The lack of stations with the tools and personnel able to assemble a module can be considered as bottleneck of the productivity of the whole product assembly. Therefore, focus on maximizing the flow efficiency ratio of these stations would increase the productivity significantly. According to Passarella (2012) this flow efficiency could be improved by reducing the actions in the assembly which could be done in sub-assemblies. Activities suitable for outsourcing from the main module assembly to sub-assemblies are monotonous actions, which are possible to conduct without interfering the quality control and monitoring of the main module assembly. According to our study of the assembly process and the research Source 6. (2019) did, some actions in activities Activity 4 and Activity

5 could be outsourced due to the nature of these actions. These are the installation of the Components_2 in Activity 4, which requires attaching approximately XX bolts, of which the majority are challenging to reach. This action is also done on the module itself, which entails risk for the mechanics performing these actions. Instead these Comonents_2 could be attached before they are delivered to the assembly or before they are lifted for installation. The same improvement proposal applies to the installation of Components_3 installed in Activity 5. These improvements would naturally bring costs in forms of an added fee from the supplier or in form of manufacturing of racks which would enable the components to be attached on the ground. Process flow is also reduced due to the limitations of the installation supports, which are not capable of handling the full load of a module in the last phases. One option could be to investigate if the weight limits are really set to that specific point, or if there is room for using it beyond the limits, with the permission of the manufacturer.

Efficiency could be improved by rebalancing some activities. The difference in actual duration for completing an activity is high between the activity Activity 1 and Activity 6, of which the latter is nine times longer. This is due to the nature of the Activity 6, which includes electrical installations which are dispersed and conducted in parallel with other activities. At the current situation any rearrangements should not be made, because Activity 1 has the most deviations due to issues with material supply. Hence, these issues are to be corrected initially.

Culture of the MES usage should be improved by strictly controlling the people inserting MES deviations and activities. This is a requirement for future improvement, and without valid and accurate data from the internal ERP, it is impossible to carry out deeper root cause analysis based on the MES data. Culture can only be changed by actively surveilling and requiring melioration. The purpose of enhanced data control is also crucial for success in this field. The culture and procedures for reporting deviations should also be improved. The current procedure has not shown necessary reductions of the *duration 1*, which implies that value adding time is lost and consequently the efficiency is reduced due to the weak reliability of the current procedure. This problem will be addressed in the Control phase.

Finally, productivity will be increased when the Andon 2.0 is implemented successfully. This gives the mechanics more time for the value-adding work, when the effort for updating MES is smaller. It will also decrease both *duration 1* and *duration 2*, if the area responsibles are automatically informed of an issue regarding the material supply. Which would also reduce waste, in terms of time it takes for the mechanics to search for area responsibles. When the Andon 2.0 is implemented, we can assume that the data from the activities is also more reliable. Which would enable process development in the future by carrying out correlation analysis between the durations of separate activities and the amount and nature of deviations.

4.2.3 Improving quality

A hypothesis can be stated regarding the quality of the assembly. This hypothesis is that actual quality related issues while operating the product are dependent on the quality related deviations occurring in the assembly process. This hypothesis is based on the process that defective components are to a certain extent discovered during the assembly process and reported ass quality related deviations. Based on this process one can assume that there are a certain percentage of the defects that are not discovered, because they may be hard to find with only a visual inspection, which is done for most components in the assembly. Based on this assumption we can state a hypothesis, that asserts that when the amount of quality related deviations is decreasing, the number of real defects on the product are also decreasing. This hypothesis has not been validated in our study. Partially because it is outside the framework and also because the product is so new, that the sample of realized defects is insufficient. From here on, when discussing quality of the product, the discussion is based on this hypothesis. If this hypothesis shows to be false, then the proposed measures for dealing with the quality are also probably insufficient and inaccurate.

In the statistical analysis time-based analysis, the deviations Reason_class_1 are severely overrepresented as a reason class. They are in total 42% of all deviations during the time period, which is 8 percent units more than the *Reason class* Reason_class_2. Of these approximately half are due to Rootcause_reason_code_2 and the other half is due to failed design. Of all quality related issues, the unspecified *Root Cause Reason Code* category is the most common. Therefore, it is hard to do any conclusions for that specific category.

The reason why the focus has been on the Reason_class_1 instead of the reason class Reason_class_2, is the development of the latter during the time period. This can be seen from figure 15 and figure 16. This phenomena is also relatively evident, due to a slope of -1,5 and a R-squared of 0,18. The only *Deviation reason code* that it is not following this trend is Rootcause_reason_code_2, in which we haven't seen any progress at all, positive nor negative. The only two *Rootcause Reason codes* that have been increasing are Rootcause_reason_code_5 and Rootcause_reason_code_6, of which the former ones have a clearer trend but are not as common as the latter, which have not a that an equally clear trend. This signifies the importance of the control over the sub-suppliers and the option to require quality related improvements from them with fines, if needed.

When going down on the component level, we can see that the most quality related issues have to do with components that are physically bigger and are casted. The defect that should in our estimation be assessed is the deviation because of corrosion and dirt. This deviation occurs due to poor storing facilities for the components. In some cases, casted components are stored outside without proper protection from wind, water and snow. When casted components are exposed to these natural elements, corrosion and rust are unavoidable.

Further on quality of the assembly can be increased with installing proper adjustable working platforms, that enables the mechanics to carry out the installation by focusing only on the work, not on their safety, as they have to do currently with inappropriate working platforms that are not adjustable. This may have implications on the torque of the bolts, failed installation due to no visual inspection after assembly and scratches on the surfaces when the mechanics need to climb on the module during installation. Such an investment would also increase productivity and efficiency drastically.

The possibility to increase the quality of the assembly is dependent on the information gathered from deviations occurring. Therefore, it is crucial that every defect is reported, which is not the case today. This problem should be addressed by changing the culture, or by implementing a system for reporting with a lower threshold for reporting than the current one. Such a system could possibly be Andon 2.0 if it is implemented fully.

4.3 Control

In the last phase of the DMAIC cycle, the focus is not about creating new solutions. Instead the focus is set to be on sustaining the improvements done in the last phase. Due to the nature of our case study with two distinct objectives phrased in the research questions and answered by doing a DMAIC cycle, we can and will conclude that the Control phase will have its distinct attributes, which are deviating from the classical approach to the Control phase. The main reason for this is the meta-analysis approach we have with the Andon 2.0, in other words, we answer partially how we would be able to do further improvements in the future if we would have more reliable data available, after the Andon 2.0 is implemented. Because of this customized approach, our Control phase consists of two separate parts: Controlling the general improvement proposals and designing and selecting a tool, which would boost the implementation of the Andon 2.0. Where the former part is mostly about ensuring that the improvement proposals will be internalized and applied.

The traditional approach to the Control phase is to establish metrics which functions as performance indicators and are monitored and managed properly. These metrices have further to be displayed and shared to the key personnel responsible for maintaining the improvements. This approach will also be included in this phase limitedly with the Andon 2.0.

4.3.1 Controlling the general improvement proposals

The general improvement proposals can be divided into three categories: Practical improvements, cultural improvements and deeper improvements based on the analytical research.

The practical improvements are to be controlled by informing the right key persons about the necessity for the specific improvements. This information is delivered in three ways, of which the first is by presenting this research, the second is by distributing this research and the third is by distributing information about the practical improvements to the responsible persons. The practical improvements are presented in the Improve phase and consists of process refinement and investments in appliances and facilities. The focus in distributing this research with its results will be on revealing which exact *Rootcause Reason Codes* are overrepresented and more specifically, which components are usually the most problematic. This list is found in this research as Appendix 1.

The cultural improvement is far more challenging to control and monitor, because it is difficult to establish key performance indicators for cultural development. But the same method as for practical improvements is applied to the culture improvement, which is informing the right personnel and ensuring that the supervisors who are responsible have the incitement to maintain the improvement. In our case study we found that the biggest challenge with the culture in the module assembly has to do with the stance towards improving the process and maintaining improvements, especially when considering the logistics. Therefore, the cultural improvement should start at the top, where the information about the current situation with the logistical issues was inadequate. This was found when having correspondence with the factory material manager, who was unaware of how the deviations of the material shortcomings were reported. The next step is on the workshop level, where the workshop manager together with the supervisors and process developer is briefed about the cruciality with this specific *Reason Class.* The main problem with the logistic deviations is that they are managed inconsequently, thus a consisting way of dealing with the issue should be defined. This way of conduct should then naturally be informed to the mechanics, area responsibles and their supervisors, so that they know which is the standard manner for addressing and reporting those deviations.

The third category for improvement is a statistical follow up, which is a core element of the classical Control phase. The statistical control of the improvement should be based on the same metrics as used in this case study, in order for them to be comparable and for the management to be sure that the improvement is controlled. Metrics proposed for use are mainly the amount of deviations for different categories and *duration 1* and *duration 2* of these deviations. The amount of deviations has to be compared relatively because of the uneven distribution of them. As a benchmark, a previous comparable time-period should be used, which can be a month or a week, as long as the sample remains measurable. Currently this is visualized in the general display to a certain extent. Currently it shows the amount of deviations in the module assembly. This could be developed for displaying the amount of deviations per *Rootcause Reason Code* and by including the *duration 1* and *duration 2*.

4.3.2 Selecting and designing the adequate solution for the Andon 2.0

Access to reliable information of the assembly has shown to be a crucial part for improvement. Separate measurements and metrices can be made up for future LSS improvement projects, but they would take a significant amount of time and resources. Which would result in that the value gained relatively to the input, would probably be neutral or negative. This is especially presumable when the investigated actions and activities have a reliable occurrence and sample big enough first when the measuring period may be as long as one year. Therefore, the data for the future improvements need to be accessible and measured continuously. For this purpose, the current methods with MES have shown to result in data to unreliable for use as a base for decision making. It is worth noting at this point that the preliminary function of the Andon 2.0 is not to provide reliable data for future improvements, but to improve the processes themselves in the assembly, which was concluded in the Improve phase.

In this phase the function for Andon 2.0 was reduced from the targets of the system. The initial target of the project was to replace the MES and deliver the data directly to the system for data integration. Due to practical reasons the Andon 2.0 has to be implemented gradually, in an environment which is representable for the final use. The first step of the implementation is focusing on the possibility to report process related issues in the segment of logistics, and further, notifying the area responsibles for that specific workshop. For opening a new deviation and notifying an area responsible the functions were configured to the back office of the Andon 2.0, but the function for delivering the notification was not tested in this case study. Instead a comparison of the best solution for delivering the notification was done.

In the current situation the information of the notification is delivered in one of three ways:

- Reporting a logistic related deviation, which is seen by the area responsibles who are occasionally monitoring the deviations.

- A mechanic goes searching for the area responsible.

- A mechanic calls for the area responsible.

After the information is delivered, the area responsible starts solving the issue. The current way of conducting this notification is unreliable and increases non-value adding time in the process when the *duration 1* is high due to this inadequacy.

After discussions with supervisors for the workshop and for the logistics and also with the Andon 2.0 project team, four potential solutions were chosen for further examination. The four candidates are:

1. Twilio (SMS to cellphone) – Delivering the notification via a service named Twilio to the cellphone of the area responsibles. The strength of this solution would be its relatively low cost and duration of implementation, because there is no need to invest in new equipment. The main weakness is the modularity for future needs and the lack of the possibility to assign one specific person for the task.

2. Telegram (Message to smartphone) – A messaging application with high cybersecurity. The notification would be delivered from a bot to the team of area responsibles. The main weakness is to implement one more application and to invest in new equipment. Future modularity is also unclear.

3. Teams Bot (Message to tablet in forklift) – The teams is a versatile communication platform which is starting to be implemented for personnel at the factory. Similarly, as in Telegram, a bot would send the notification and it would be possible to assign an issue by answering the bot by messaging. For this solution, it would be favorable to utilize the tablets in the forklifts, but the purpose of getting a consistent instant response is missed. If the teams are installed to a new smartphone, then this solution is comparable with Telegram in terms of functionality but superior due to uniformity of systems.

4. A new application (used in a smartphone) – This has been under development in the factory 2, but is of a completely different magnitude compared to the previous three options. The main strength of the application is that it could be further developed according to new emerging needs. On the other hand, this is also the main weakness, it would take a lot of time to implement it and to get it up and running.

These solutions are different in several aspects. There are multiple dimensions that should be considered when choosing the best possible solution. Because of the human factor, it is challenging to just pick the best solution based on intuition. Instead methodologies in LSS value quantitative and unbiased analysis as a base for decision-making. Voehl et al. (2014: 362-363) describes the Decision Matrix as a tool which can be applied when multiple factors have to be considered. They also emphasize that the Decision Matrix is well suited for choosing alternative solutions in order to improve processes.

In our case we generated twelve attributes that were to be considered. These attributes were weighted according to their relevance and importance. The scale for the weighting was from 1-10 as well as the scale for the scores. The attributes were divided into five different groups: Financial, Implementation, User, Internal Process and Standardization. Of these the most important group was Internal Process, which was accounting for 45,5% of the weight and 5 out of 12 criterions. The second was Implementation, in which the factors affecting the implementation were considered. The decision matrix itself is shown in Table 4.

Table 4. The decision matrix for evaluating the four potential solutions for delivering the notification of a logistic deviation.

WEIGHTED DECISION MATRIX	Weight 0-10	Twilio (SMS) Rating	Twilio (SMS) Score	Telegram Rating	Telegram Score	Teams Bot Rating	Teams Bot Score	Mobile application Rating	Mobile application Score
Financial	7,8 %								
Cost of investment	2	7	14	3	6	7	14	1	2
Cost of operation	4	8	32	6	24	8	32	4	16
Implementation	23,4 %								
Time for implementation	10	9	90	3	30	5	50	1	10
Resources for implementation	8	9	72	5	40	5	40	2	16
User	16,9 %								
User convenience	8	8	64	6	48	5	40	7	56
User learning	5	10	50	5	25	4	20	4	20
Internal process	45,5 %								
Process efficiency	7	5	35	5	35	4	28	9	63
Adoptability to current systems	5	9	45	3	15	3	15	6	30
Adoptability to current needs	8	4	32	6	48	7	56	7	56
Adoptability for future systems	7	2	14	7	49	8	56	10	70
Cybersecurity	8	2	16	9	72	6	48	7	56
Standardized	6,5 %								
Alignment with factory 2	5	3	15	6	30	4	20	10	50
SCORE:			**479**		**422**		**419**		**445**

As seen from the decision matrix, one solution gained the highest points. This solution was the Twilio and the reason for its success are the categories implementation and financial. The interesting finding is the polarization in the results. The two solutions, that can be regarded as compromises received the lowest total score, whilst a completely different solution, the application, gained the second-best score. Based on the results from this comparison the Andon should be continued by implementing the Twilio, which would deliver the notification to the area responsibles. For this purpose, the cellphone numbers were collected and the names of the area responsibles were configured into the Andon 2.0.

As stated previously, one purpose of the Andon 2.0 was to collect reliable data from the assembly, in the phase regarding the *duration 1* and *duration 2* of the deviations. By implementing the solution proposed, it is fair to assume that the *duration 1* would be decreased significantly. This assumption will be confirmed when the solution is implemented to the first phase. The process for notifying the area responsible is simple and consists just of a few steps for the mechanic reporting the deviation. Despite the simplicity for the operator several steps have to happen in terms of collecting the information. Therefore, the process was designed so that, the necessary data would be collected when the system is running. This process consists of several steps which can be seen from appendix 5, the symbols are explained in appendix 6. This pilot version of the process presented in the flowchart is based on the assumption that the data is not aligned with the data from the MES. Hence, the module and phase have to be asked separately. This information is not necessary in order to do a minimal pilot testing of the solution, but it would generate usable information for deeper analysis and process improvement.

5 DISCUSSIONS AND CONCLUSIONS

This case study had a distinct nature because of the two different targets, which were managed in one study and both incorporated in the DMAIC cycle. To deal with both of these targets required us to have several approaches to the objective. The first approach was the statistical analysis based on the data defined in the measure phase. This statistical analysis gave us an understanding of the problematic elements in the process. A statistical analysis was not sufficient in itself. Therefore, it was combined by a physical monitoring of the process. These two approaches enabled us to find the crucial spots and shape necessary solutions for improving the process. The challenge in the study was to incorporate the second research question regarding the Andon 2.0 into this DMAIC cycle and this case study. As a process, the Andon 2.0 project was running meanwhile the process of answering the first research was ongoing.

The first research regarding the improvements in the assembly process was approached preliminarily from a statistical point of view, but due to the unreliable data of the assembly times, it was not possible to do any eligible conclusions only based on the data. Therefore, the focus shifted more to analyzing the deviations, which was done by creating an excel tool, described in the Analyze phase. This knowledge was combined with knowledge retrieved from the workshop supervisors and process monitoring, which led us to form several improvement proposals for productivity, efficiency and quality. These were thoroughly described in the Improve phase.

The second research question was about the Andon 2.0, which was more challenging to integrate in this case study. The main challenge was that the approach of the study was based on the research question one and the research question two had a completely different dimension. During the process there were also practical challenges with getting the module connected to the network and to proceed with the project. As results to these reasons the module was not piloted according to the initial plan. Instead the functions and solution for the notification was assessed from a theoretical point of view. Fortunately, this was possible to integrate in the DMAIC cycle, due to the potential that the module has regarding monitoring of the process. It can be concluded that the research question two was answered, but by a different perspective than the initial plan. This answer is integrated in the DMAIC cycle and is found in the Control phase.

Some general statements about the assembly process can be made. It is evident that the process is relatively new, and that there are several challenges which are typical for processes which are not established. This finding can be concluded both from the analysis of the deviations as well as based on the monitoring of the process. These issues have a simple solution, which is resources. But that would still not fix all the problems at once. Challenges with the culture and processes would still be more difficult to solve. But by adding resources, many deviations and bottlenecks would be removed. The question that should be asked is for how long will these modules be manufactured in this environment? The longer the answer is, the higher should the investments to this process be. It is worth emphasizing that this study is only about one module of the whole product. Thus, we can't presume that the assembly of this particular module is the most critical part of the whole process. This dimension was not considered in this study, but it would be worth examining the impacts for different sub-processes on the main assembly process before a significant amount of resources are directed to one specific part of the whole process.

General statements regarding the Andon 2.0 can also be made. As concluded previously in this study, the importance of developing and refining the manufacturing in order to stay ahead of the game, cannot be overemphasized. The Andon 2.0 is definitely a leap towards smart manufacturing and more efficient information flows. It is fair to argue that striving for a system like Andon 2.0 is desirable for all stakeholders. The Andon 2.0 was still too poorly defined and the targets for the project was not established well enough. This led to multiple challenges in implementation of the process. Basic problems like poor network connections were an obstacle during a period of several months, and finally it resulted in that the piloting of the system had to be excluded from this study. Another concrete example was the absence of the defined relation with the current assembly and the futured methods used in the innovation factory. Despite these challenges the Andon 2.0 should not be aborted as a project. Instead it should be better defined, and the necessary resources has to be assigned, in order to achieve desirable value-adding results. One simple reason why the Andon 2.0 is desirable, is that, if implemented properly, it enables future statistical studies like this to be carried out with less effort. Also, in terms of information distribution, it would be desirable to have reliable information to distribute for the management, which is not the current situation.

The methodology used in this study was well suited for answering the research question one. LSS is favorable in many ways for conducting case studies. The main strength is the structuring of the process, which prevents the project from escalating in terms of timeframe, targets and budget. The DMAIC cycle functions also as guideline when dividing the project into smaller segments. Another advantage is that it includes numerous tools which can be utilized depending on the case and that there is plenty of information available of the methodology both on the internet as well as in the scientific literature. The methodology is also flexible, and it is possible to customize it to a specific case, which was done in our study when the data used was sourced, not measured and when the Andon 2.0 was integrated in the Control phase.

This study answered the necessary research questions stated in the initial phases. But it also opened up more potential research objectives. These researches could be carried out in cooperation with a university or internally.

As previously mentioned, for the purpose of productivity, it is necessary to focus the improvements on the right bottle necks. Probably a Pareto effect is happening in the manufacturing between the departments also. This effect isn't necessarily apparent, and should therefore be investigated similarly to our case, but instead from a macro-perspective. One useful tool could also be a regression analysis investigating the correlations between issues in different departments and delayed production. The data for this study should be available from the internal MES system, and by finding these bottlenecks, the efforts for improving the process could be directed more effectively.

The Andon 2.0 was designed only as a pilot version. The functionalities were minimized in order to lower the threshold for the pilot testing. A proposed progress direction for this project would be to assign a team for the implementation of the pilot version with one person completely dedicated to completing the testing. This implementation should also be done in close cooperation with the team designing the manufacturing systems for the innovation factory. Such a cooperation would increase the potential of the Andon 2.0 and the possibility to get the project properly implemented. It would also provide value with long term perspective. The team implementing the pilot version could implement test the first version according to the functions defined in the process flowchart in appendix 5. As the tool for receiving the notifications Twilio could be used, as concluded in this study. Further the Andon should be developed for communicating via the system for data integration and new KPI: s could be created based on more reliable data. The functionalities should be further developed with an aim to set aside the current MES system, because it cannot be regarded as favorable to have two systems parallelly in use.

The implementation of a pilot version of the Andon 2.0 showed to be challenging when different obstacles were repeatedly encountered. After discussions with personnel from other departments it is possible to conclude that this is not an exceptional case. It seems to be challenging to implement new solutions and to really appoint personnel committed to execute new projects. The resistance towards change was obvious and should be further investigated. This could be done with an external research on the culture of change in the organization and the lack of will to commit to new solutions or procedures.

If the Andon 2.0 is not implemented as proposed, then a clear statement for operating the MES correctly should be done for this specific assembly, with the aim to get the personnel to use the system properly. This would enable the process developers or external researchers to use accurate data for carrying out a correlation analysis. For the purpose of the analysis it would not matter if the data would originate from an Andon 2.0 module or the MES. This analysis could investigate the relation between performance of different activities and the nature and amount of deviations. Such an analysis would give more accurate information about which deviations and problems are really affecting the assembly process negatively in terms of productivity.

When the amount of products under operation on the field is increasing, the sample of quality related deviations is also increasing. This data should also be analyzed compared to the quality related deviations in the production. Such an analysis could prove the hypothesis made in the Improve phase regarding improving quality.

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