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# SIX SIGMA TO IMPROVE QUALITY – COMPONENTA CASE

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SIX SIGMA LAADUN PARANTAMISEKSI – COMPONENTA CASE

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Tämä opinnäytetyö käsittelee laadun valvontaa. Työ on tehty yhteistyössä Componenta Pori:n kanssa, valimo joka sijaitsee Suomessa. Työ on prosessin hallinnasta ja kuinka parantaa yleisesti laatua muutamasta valitusta prosessita tuotantolinjassa. 3 Prosessia tuotantolinjasta ollaan huomattu tekevän huonoja tuotteita joka ylittää yhtiön keskimäärän eli 8% valmistuneista tuotteista. Kyseiset prosessit ovat muotin valmistus, ytimien sijoittaminen muottiin sekä molempien muottien puoliskoiden yhdistäminen, työ avaa näitä prosesseja analyyttisesti hypoteesein sekä parannus ehdotuksin.

Teoria, jota työssä käytetään, on Six Sigma, tarkemmin DMAIC prosessi työkalu joka tukee työtä antamalla työkalut prosessin parannukseen sekä laadun hallintaan. Toiminta-analyyttinen toimintaotetta käytetään työssä jota tukee havainnointi, haastattelu sekä työntekijöiden kommentit. Käytännön testit hypoteeseille eivät ollut mahdolisia joten oikeita tuloksia kyseisistä hy poteeseista ei saatu.

Lopullinen työ voi parantaa yhtiön työympäristöä prosessien sekä työntekijöiden kannalta, jos kyseiset ehdotukset otettaisiin huomioon. Parannusehdotukset ovat tavallisia mutta sellaisia, mitä jokainen yhtiö kannattaisi ottaa huomiooon toiminta mallissaan.

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This bachelor thesis deals with quality management. This work is done in cooperation with Componenta Pori, a foundry located in Finland. Work is about process management and how to improve the overall quality of few selected problem processes inside the production line. 3 processes inside the process cycle has been reported to make defects that results in bigger defect ratio that the company has an average of 8%. Processes in question are Sand mold making, placing cores inside mold and combining two sides of sand mold together and the work will open up these in analytical manner, with hypothesizes and suggestions in order to better them.

The theory supporting the case study is about six sigma and more specifically DMAIC process tool, which is all about making process better and improve quality of it. Action research is applied to the processes with the support of observation of the processes, survey interview as well as employee comments. Practical test for hypothesizes introduced in the work has not been done, so no actual result has not been gotten from them.

Final work can improve company's working environment in processes and within the workers, if the suggestions mentioned in this work would be taken into consideration. Suggestions are basic, but every company should look into these in their business model.

# 1 INTRODUCTION

In this thesis, there will be explained different quality management tools involved in the systematic quality management process. Six Sigma has become one of the most widely known quality management tools or toolkits within the companies that wants to improve services and cut unnecessary loss. Six sigma has 2 methods in it, DMADV (Define, Measure, Analyze, Design, and Verify) also known as DFSS (Design for Six Sigma and DMAIC. The process in here, DMAIC, will be the main focus that will be going through in the theory part as well as including the methods of the foundry itself. DMAIC consists of 5 steps to help the quality in processes: Define, Measure, Analyze, Improve and Control. Every step has their own set of tools and methods that help in the quality management and will be going through all of them.

After the theory of the quality management, there will be a real case process in the foundry. There will be a real product(s) involved in quality management process and a conducted research where did the product get faulty in the whole process and afterwards come up with improvement methods to keep the fault to not coming up again.

## 1.1 Componenta – Pori

Componenta is Finnish metal foundry founded in 1823 in Karkkila, Finland. It has another foundry in Pori and one in Turkey but in 2017, the operation was sold. With the foundries, they also has machining and painting shop in Främmestad, Sweden. Componenta manufactures parts from cast iron to different size machines and equipment. Not only do they cast, but also machine them to meet the taste of the customer.

## 1.2 Background

Idea for this thesis came from the need to fix a relatively big problem inside the company. After observing the different quality instructions for different products, the need to improve in the problem area started to rise. This problem can be seen especially in the inspection section of the company, where there are many different products that needs inspection to all kinds of different places, a thorough inspection would take too much time so all the places needs to be memorized.

After asking for details and permission for this thesis, the company decided to have the whole quality improvement for many different product, boil down to only one fault type as a focus and to limit the amount of them by creating an improvement to whatever the process it might be.

## 1.3 Problem at hand

Componenta manufactures parts to heavy machinery mostly, but do have smaller, more fragile parts to small machines. These heavy machine parts are placed into important locations, such as motors, drivetrain, transmission or rear of a truck for pulling. This means, that these parts are under heavy pressure and they need to perform perfectly in order not to make accidents happen.

The most common fault (for most parts) is related to the sand, where the parts are molded and casted. Slight mistake when pressing, pulling of combining these casts will make the sand so shatter from somewhere, allowing the sand to drop into the pit, where the metal would be poured, creating a “Sand hole” or “sand fall”.

The processes where the sand is handled is the main focus now, since it is known that these are the cause, but how to (potentially) reduce the amount of these faults is now under investigation. More about the processes after theoretical part.

## 1.4 Aim and boundaries

Aim for this thesis is to create solution or solutions for the current problems inside the production cycle. Since the problem is in the already mentioned 3 processes, this thesis won't address any other processes before or after the processes mentioned here. The main aim for this is to find solutions and suggestions to the existing processes in order to increase the current defect ratio of over 15% to the company average of 8% or less. This means, in order to increase something, company might have to invest into something.

## 1.5 Methodology

### 1.5.1 Research Method

In this thesis, Action research will be used when talking about analytical part. The observation and ideas will be in $1^{st}$ person (me or I) since hypothesizes are made by one person only. There will be also information from employees and also small survey to make analysis better which are also done by one person. Thesis uses this kind of research method because physical tests inside the foundry are not possible, so creating hypothesizes and ideas outside the foundry had to be made.

### 1.5.2 Qualitative and Quantitative research

Methodology is the validations of used data in a thesis. There is 2 types of research methods, qualitative and quantitative. Qualitative is purely based on text, words and meanings. Qualitative can have interviews and survey results as a base for a research. Using qualitative research methods allows the opinions of individuals to be brought up more easily.

Quantitative has numerical values and graphs as a data. It uses numerical data for comparing 2 or more results together to show differences in process for example. Unlike qualitative data, this allows the comparison of multiple people. For example "40% of people, who answered the questionnaire liked it, the rest 60% did not."

In this thesis, both qualitative and quantitative research methods were used. However the qualitative has been more dominant. This is due to current company situation where qualitative research has been more beneficial for the client and for the thesis. Quantitative research is used when hypothesis were made as an indication in production.

### 1.5.3 Survey research

A survey was conducted when making this thesis. The survey was conducted as an individual interview through Email. This was used in order to gather more specific information about the process and machinery used in it. The answers were used to make hypothesis about whether or not the company should change their ways of production. Questions in the interview were both quantitative and qualitative because both were required to construct realistic hypothesis about production. (Hirsijärvi, Remes & Sajavaara 1996, 180)

Before starting to write analytical part in the thesis, company suggested a visit for better knowledge of the processes and the problems. The total visits were 5, 2 being overall discussion about the aims of the project and rest 3 introduction to the processes and problems.

# 2 QUALITY AND QUALITY MANAGEMENT

In this thesis, there will be many tools explained how to control and improve quality in many different ways, but before we can start controlling and improving this, we need to understand little bit about quality itself. Every individual determines quality in service or in product, but the underlying fact is that it always answers same questions for them: Is this product/service worth the money? And the answer was yes. The definition of quality does not end there however, but that is the simplest way to put it so everyone can understand.

The definition of quality by the ISO 9000:2000 quality management systems is following: degree to which a set of characteristics fulfils requirements. This means, that the set requirements from the customer are met (taste, performance, as advertised), and it is decided that it is “quality” service or product. Of course, to another customer, the set requirements might be higher or lower in which case the judgment and verdict is totally different. (Foley & Johnson 2003, 3)

All that is mentioned above is one definition of “quality” and there are as many definitions of it as there are customers and individuals which makes it rather hard to put it in few words. However, customers can agree that the product or service did “fit for purpose”, meaning, it fulfilled a purpose that the service or product needed to fulfill in the customers mind. (Foley & Johnson 2003, 4)

Quality control can be defined as “industrial management technique by means of which product of uniform acceptable quality is manufactured”. This means that controlling the inputs that are involved in the process or service to keep the defined end result. Inputs affecting the quality are, for example, employees, materials, production/service methods or product/service design. Alongside these are many, unnamed inputs that are constantly affecting the end result and these are inputs that are impossible to control. In order to ensure the quality that is defined, constant monitoring of statistics, reviews, customer questioners or similar are essential. The objective is to keep the already accepted quality of the product or service defined by the customer, make sure that the process does not have variance in it and preventing products under the accepted quality from reaching the customer. (Naidu 2006, 5)

# 3 METHODS FOR IMPROVING OVERALL PROCESS QUALITY

The theory for improving quality overall to a process (or processes) is process called DMAIC. This consists of Define, Measure, Analyze, Improve and Control, making it ideal tool to see where and what causes a faulty product or service. It digs itself to the core, works itself to the many different aspects of the process and comes on top to keep the made improvements to stay.

The process holds many tools in its many stages for different situations. That is why it will go to almost any situation, no matter what process is in question. For every step, I am going to list 1 or more tools for that particular process step, some steps might have more than others.

## 3.1 Six Sigma as quality manager

Six Sigma method is very recent as a concept, since it was developed in 1980 at Motorola to improve Manufacturing Process Capability and later implemented to Business Process Capability. After this, many companies have taken this method into use because of its capabilities according to statistics.

Six Sigma has already developed methods and basic mathematics inside of it and utilizes them together, forming a fully fleshed method. Critical to Quality (CTQ), DPMO (Defects per Million Opportunities), Mean calculation and Standard Variation and Deviation are methods implemented inside the Six Sigma thinking. Alone, each of them handles different aspect in the quality management, but together manages it as a whole. (Deepali 2010, IV)

Companies have changed the way of thinking in the years from “how to be successful” to “how to remain successful”. The other aims to become when the other wants to remain and this is very different. This is why the Six Sigma thinking has become one of the best ways to keep up with the changes in the markets when it is implemented into the company policies correctly. At first, this was only a thing to improve the rate of defects in a process but later on also got its way through to other types of processes, like medical and services.

Why is Six Sigma so good with only the methods implemented in it? Six Sigma is not only the methods and tools for managing quality but rather a way of thinking and ambition to continuously wanting to improve the quality. If only the management thinks that this has to be in the company policies but the employees do not, it will became extremely hard to keep up with the process. Everybody inside the company has to think alike. It is obvious that companies want to keep customers happy and customers want the best products with excellent quality.

## 3.2 Lean Six Sigma

Probably the most famous Six Sigma out there is the Toyota’s Lean production, also known as TPS (Toyota Production System). It is a Philosophy, tools and techniques that eliminates the hidden waste inside production. With it, these hidden wastes will surface themselves and company can plan actions for its elimination. Lean Six Sigma on the other hand, combines these ideas, the excellent quality management and elimination of the hidden waste has to be the ultimate goal for any company. Even though it is something to drive for, it is extremely hard and requires the very company core to change towards achieving this. (BarCharts 2016, 1)

# 4 DMAIC PROCESS

Before explaining the steps in the DMAIC process, walking through the reasons and situations where and why is this used in the companies would be better way to start this. It is 5 step process that is designed to seek a problem and to find a solution for it. The steps are Define, Measure, Analyze, Improve and Control and I will be going into more detail for each steps when I am going through the process step by step.

Questions like when and why will come up when it comes to DMAIC and the answer to those are not self-explanatory either. The company most likely already knows that there is a problem or problems that needs to be solved if they keep thinking whether or not this problem solving process should be used. Since DMAIC looks deep into the process, using this when the problem is not complex would be waste of time and resources. Skipping some of the steps in the process would be advised since if some of the aspect are already known. In this case, there are also plenty, more accessible and easier methods/processes for less complex problems but you never know whether or not the process would find unexpected results with the more complex process.
Focusing on the problem area with the right tools is the main idea when trying to figure out what is the problem, of course, when the actual area is unknown, the whole DMAIC comes into play.

DMAIC is not a method that can be implemented into the company for the best practice but rather to find the best one. It follows strictly data from process, is customer orientated and focuses on solving the problem.

## 4.1 DEFINE

DEFINE phase is designed to lay the foundation for the whole process, the more work is done in this phase, the easier the rest phases will become. Since DMAIC will take great deal of time and resources from the company, before starting anything, it would be wise to check if it is even suitable to begin with. Things like: is there data available?

Is DMAIC needed or is it a case of “just do it”? (There is known method, needs to be implemented) and the most important: is the goal of this profitability, customer satisfaction or employee satisfaction? These are really important questions, since the whole process is customer driven and oriented. Many times out of ten, companies want customer satisfaction and if the company is not chasing that as number one, is this process the right one to begin with. (Deepali 2010, 41)

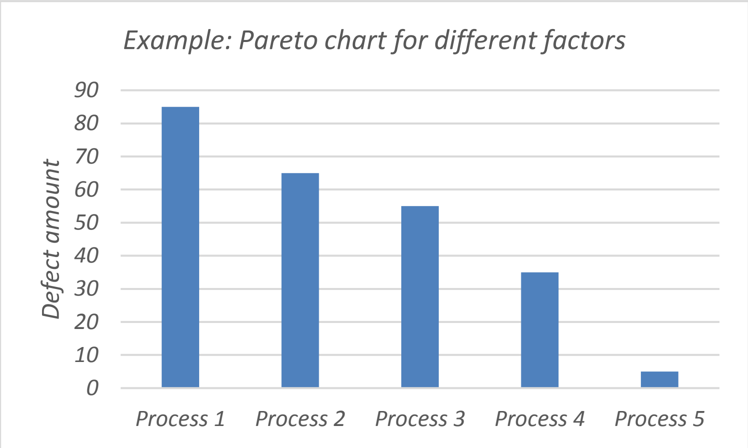
Before jumping into the process, process maps and defining the problem in more detail, few simple things to help the team keeping track on what are they working on, are Business case, The problem, Constraints, Scope, Roles and Process plan. All of these are in one or two sentences, quick black-on-white reminders for the team what are they working on. Business case is quick definition of the issue, The problem is description of what is being the problem, Constraints are the limitations of the project, Scope is almost the same as constraints but also sets both boundaries, Roles is the assigned roles written down for each member and process plan is rough timeline when and where would each process be completed. (Deepali 2010, 45)

After the team has been established and the company has identified that there is some problems with the process, the team starts the DMAIC process. The first phase being DEFINE, in which the team identifies the scope of the problem. DEFINE phase start by the team selecting the approach to the problem. There are many ways to approach a problem and DMAIC is not the only one. The project might need different tools to be used, such as COQ (cost of quality) or CAPA (Corrective and preventive action) as the improvement project approach (Shankar 2009, 6)

### 4.1.1 Pareto Chart

How is the project selected? There is helpful tool to be used to narrow down the external or internal problem, and that is Pareto chart. Pareto chart shows each category by type of customer, service offering or cause of failure. The reason why Pareto chart is used in determining the project is because it helps the organization to see, where the organization needs most attention and also it focuses on the problems which helps to find the bigger problems. In it, the vertical axel shows the occurrence and the horizontal axel all the different categories like service types, customer types or the number of different parts. By this logic, the biggest bar represents the biggest problem area and so where the company should be focusing on. Having multiple Pareto charts from different perspectives can show different problems. For example, from product perspective, the highest might be the lowest in the perspective of cost (Shankar 2009, 3)

Figure 1: Example of Pareto chart. (Anttila. K 2019)




### 4.1.2 End of DEFINE phase

In the end of the DEFINE phase, where the focus has been selected. Now, using the define phase checklist to see if all the steps have been taken. With this checklist, showing the progress to management becomes easier too. (Shankar 2009, 9)

Table 1: Example Define checklist (Anttila. K 2019)

| Example: DEFINE phase checklist | | |
|---|---|---|
| | Completion | Comments |
| Process | | |
| Pareto chart | | |
| Problem | | |
| Team Leader | | |
| Team meeting | | |
| Management meeting | | |

Above is example of this checklist. List itself if simplistic lacking extremely detailed information, but necessary to inform management about the progress. There will be example checklist in every END phase.

## 4.2 MEASURE

Now that there is a problem and goal determined for the team, MEASURE phase comes next. This phase is to gather bottom information about the problem at hand. This basic information is needed to fully understand the process (Shankar 2009, 11)

The information gathering in this phase is based on historical data if there is any. From this, the amount of times the failure has happened in recent history can be seen. This data is crucial in the last phase in DMAIC (Control) and to show the management that progress has been made.

To make the MEASURE phase much more effective and the data gathered more accurate, the process needs to be studied and the data from that to determine what might have happened. This is because not all companies keep this kind of information so the real process information compared to the fault will show the historical data.

### 4.2.1 Creating process map

To get the full grasp what is happening in the process, is creation of the process necessary. Doing so, makes understanding the process easier, showing every step in the process and it might make the finding of the problem easier also. There are multiple different maps such as SIPOC diagram, Flowcharts or Value stream map. All of these maps will do what is required, as long as all the needed information is captured (Shankar 2009, 12)

Flowchart explains the process as instructions or procedures and not as factors that influence the process, using it does not give the right information for us to continue successfully in the process. Instead of flowchart SIPOC diagram from DEFINE phase could be really useful in this case. Of course, further expanding to this is needed, since it does not yet ask the right questions. In order to get the right answers to right questions, the following things are needed:

- Understand the process in steps. Use multiple steps to make it more detailed.
- Understanding the inputs in the process. anything coming from the suppliers (inputs) needs to be meeting requirements
- Understand the roles of:
    - Personnel.  People are responsible of different steps in process
    - Machine and/or equipment. In many processes, there is machinery involved, what do they do?
    - Materials. Not all processes use raw materials, but if there is, where is it from? Was it good?
    - Methods. The person(s) in the process, did they follow methods? Are the instructions clear and does it take everything into consideration?
    - Measurements. Is there data to be collected in this process? is it correct or correctly collected? Is there quality checks?
    - Environment. Is there factor(s) that effect the process? Like humidity? (Shankar 2009, 13)

Every process step needs to be carefully investigated and each needs to answer the questions above. Having the inputs in different categories makes process much clearer. What is procedure? What is the noise factor or things that person is not able to take control? There are symbols for each category, CR for critical, S for procedure, N for noise and C for control (Shankar 2009, 14)

These were the *inputs*, where things are putted in to process, next up are the *outputs.* The outputs are indicated as Y, and the output is the expected result of the combinations of inputs. There is good to have the question “how do I know that the step is fully completed?” and to the question, the result of inputs (AKA output) is the answer.

Organizations use Input-Output model to answer these questions quickly and in one place. The model can look different from organization to another, but the bottom-line message is the same. If all that information is written there, one of the tools in MEASURE phase is ready to be used, FMEA (Failure mode and effects analysis)

### 4.2.2 FMEA

In order to use FMEA in the process, process map needs to be fully written down. The FMEA examines the process from the failures perspective. For example, the effects of the severity, causes of failure, the inspections process and how well it does function related to the failures

Failure mode in the FMEA is the ways in which the process can fail, when the Effects are the ways the failure can lead to possible waste, failed product or nasty surprises for the customer. There are few types of FMEA: Design and Process FMEA. Design is focused on the product side like the length of life cycle, malfunctions and safety. Process side focuses on finding the failure that will affect the quality of the product, possible lack of safety in the process, the satisfaction (or dissatisfaction) of the customer and the impact to the environment from different aspects in the process. Both types go around the process and product but asking different questions and like that discovering almost all (if not all) problems with the process/product.

FMEA is usually used to detect very early the failure in the process. In long run, if the failure is not dealt with, it will increase the costs a lot, compared to the money spend for discovering the failure and getting rid of it. FMEA is of course one of the many tools to discover any possible failure in process, and there are many benefits to use it like numerous choices for lessening a potential risk and cooperation between Design of the process as well as the product (Website of the Quality-One 2016)

FMEA is used when organization is doing something with their process, product or service design. Improving any of them or seeking the failure, FMEA is used.

### 4.2.3 Steps to successful FMEA

FMEA is relatively long process to go through. The process is seven steps long with important activities in each step that needs careful completion.

Step 1: Pre-work.

Pre-work consists of collection and creation of important information. The process goes smoothly when the right documents are being used. The pre-work may include FMA from past failures, boundary/block- or parameter diagram. Alongside these documents, there are things that needs to be included and/or in order to continue fluently. Here is example of things that might be needed:

- Requirements to be included
- Design and / or Process Assumptions
- Preliminary Bill of Material / Components
- Known causes from surrogate products
- Potential causes from interfaces
- Potential causes from design choices
- Potential causes from noises and environments
- Family or Baseline FMEA (Historical FMEA)
- Past Test and Control Methods used on similar products

(Website of the Quality-One 2016)

Step 2: Risk Priority Number.

Next step is to determine which failures are the most risk to the process and this is calculated with 3 different numbers which comes from 3 different tables. RPN (Risk Priority Number) has to be calculated in order to see where the team should focus This number is not very complex compared to real calculations, since it is only based on assumptions from the team. RPN is calculated with Severity, Occurrence and detection Table results. Using these with each process, will the riskiest process show up and actions can be take place. First up is Severity. (Website of the Quality-One 2016)

Severity table has few things in it. It is calculated with the help of functions, Failure Modes, effects of failure and the severity ranking. In order to fill out the first column of the table, using the previous information from processes or other failures. The table itself is pretty self-explanatory, Failures are written in anti-functions. Full function failure or unintended function failure, the potential results are written down. This same logic is applied to effects and the column is result of a failure. These effects are arranged from 1 to 10, 1 being lesser effect than 10.

Table 2: Example of severity table: (Anttila. K 2019)

| Effect | Severity on product (customer) | Rank | Effect | Severity on product (manufacturing) |
|---|---|---|---|---|
| **Did not meet safety requirements** | *Potential injuries during use* | *10* | *Did not meet safety requirements* | *Process may injure employees* |
| **Loss of primary function** | *In vehicle: Inoperational.* | *9* | *Mass callback of product* | *Product line needs to be scrapped until functions are back* |
| | *In service: unusable* | | | |
| **Loss of secondary function** | *In vehicle: Operational unless severe* | *6* | *Callback might be needed* | *Line needs to be checked* |
| | *In service: Usable unless severe* | *5* | | |
| **No effect** | *No effect* | *0* | *No effect* | *No effect* |

Next is Occurrence Table. Using past information from process fails and occurrences will help here too, similarly in Severity table. DFMEA (design FMEA) and PFMEA (process FMEA) goes hand in hand, having the most occurred failure at the top. This is mostly with the new designs because of the unknown behavior, which the company do not know yet. At the bottom are the least occurred failures or even eliminated failures. All these are given a rank which is used in the next step.

Table 3: Example of Occurrence table (Anttila. K 2019)

| *Occurance* | *Occurance data* | *Occurance in products* | *Rank* |
|---|---|---|---|
| *Very high* | *New process/ machine, no data* | *1 or more in 10* | *10* |
| *High* | *Failure in new design, Little data* | *1 or more in 20* | *8* |
| *Moderate* | *Occasional failure in hard process, High data* | *1 or more in 20* | *6* |
| *Low* | *Infrequent failure in process, High data* | *less than 5 in 50* | *3* |
| *Very Low* | *Failure eliminated* | *No failures* | *1* |

Detection table is the last number that is needed in order to calculate the RPN. Detection of a failure is extremely important in processes. There is possibility that the constant failures may increase costs, cause injuries or reach customer and effecting the relationship. The top has the failure that is hardest to detect with no design or process control. With proper design and process control, the rank and detection likelihood drop and the process has methods to minimize failure.

Table 4: Example of Detection table (Anttila. K 2019)

| Detection chance | Criteria | Rank | Likelihood | Criteria |
|---|---|---|---|---|
| *No* | *Not analyzed, cannot detect* | *10* | *Not possible* | *No contol* |
| *Not likely* | *Design analysis has weak chance* | *9* | *small to none* | *Failure mode not easily detected* |
| *Post design* | *Handling test* | *8* | *slim* | *Possible post design by audits (multiple tests)* |
| | *Fail occurance test* | *7* | *Very low* | *same, can also be detected in mid-process* |
| *Prior to design* | *More specific test* | *5* | *Medium* | *operator can detect with machine* |
| | *(as above, preformance, until fail, data trends)* | *5* | | |
| *Virtual analysis* | *Strong detection chance* | *2* | *Very high* | *Automated system can detect* |
| | *Virtual analysis almost the same as real process* | *2* | | |
| *Nothin to detect* | *fully prevented* | *1* | *Almost a 100%* | *error proof* |

Using these 3 Tables for the same processes, it can be seen from 3 different perspectives, what exactly is the most dangerous process in the company. Also, with these, the next step is called Action priority.

Step 3 Action Priority.

Now that the processes are listed in the 3 different tables, RPN can be calculated. Using this RPN, the process that does need the most attention can be seen. The most severe failure does not mean that it should be focused on, if the occurrence or detection is low on it. The decision should not be done solely on the highest RPN but after discussion in team. Afterwards giving all members assignments when the best process has been voted, preparing the actions can be started. (Website of the Quality-One 2016)

Table 5: Example of Risk Priority Number (Anttila. K 2019)

| *Risk Priority Number (RPN)* | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | *Process 1* | *Process 2* | *Process 3* | *Process 4* | *Process 5* |
| *SEV* | *10* | *4* | *2* | *5* | *7* |
| *OCC* | *2* | *8* | *10* | *5* | *8* |
| *DET* | *2* | *7* | *9* | *5* | *1* |
| | | | | | |
| **RPN** | *40* | *224* | *180* | *125* | *56* |

Step 4: Taking Actions.

The purpose of the whole FMEA is to find the failure and to come up with counter measure for it. Successful FMEA is situation, when process/processes have been dealt with proper counter measures, but if after actions the failure occurs in the same rate or is as severe as before, the FMEA was non-value added and team needs to re-evaluate the processes, failures or actions. (Website of the Quality-One 2016)

Step 5: Evaluating RPN after actions.

When actions have taken place to certain failure, the team needs to use the severity, occurrence and detection table again to the specific process which had the problem. Evaluation takes place because organization needs to know if the actions have been successfully reducing costs and risks. This is the part where everyone will know if further actions needs to take place. After evaluation, the new value and the previous RPN value will be compared for full understanding of the effect of the actions. Afterwards the team will know if something needs to be done. (Website of the Quality-One 2016)

### 4.2.4 Process sigma

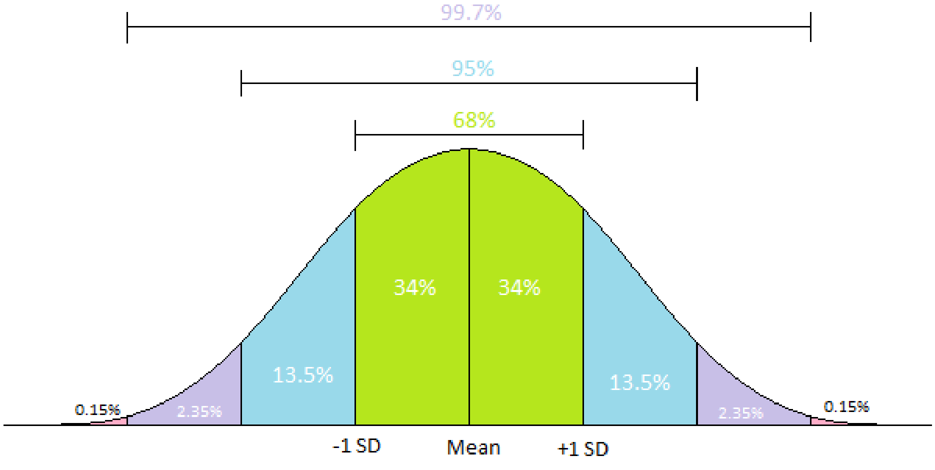
Process sigma is a tool to calculate the defect rate in processes. Sigma itself is a tool to measure the quantity of defects and/or failing to meet the requirements from the customers. Process sigma, as the name suggests, measures if the process itself is capable of meeting the requirements.

Following the process sigma can result in 3,4 defects per million or rate of 99,9997% of not getting defects in the process. This, of course, is all up to the customer specifications. However, most of the times, companies do not aim towards this level of quality for few reasons: it is really expensive and in some cases might change process in a way that it might have other trade-offs. By doing this, would change process into reliable and consistent form but in most cases, it might be too much for the company. (Deepali 2010, 49)

Process Sigma most commonly uses mean and standard deviation as a tool/graph to show the information. Standard deviation shows the spread of information and with it, what is the most common (mean) result from the information that has been inputted. The very right and left represents the extreme cases which happen very rarely (thus being very small and far away from the standard). (Shankar 2009, 20)

After the needed information has been gathered, the deviation and mean can be calculated. 2 very important information's are Voice of Process (VOP) and Voice of customer (VOC). Upper and lower control limit needs to be calculated and this is done by the following calculation = Mean + 3 x standard deviation. The lower is done the same, except Mean – 3 x standard deviation. With this, VOP has been calculated. This tells the standard results in the process, but in order to know if these results are acceptable, voice of customer is needed to be compared with. This cannot be calculate, since it is far easier to ask the far ends from the customer itself. Having the information from the process, this needs to be compare with the far ends in VOC and ideally it needs to be narrower than the VOC. In that case, process is meeting far more often the requirements, but if the process is more flat than VOC, the process, unfortunately, fails to meet requirements far too many times that it might result in losing the customer. (Shankar 2009, 21)

Figure 2: Standard Deviation. (Website of the Biology for life 2017)




### 4.2.5 End of MEASURE phase

The end of Measure phase, same as Define phase, will end in the check list to keep track of all the tasks done. The check list contains the upper mentioned tools and tables nicely summarized. With this checklist, it is also easier for the team to make up a presentation for the company head about the changes. This is also perfect opportunity to voice suggestions or improvements to these done tasks and how to go forward from here. (Shankar. 2009. 30)

## 4.3 ANALYZE

In the process of DMAIC, the Analyze part goes into practicalities and testing the result to many calculations and tables from Measure phase. By doing so, less important inputs are being eliminated from the equation and only having the major inputs left. (Shankar 2009, 41)

The ultimate goal of this phase is to identify the root causes of the problem in the process and afterwards confirm these with the collected data. (Deepali 2010, 51)

The team narrows down the options in so called Analyze Cycle. The team will combine their own experiences and data from the process and creates an initial guess or hypothesis of what would be the problem from these. Depending on the size of the team, this analyze cycle will take time to do. A small time will obviously create a lot less hypothesis than a larger one which results in longer cycle and longer indentification of the problem. 5 to 10 man team will definitely create valuable hypothesizes for the process and most likely some of them are in the right tracks. This continues until the best hypothesis is refined (and tested) and in the end the root cause is found. (Deepali 2010, 54)

Analyze phase begins in having greater data from the processes after the changes have been tested out. These result are then used in one or more tools to see, if the changes are working as intended or are they creating more unwanted effects to the process? These tools can be Hypothesis testing, Correlation and regression or Analysis of variance (ANOVA). One or more tools can be used as long as the needed data is being collected.  (Shankar 2009, 41)

The first mentioned tool, Hypothesis testing works in asking questions and to claim something happened. If the statement in this situation is true, hypothesis is null hypothesis (H0). Claiming that the process will be resulting in A but will result B, the hypothesis is alternate hypothesis (H1).

### 4.3.1 Hypothesis

In order to make a hypothesis test, the state of the null hypothesis needs to be stated, since this is the "nothing happened" statement. For example, if the process needed to be more efficient and faster, the hypothesis should sounds like "The new process method efficiency takes greater or equal amount of time than the old", the"=" is statement that 2 factors are the same, and in this case the new process method did the exact same amount than the new. Alternate hypothesis would be "The new process method efficiency takes less time than the old" (Shankar 2009, 42)

Hypothesis test has a lot of depth to it and a lot of different situations:

- One or two tail test (alternate hypothesis has greater or less than's in it, otherwise null )
- t- and Z-test. (t-test has less than 30 test samples and standard deviation unknown. Z-test is opposite)
- one or two column t-test (one sample has one column or historical data, two columns compares two sample data)
- one or two sample Z-test
- Means or propositions (t and Z-tests are for mean. propositions are when there is attribute data). (Shankar 2009, 43)

In hypothesis, risk will be factored in too. The risk is called Alpha risk and the symbol is P. Since it is only based on assumption and gut feeling, it is most commonly given the value of 5% (.05) in deciding to reject the null hypothesis. Meaning that the observation has 5% chance of being wrong. Deciding against the initial decision, makes the error Type I error, so incorrect rejection of null hypothesis, the other error type is Type II error, so incorrect acceptance of null hypothesis

The value can be from 5% to 10% depending of the confidence level. When deciding if the hypothesis is incorrect or not, the risk level takes place in the equation. When something needs to be determined, for example if production increased or not. (Shankar, 2009, 43)

### 4.3.2 Correlation and Regression

Correlations and Regression are tools to calculate the correlation or regression of 2 values. Correlation looks at the 2 values and tries to find out if they have something to do with each other, for example value X increases and so does the value Y. This means, these values have correlation between them. There are few types of correlations: X increases and Y increases, X increases and Y decreases (vice versa) or both numbers stays the same. These cases have marks to represent the link between them, and they range from +1 to -1. R=1 shows that the values have 100% correlation between them. When the X changes, the value Y increases. R=-1 shows that the values has 100% correlation between them, but this time either X or Y increases, the other decreases. Finally, R=0 shows that there is no correlation between the values, X changes but won't affect the value Y. (Shankar 2009, 48)

These test can be only run when the values are both either variable or continues data. In correlation, the commonly used coefficient is called the Pearson correlation. It quantifies the strength of the link between the two values. (Shankar 2009, 48)

This correlation can also be used in combination of hypothesis. For example, null hypothesis: There is no correlation between X and Y. alternate hypothesis: there is correlation between the X and Y. Similarly, when calculating P value, when it is less than the alpha risk (.05), reject null hypothesis and there is correlation between the X and Y. If it is larger than the alpha risk (.05), fail to reject and there is no correlation.

When the correlation calculation compares the 2 values and seeks correlation, regression quantifies the relationship between the 2 values. This test can be only done after the correlation and seen the relationship between values. Regression uses the same values as correlation, X and Y. X represents independent value and Y dependent value, or in some cases response. In graphs, regression is shown as a line, or a curve and the equations of the line is called regression equation or prediction equation. This can be used to predict the values of Y when the value of X is changed. In regression, low P value when comparing to alpha risk shows, that the regression equation is “significant”. (Shankar 2009, 49)

Regression contains one important value: R-sq. This is also known as coefficient of determination. It explains the amount of variation between the X and Y. This can be explained, for example, the more X increases, the more or better Y increases. This is shown as percentage and the percentage, let’s say 30%, and shows how much the X is attributable to the value Y. (Shankar 2009, 50)

### 4.3.3 ANOVA

ANOVA (Analysis Of Variance) is pretty similar to already mentioned hypothesis test, where the null or alternate hypothesis is stated to see the effects in process. Hypothesis has the two, null and alternate similar to ANOVA, but ANOVA is many times more complicated with the values is has in it. In null hypothesis case, everything is equal, so nothing changed and when rejected (alternate), statement changed. ANOVA, null hypothesis is same, but the effecting values are in greater numbers, so it is very possible to have alternate in it. Alternate in ANOVA has to have at least one mean different to state that the hypothesis is alternate. Of course, further tests needs to be made to determine which value is different. (Shankar 2009, 53)

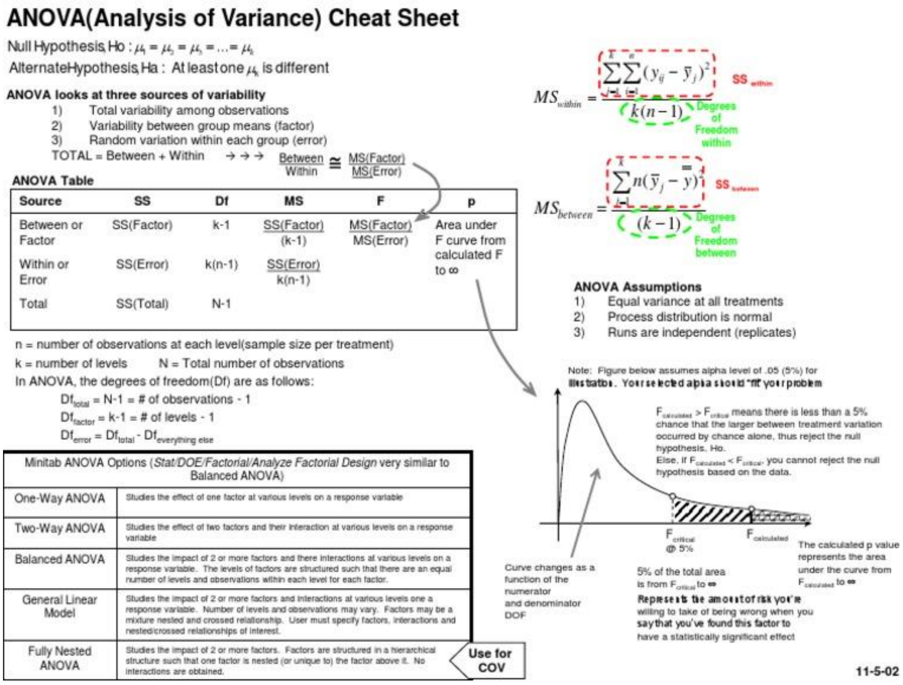
Like in hypothesis test, ANOVA has one and two way test. Like the name suggest, one way has only one input factor and two way has two. Test can be anything and the factors are simple things like effectiveness of materials in tools or grip power of different leathers. These one factor test are one way, but in two ways, there is two factors and using the previous examples, these could be two different materials, first factor as material A and second factor as material B and see how the materials are handled. The point in two factor one, is to have as many second factor option as the one to have the best result. Setting up an ANOVA is pretty easy: Factors are needed, either one or two. In two way test, same amount of factors are needed. Final output is also necessary, why is this test conducted in the first place? Doing a test and collect data and input data into software. From the remaining data (residuals) must be gathered in random patterns. This means, no slopes or fans. (Shankar 2009, 53)

In one way ANOVA, as long as the P value is smaller than alpha risk (reject null hypothesis = one or more is different), so called "Tukey test" can be done. Basically, Tukey test, if there is 0 values in the data, it means there are no different in the means. If, on the other hand, the readings show all negatives or positives, then it means that the means are different. The two way ANOVA does not need the Tukey test, because significance (P is smaller than .05) from the factors and interaction P values. (Shankar 2009, 54)

There is cheat sheet created for ANOVA to help out with the results. One example below. (Shankar 2009, 55)

Below are listed many ways of conducting the Analyze phase and using them will come up with really good data, but even though there are many ways of doing research, does not mean they would be the right ones to find the answer to a problem. That is why the hardest part in this phase is choosing the right tools. (Deepali 2010, 54)

ANOVA cheat sheet (Website of the Scribd 2017)




### 4.3.4 End of ANALYZE phase

End of Analyze phase, like all the above, ends the same. Using the checklist below to check every action taken. Using this list, progress can be explained easily to management and other higher ups in company. (Shankar 2009, 65)

Table 6: Example of Analyze phase checklist. (Anttila. K. 2019)

| *Example of End of Analyze Phase checklist* | | | |
|---|---|---|---|
| *Items* | *Completion* | *Comments* | |
| *Hypothesis* | | | |
| *Correlation* | | | |
| *Regression* | | | |
| *One/Two way ANOVA* | | | |
| *Communication according to contract* | | | |

## 4.4 IMPROVE

Improve phase is the phase where all the information from analyze phase is taken and DOE is conducted (design of experiment). All the test from the analyze phase tells different side of the process but from hypothesis, it can be seen if the calculated guess worked. If it shows it didn’t, something else needs to be developed instead.

The ideas for improvement comes from the project team. The most ridiculous ideas from brainstorming sessions are needed in order to see the many aspects (even if they might be ideas that can be implemented) of the process. In fact, this type of brainstorming is encouraged, “thinking like a child” and “the truth comes from child’s mouth” are terms what might be just needed in order to fix a difficult problem. (Deepali 2010, 54)

### 4.4.1 Design of Experiment

DOE uses inputs and outputs from the process so the model needs to be modeled according those. In DOE, the process is modeled mathematically model using the significant input factors from the previous phase and make it so, that the values would have better relationship, and any person would have better control over them. (Shankar 2009, 67)

Now, DOE uses the statistics from the Analyze phase and specifically from ANOVA. The most significant points in the ANOVA (The points that affects the process the most) should already be known. This information is really important because designing the experiment becomes a lot easier when the values are known that the team would like to change. However, knowing which area in the process has the significant values, does not mean it needs to change. When the whole process is known, looking at the values and to which process step those values belong, it should not be hard to determine which step should be changed.

DOE has few easy steps in it. From the start, output needs to be defined(Y), meaning, what is going to be measured and how? Are there any tool that are going to be used to help with the measure? Next up are the input factors (X). These are the values that will be in control in the experiment. Changing these value, will change the output. Ideally, the wanted output value is achievable by changing these values. Consider the most significant values in the ANOVA. When designing something new, the estimated cost and time needs to be calculated. How long, how much and who will be in the process are information the company heads wants to know. (Shankar 2009, 68)

Before starting the experiment, it is always good to remember to work within the safety regulations in the company. So making sure the experiment does not go over any of them and put someone in harm. After all these conducting the experiment is next.

When starting the experiment, it is always good to be present during the tests. It might be easier to give this task to someone else, but for getting the full understanding, at least one of the team members should be present. The results from the experiment are then written into the computer software which also makes the experiment run randomly eliminating any biased actions and giving best result. Results are then analyzed and from these, the team can start making decisions in which way the experiment went and is the new solution any good. (Shankar 2009, 69)

The selection of the ideas from the test and brainstorming is the last thing in this phase. To select the best improvement idea, including the people involved in the process design in the company, will clear out many questions in the DMAIC project group. The group needs to know if some of the decisions are within the budget- and timeframe for the company. Implementing the idea is also very hard for the project team since they do not know how to actually place the ideas in the process itself. (Deepali 2010, 55)

### 4.4.2 End of IMPROVE phase

End of Improve phase has check list for the team to check progress and make report for the management.

Table 7: Example of Improve phase checklist. (Anttila. K 2019)

| *Example of end of improve phase checklist* | | |
|---|---|---|
| | | |
| *Things* | *Completion* | *Comments* |
| *DOE* | | |
| *R&R before DOE?* | | |
| *Communication according to contract* | | |
| *Meeting with management* | | |

## 4.5 CONTROL

The final phase of DMAIC is the control phase. This phase happens sometime after the improve phase, purely because the process needs time to collect data for the control phase. After enough data has been cumulating, can the control phase begin. If the control phase shows that the wanted results (number of faulty products from process) is true, it can be conclude that the new, improved process model is in fact better and will decrease the costs to the company. (Shankar 2009, 95)

End of CONTROL phase, below is example of the list of items that were in the CONTROL phase. Control phase has a lot more in it, but depending on the process itself what kind of actions should be taking place so listing them up is relatively difficult. It contains the updated maps for different processes such as Process map, FMEA or even Process capability. In the end of the whole DMAIC, calculating the financial and even the raw material input, did the team manage to come up with something that reduces costs or raw material loss? (Shankar 2009, 100)

Table 8: Example of control phase checklist. (Anttila. K 2019)

| **Example of control phase checklist** | | |
|---|---|---|
| **Things** | **Completion** | **Comments** |
| *Mistake-proofing* | | |
| *Control plan* | | |
| *Updated documents from previous processes* | | |
| *communication according to contract* | | |
| *Meeting with management* | | |

# 5 DMAIC IN THE COMPONENTA CASE

The DMAIC project is a long and hard process to be used in any situation. Because of the current company situation, there will be only analysis of the problem and hypothesizes about the possible problem that is in correlation with the defect ratio and quality. There will be analysis of the problem to each process, then hypothesis for possible solutions from different aspects. There was 5 steps inside the DMAIC process, but this will only have DA and I to help the company. Measure phase will be skipped since the processes has been known for a long time. There would have been DOE as well, if the situation would have allowed it, but doing experiments to the hypothesizes is not possible due to the situation and also, changing anything within the production that is almost 24 hours a day, 7 days a week working, is really difficult.

After the theory part, next up is the analytical part of the real problem inside the foundry. The target problem has been discussed with the company and the observation of the processes where the problem has been investigated in order to make any analytical thinking.

The foundry (like many manufacturing fields) will always suffer from faulty products that will not meet the requirements of the customer. This means that these faulty products will not go to customer and the company manufacturing them will only make loss, so getting rid of them is a real battle.

In one of the meetings with the company, it was decided to investigate one fault type and make an investigation to that. There are 94 different fault types inside the company, ranging from missing to different faults with the sand (mold) or even metal having insufficient amount of material. From these 94 fault types, the most common are to do with the sand molds. Sand hole and sand drop (sand inclusion) are almost the same kind of fault since they look the same but in a way the hole is in both of them so we will be referring the both of them as sand hole.

# 6 DEFINE - THE PROBLEM

The following information is the deciding factor for this project entirely. From these, it can be concluded, what would be the best targets for investigation?

Below, are the list of 11 different products with the top 4 fault types listed. As can be seen, the 2 types of fault I mentioned in previous chapter, sand hole and sand drop are almost the same fault and we can see from these, that it is the most common and sometime by big margin too, which ultimately made the decision to take actions. There will be pictures from the processes in question including picture of one of the products in the list

| | | | | |
|---|---|---|---|---|
| | | | 1,103 | 17% |
| 1121/1062 | F3 Sandhole | | 178 | |
| 1121/1046 | E7 Sand drop | | 71 | |
| 1121/1131 | K2 | | 36 | |
| 1121/1030 | D1 | | 23 | |
| | | | 360 | 15% |
| 1121/1046 | E7 Sand drop | | 186 | |
| 1121/1030 | D1 | | 57 | |
| 1121/1062 | F3 Sandhole | | 55 | |
| 1121/1182 | P3 | | 54 | |
| Tulos | | | 472 | 33% |
| 1121/1030 | D1 | | 245 | |
| 1121/1062 | F3 Sandhole | | 201 | |
| 1121/1190 | R1 | | 31 | |
| 1121/1131 | K2 | | 30 | |
| | | | 539 | 28% |
| 1121/1020 | C1 | | 176 | |
| 1121/1046 | E7 Sand drop | | 160 | |
| 1121/1081 | G2 | | 59 | |
| 1121/1190 | R1 | | 57 | |
| | | | 513 | 12% |
| 1121/1061 | F2 | | 151 | |
| 1121/1046 | E7 Sand drop | | 133 | |
| 1121/1062 | F3 Sandhole | | 59 | |
| 1121/1033 | D4 | | 21 | |
| | | | 368 | 19% |
| 1121/1131 | K2 | | 380 | |
| 1121/1062 | F3 Sandhole | | 150 | |
| 1121/1190 | R1 | | 71 | |
| 1121/1069 | F10 | | 47 | |

| Reason | | | KPL | % |
|---|---|---|---|---|
| 1121/1062 | F3 Sandhole | | 386 | |
| 1121/1190 | R1 | | 169 | |
| 1121/1030 | D1 | | 132 | |
| 1121/1046 | E7 Sand drop | | 31 | |
| | | | 800 | 14% |
| 1121/1131 | K2 | | 512 | |
| 1121/1190 | R1 | | 421 | |
| 1121/1062 | F3 Sandhole | | 383 | |
| 1121/1030 | D1 | | 199 | |
| | | | 2,063 | 17% |
| 1121/1046 | E7 Sand drop | | 340 | |
| 1121/1062 | F3 Sandhole | | 63 | |
| 1121/1030 | D1 | | 36 | |
| 1121/1190 | R1 | | 15 | |
| | | | 473 | 19% |
| 1121/1046 | E7 Sand drop | | 341 | |
| 1121/1061 | F2 | | 126 | |
| 1121/1182 | P3 | | 78 | |
| 1121/1190 | R1 | | 61 | |
| | | | 675 | 55% |
| 1121/1062 | F3 Sandhole | | 273 | |
| 1121/1061 | F2 | | 147 | |
| 1121/1046 | E7 Sand drop | | 42 | |
| 1121/1190 | R1 | | 35 | |
| | | | 563 | 12% |
| 1121/1131 | K2 | | 500 | |
| 1121/1062 | F3 Sandhole | | 270 | |
| 1121/1030 | D1 | | 168 | |
| 1121/1190 | R1 | | 58 | |

Figure 3: Product list with different fault types. (Anttila. K 2019)

Like mentioned, this problem is by far the most common and from personal experience I can say so myself. Most of the occurring defect types comes after the pouring because there is many variables that can change during and after the pouring process. Fortunately, sand inclusion (sand drops) only occur in already defined processes, so the next thing we need to figure out is what is causing them inside the processes.

During my visits, I took few pictures showing this particular defect in an actual product. Because of these, the structure of the metal is different and can shatter in use. Even though it seems little, the hole has potential to go deeper into the metal, changing, for example, the level of stress the product can withstand.

Below, I have 3 different pictures of this fault, ranging from larger, more prominent to smaller and harder to see sand holes. Each of them are a fault and cannot be shipped to customer.

Picture 1: Sand hole. (Anttila. K 2019)

Picture 2: Sand hole. (Anttila. K 2019)

Picture 3: Sand hole. (Anttila. K 2019)

# 7 ANALYZE - THE PROCESS

After defining the problem with the company and getting the goals ready, I visited the company few times in order to know the process better, to get insight to the problems in the process and also take pictures to illustrate the process.

The process, in which the fault comes, is in 3 parts. First one being making the sand molds. Componenta uses so called “Green sand” which, even though the name suggests, is not green by color, but the state of the sand. Green sand is wet sand with mixture of things in it, and the reason it is called green is because the wet state is not “set” or uncured state. The sand can have 3 different kinds of sand (silica, chromite or zircon), bentonite, water, inert sludge and anthracite. There are different ratios to the mixture and they change in order to change moldability, surface finish and the ability to degas the hot metal.

The second process is adding the cores into the bottom half of the sand mold. Employee grabs the core and places it inside the mold as intended and so it would not t ouch or break the sand. There can be other parts added into the mold to help the metal to shape. This core allows the metal to shape in differently, without them the metal would fill out the area.

Finally, the third part is combining the 2 sides of the mold, making it as one big mold where the liquid metal will be poured. This process does not have that many things that could be changed, but I will be providing my best analytics as possible.

In these 3 parts the sand hole comes, and only these. This makes finding the problem a little easier, but no means easy. Componenta has tackled these problems for years with some results but since it keeps happening and also keeps surprising the management, some actions needs to be done.

## 7.1 Analyze – The problem

From my visit to the company, I have gathered information what previous problems have been and I am going to explain this in order to make hypothesizes for possible solutions. I am going to divide this into 3 parts, since the problems have occurred in all of them, I listed the 3 processes above.

I will explain the processes in more detail with pictures and afterwards, in the Analyze – hypothesizes I will go in more detail the observations in the visits.

### 7.1.1 Making the sand mold

The three processes start from making the sand mold by pressing the sand against the plastic (can also be made from metal or wood) shape. There are two of the plastic shape molds in the machine, and while the other side is pressing the sand, the employee cleans the mold from excess sand and wets it, in order for the sand to stick better. It takes up to 30 seconds for one shape to be pressed, so 1 full minute for full rotation.

The pressure and the nature of the green sand, it keeps the shape. This is why it is important to get the green sands rations right, since when the sand and the plastic shape separates, the sand cannot crack. This results in the problem, the sand drops inside the mold and when the time is to pour the metal in, the small sand makes the little drop like shape in the metal.

Picture 4: Making the sand mold. (Anttila. K 2019)

### 7.1.2 Placing cores inside the mold

Like mentioned in the Making the core – section, this is where the biggest problem is hurry. Most of the products are easier to handle and there is no need to work fast, the products in the Figure 3 have few things in common: very hard shape to handle or the mold has many pieces in it to make the second process hard for the employees. When the employee needs to work in a hurry, it is common mistake that the core placed inside the mold, hits the edge of the mold itself and cracks it a little and leaves the sand inside the hole.

There is also possibility that these cores inside the mold hole, weighting down the sand and causing it to crumble a little underneath. Smaller cores won’t do this due to the light weight, but with the bigger ones it is always a possibility. Changing the solution in the sand to match the weight would fix it, but it would also change other characteristics of the sand. It would also fix that problem with other products too (Website of ScienceDirect 2019)

Picture 5: Cores inside mold. (Anttila. K 2019)

### 7.1.3 Combining the 2 sides of the mold

The final process in this is combining the top and bottom mold together, forming the complete mold where the liquid metal is ready to be poured. This, alongside the first process, is fully automated and there is no employee involved in the combining of the parts. It is extremely precise process and have had its fair share of problems in the years and still it needs some work. If the 2 molds are not lining up perfectly, the cores inside the bottom half will chip away the sand in the top mold. Because of that, pinpointing some of the causes in this process is easy and hard at the same time, since it is automated.

Picture 6: Machine combining the 2 molds. (Anttila. K 2019)

## 7.2 Analyze – Hypothesizes

Now, since the problem processes are known, the next step is to think of different possible solutions for the processes. Because of the situation in the company and since it is running full time, it is really hard to conduct any actual tests in this short time, and because of this, there is only going to be ideas and suggestions to many different aspects in each process involving different solutions from the internet posted by different foundries having the same kind of issue. I will be doing the analysis, based on my observation, interview and employee comments. The hypothetical result in each chapter is "If this aspect is changed, the defects will go down".

## 7.3 Analysis from different cases

The following quotes are from different papers provided by Academia. These papers are from different foundries and their statements to the processes in question and how did they figure out the sand inclusion problem in their processes. I will be using these also for my analysis.

According to, ”The critical casting defect in cast iron: sand inclusion – review”, thirty to forty percent of all defects in a foundry is a sand inclusion. There is few types of sand inclusions and sand drop, the one that is under the investigation in this thesis, is one of them.

A direct reference from website of the Academia “a defective casting is the result of reasons like movement of sand mould wall or collapse of core. Inadequate ramming, cores in green state, incomplete drying of cores etc. were the reasons considered for enlarged mould resulting into oversize, overweight and defective casting. The weighing or measuring technique is discussed to find iron casting soundness of any weight, size or shape.” (Deshmukh & Sarda 2015, 33)

Componenta have had problems with the sand before and this is why it cannot be overlooked this time, even though it might be good to other products. With the phrase from the website of Academia, it can be assumed that the pouring process (after the 3rd process investigated in this thesis) could also be one of the causes of the sand inclusions defect.

A direct reference from website of the Academia “insufficient cohesive strength of sand, poor gating, defective drying of mould and core, improper casting and mould design, poor green strength, improper alignment of mould halves, careless pattern removal, failure to use nails and gaggers, poor condition of pattern, varying strengths developed in different layers of mould. The precautions like gating system redesign and relocation, mould cavity reinforcin, timely mould repair and due care while moulding, provision of more draft, provision of aligning devices, correct pattern stripping, use of nails and gaggers etc. should be taken to avoid the sand inclusion defect.” (Deshmukh, Sarda 2015)

This quote is really important also for Componenta, since the sand itself needs to be correct in order it not to get broken during these processes. The plastic molds could also be the reason for these poor molds, but unfortunately there is very little that can be done. It also states, that poor aligning of the device can result in the forming of the sand mold

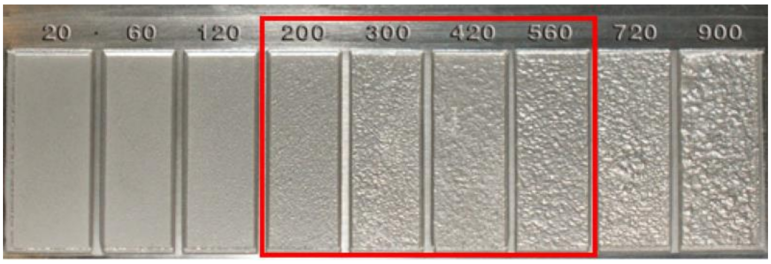
### 7.3.1 Making the sand mold

There are few factors that can be the cause of the problem: the sand is bad in some way, the pressing is done too quickly or it is slanted, the mold itself has something on it preventing the mold from forming. Or it is taken too quickly out of the mold.

From these, either the machine has sometimes problems, the mold or the employee. Machine is really old and has been in repair many time before so it can be assumed that it might be the biggest reason (in this process) that makes defects. Like one Academia paper stated, Poor alignment of the mold can and will break the mold. New machines costs a lot, so buying spare parts would be the wisest. The machine is used in many different foundries so there are manufacturers that do sell parts for these. Buying a whole new machine is always an option to keep the quality of every product up but in the current situation, not recommendable.

One of the Academia papers stated, that different methods will decrease sand inclusion, and since the aim is to improve the quality of the process and to find a way to avoid the sand holes from forming inside the product, different method could be taken into consideration in Componenta's case too. This, however, is the most expensive way of trying to make the process better. One way is to use resin sand casting. While green sand casting uses green sand, resin casting uses resin sand. It is formed with the combination of phenolic resin, urea-furan and chemical catalyst which makes the sand extremely hard and in casting, smooth outer surface and lesser sand inclusion defects. (Website of the FV Cast 2019)

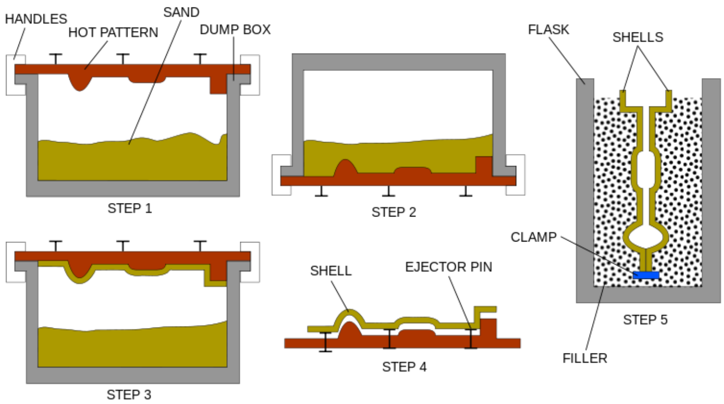
The reason why this might not be the best for the company, is the production time and the additional costs it comes with. It requires the new chemicals and extra time to be done with the mold and also the fact that it is better to be used when the manufactured product is extremely big. (Website of the FV Cast 2019)




Picture 1. Resin sand casting surface quality. (Website of the FV Cast 2019)

Similarly to green sand casting, shell mold casting also has the pouring done into expendable mold. However, this method uses few extra steps when it comes to making the molds. Like green sand, the both sides of the mold are made separately and combined afterwards, the shell casting does not use the pressing process like green sand does but makes a shell like sand pattern inside the mold. This happens when the sand hits the preheated pattern and will be let to sit there for few minutes, resulting in smooth surface, hard shape. (Website of the FV Cast 2019)

Figure 10. Shell casting step by step. (Website of the Wikipedia 2019)




### 7.3.2 Placing cores inside the mold

All the work in this part is done by an employee making it human error every time defect happens. The defect type that is under investigation is the sand drop and from all of the processes, this one has the potential to be the biggest issue. The management has mentioned that the employees have hurry in these certain products because of the sheer amount of the products inside the mold.

Logically, it comes from hurry since the work load is not that huge otherwise and that is why it might be wise to try reducing the amount of products inside the mold or slowing the machine down. The latter of course results in all around slower manufacturing since the machine works at the same speed for every product. Recalculating the standard would also be wise to do, every new employee cannot keep up with the more experienced ones.

If we would follow the idea of reducing the amount of molds inside one of the products (Picture 5) how would it affect the production and costs? Using the normal production speed of 700 mold/shift and the current defect ratio of 14% and compare that to the hypothesis of “reducing mold amount will increase quality”, what would happen? I have created a table to illustrate, with made up material costs and selling prices, what would the profits look like. Below, the table shows that having the company maximum average of 8% defect ratio, production of good products is lacking and profits are little less than the normal mold amount, but when it comes to profit%, we can see that with this, the company makes potentially more since they won’t invest as much in materials.

Table 10. Example 1 of quality vs. quantity (Anttila. K 2019)

| Production | Mold amount | Ready | Defect % | Defects | Good products | | |
|---|---|---|---|---|---|---|---|
| 700 | 6 | 4200 | 14% | 588 | 3612 | | |
| 700 | 5 | 3500 | 8% | 280 | 3220 | | |
| | | | | | | | |
| cost and profit example | | | | | | | |
| | materials | wages/h (8) | | Selling ready | defects | Profit€ | Profit% |
| Production | 100 € | 12 € | | 200 € | | | |
| 4200 | 420,000 € | 2,880 € | 422,880 € | 722,400 € | 588 | 299,520 € | 41% |
| 3500 | 350,000 € | 2,880 € | 352,880 € | 644,000 € | 280 | 291,120 € | 45% |
| People working | 30 | | | | | | |

But if we assume that the max production in the molds is 1000 molds per shift, that is 125 per hour and 2 molds a minute. Component could produce 6000 thousand of the product in picture 5. It can be assumed also, that the defect rate would go up a little from 15% to 20% meaning that 1200 defects and 4800 ready products. Compared that to the lesser production of 5 per mold, 5000 thousand overall production, decreasing the defect ratio to the company average of 8%, the result is 400 defects and 4600 ready products. This is why the question is important since we would be able to use the defect products on later date for the same or another product. Reworking the defect materials means another production cycle, takin more time from other products and potentially creating more defects. Under this, is example of this with example material costs and selling costs as well as hourly wage of the workers. Even though, they would have more ready products, the material costs compared to the profits, the percentages are far less than in the 5 mold model. This can change depending on the real costs and selling prices, but it shows some truth in it.

With these 2 tables, it can be seen that the more they produce with the better defect ratio (even though the mold amount is less), they will increase the profit% ratio between the 2 amounts.

Table 11: Example 2 of quality vs. quantity (Anttila. K 2019)

| Production | Mold amount | Ready | Defect % | Defects | Good products | | |
|---|---|---|---|---|---|---|---|
| 1000 | 6 | 6000 | 20% | 1200 | 4800 | | |
| 1000 | 5 | 5000 | 8% | 400 | 4600 | | |
| | | | | | | | |
| cost and profit example | | | | | | | |
| | materials | wages/h (8) | | Selling ready | defects | Profit€ | Profit% |
| Production | 100 € | 12 € | | 200 € | | | |
| 6000 | 600,000 € | 2,880 € | 602,880 € | 960,000 € | 1200 | 357,120 € | 37% |
| 5000 | 500,000 € | 2,880 € | 502,880 € | 920,000 € | 400 | 417,120 € | 45% |
| People working | 30 | | | | | | |

### 7.3.3 Combining the 2 sides of the mold

The last process has the least problems after analyzing the situation. Logically, since there is a machine in the entire time the process is active, retiming, spare parts or recalibrating the machine would be plausible options.

Changing the process would not change the result in the rate of defects and there would be no other way to do this that would significantly improve quality or make the process faster. New machine and new technology is always an option, but investment is out of the question as of now.

# 8 IMPROVE

This chapter is dedicated to explaining the analysis and collecting other ideas outside the processes that could possibly help the company overall. These are made mainly from employee comments and my personal experience, but also from the previous process analysis.

## 8.1 Hypothesizes in priority order

Hypothesizes mentioned in this thesis, it is unclear which ones are better than the others. Even though, all of them are viable options, considering the company's situation, it needs to be prioritized. Below will be a priority list (similar to Risk Priority) to show, what the company should prioritize from all hypothesizes. There will be different categories within the list, like costs, efficiency, difficulty etc. to show the different sides of the hypothesis. Like the priority number, some have better values in different field compare to others, but to see the overall best solution for the company's current situation are listed in green color.

The list ranges from 1 to 10, the bigger the number, the better. The number in the list are from my observation and calculations, that what would be the best for the company. In the list, the most points accumulated is suggestions from the workers, followed by sand mold maker speed down, placing cores: machine down and mold amount. Why are they so high? The effect coming from them compared to the costs is very little. Costs in this case means the potential less profits from lesser production, unlike in the 2 entirely new types of producing, where it means investment in machines etc.

After the best scores are ones that I have valuated to be somewhat important, but not effective, the spare parts. It can make the difference in right place in right time but I believe this is not it. The least points accumulated hypothesizes were the new casting processes. This is due to the large amount of investment the company would need to have in order to get it working and also the complete rework of some of the processes and products. It would, however, remove sand inclusion problem almost entirely.

Table 12: Priority list of hypothesizes. (Anttila, K 2019)

| *Hypothesis* | *Costs* | *Difficulty* | *Efficiency* | *Priority* |
|---|---|---|---|---|
| *Sand mold maker: Speed down* | *8* | *10* | *3* | *240* |
| *Sand mold maker: Resin sand casting* | *2* | *2* | *10* | *40* |
| *Sand mold maker: Shell casting* | *2* | *2* | *10* | *40* |
| *Sand mold maker: Spare parts* | *6* | *8* | *2* | *96* |
| *Placing cores: Machine speed down* | *8* | *10* | *3* | *240* |
| *Placing cores: Mold amount down* | *8* | *10* | *3* | *240* |
| *Combining 2 sides: Spare parts* | *8* | *9* | *3* | *216* |
| *Combining 2 sides: recalibrating* | *8* | *9* | *2* | *144* |
| *Suggestions from workers* | *10* | *10* | *3* | *300* |

## 8.2 Process analysis

To improve the processes, one question should be asked first; which of the upper mentioned analysis would be best for the company to take? To answer that we would need to know, which process makes the most defects?

In this case, saying that one of the analysis is right and one is wrong is not the right way, but to make an analysis to the 3 processes all together. Finding the biggest defect maker from the three should be prioritized over finding the solution. From the process 1 to process 3, it could be narrowed to the last 2 processes by slowing the process 1 down and manually keeping eye on the mold that is it already broken or not. Comparing these defect finds to the defects found after the last 2 products will show if the $1^{st}$ one causes the most defects. By doing this, it could be easier to focus on the real problem process instead of all 3. As mentioned in chapter 7.1.3, the cores can weigh down the mold, causing the defect even if the employee is well trained. The solution to this would be making sure that the green sand solution is right for the product since some of them are heavy cores. This would mean that if would affect all big core products and fixing that would decrease these holes from many products.

### 8.3 Changing the old ways

In many companies, changing the ways of working has made them increase in profit, minimize wastes and get rid of unnecessary process steps. Like listed in hypothesis, changing the green sand casting in come products could affect the whole production. Unfortunately, it requires investment and also space for the machines that, at the moment, could be unrealistic steps. However, it would undoubtedly increase quality and decrease the amount of sand inclusions in products

Small investments like better working tools, clothes and machines could increase motivation of the workers and show that the company is aiming for more modern approach. If the workers have bad imagine of the company and motivation starts to shrink, who knows how irresponsibly they perform in their work tasks. The only thing the company, in this kind of situation, can do is to ask the workers and listen to their needs. Simple acts like this would show employees that their voice matters and seeking faults in processes or methods could possibly help even a little. Not only could it help with processes, but definitely employees would feel better.

## 9 CONCLUSION

The aim for this thesis was to work with Componenta Pori to figure out ways of bettering 3 processes that have had problems with quality. The 3 processes work with the main method, green sand casting, which uses sand in “green” state (wet). These processes create, so called “sand inclusion” defect type in the products which means the sand mold breaks and leaves a little sand drop inside the pit in which the liquid metal will be poured, resulting in a hole in metal.

Process control and process management are really important when it comes to quality management and this is why Six Sigma and especially DMAIC is selected to be the theory behind the thesis. Personal observation, interview and employee comments have been used in order to construct a realistic ideas how the quality and the process could be fixed. The ideas range from simple employee interviews and suggestions to changing the entire method of producing to chase after the better quality and production efficiency.

After all, the hypothesizes should be tested out in real life situation in order to figure out if they do the intended functions, but due to unfortunate circumstances, we were unable to perform any kind of test. This, however, did not stop me from making logical and realistic suggestions for the company to improve upon. This does not mean that the hypothesizes cannot be tested at all, but some of them would require investment.

To conclude this work, I would say it worked out really well in the end. The initial aim did change during the making of this thesis but adapting to the situation and to make the most of it had to be done. Even with the lack of tests and proper results, I believe the ideas presented could be valuable for the company in some level.

# REFERENCES

BarCharts, I. 2016. Lean Six Sigma - Quick Study. Boca Raton: BarCharts, Inc. Referred 15.10.2019. https://samk.finna.fi/Record/nelli26_samk.3710000001404144#image

Deepali, K, 2010. Six Sigma, New Delhi Himalaya Publishing House. Referred 10.10.2019. https://samk.finna.fi/Record/nelli26_samk.2670000000056581#image

Foley, B. & Johnson, J. 2003. Achieving Quality. Burlington: Elsevier. Referred 27.11.2019. https://samk.finna.fi/Record/nelli26_samk.1000000000350503

Hirsijärvi, S., Remes, P., Sajavaara, P. 1996 Tutki ja kirjoita. Jyväskylä: TAMMI.

Prof. K. Shridhara Bhat. 2010.Total quality management. Global Media. Referred 02.12.2019. https://samk.finna.fi/Record/nelli26_samk.2670000000047657#image

Shankar, R. 2009. Process Improvement Using Six Sigma - A DMAIC Guide. American Society for Quality (ASQ). Referred 20.9.2019. https://samk.finna.fi/Record/nelli26_samk.2670000000056581#image

Website of the Ablebits. Referred 10.7.2019. https://www.ablebits.com/office-addins-blog/2018/06/27/make-pareto-chart-excel/

Website of the Academia. Referred 3.12.2019. https://www.academia.edu/21354219/THE_CRITICAL_CASTING_DEFECT_IN_CAST_IRON_SAND_INCLUSION_A_REVIEW

Website of the Biology for Life. Referred 13.7.2019 https://www.biologyforlife.com/standard-deviation.html

Website of the FV Cast. Referred 3.12.2019. http://www.fv-cast.com/en/production/#top

Website of the Scribd. Referred 17.7.2019 https://www.scribd.com/doc/116078430/ANOVA-Cheat-Sheet

Website of ScienceDirect. Referred 22.11.2019 https://www.sciencedirect.com/topics/engineering/greensand

Website of the Quality one. Referred 14-15.7.2019 https://quality-one.com/fmea/

Website of the Wikipedia. Referred 3.12.2019. https://en.wikipedia.org/wiki/Shell_molding

Website of Willman Industries. Referred 30.09.2019 https://willmanind.com/what-are-green-sand-castings/

# APPENDIX 1

Survey:

How fast does the machine work in regular basis?

What are the minimum and maximum production rates?

Does the machine change rates for every product?