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Mapping and Analysing Manufacturing Processes

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Opinnäytetyössä kartoitettiin ja analysoitiin kahta samalle laakeriholkille tarkoitettua valmistusprosessia Oy Johnson Metall Finland Ab:lla. Työssä tuotettiin yritykselle kattava visuaalinen kuvaus valmistusprosessien työnkulusta, ominaisuuksista sekä niiden laadun tuottamiskyvystä. Työ toteutettiin tutkimalla nykyinen käytössä oleva valmistusprosessi sekä vaihtoehtoinen valmistusprosessi käyttämällä vuokaavioita, arvoanalyysejä, arvovirtakuvauksia sekä SPC:tä. Tukena työssä käytettiin teorialähteitä Six Sigmasta sekä SPC:stä. Tarve kartoitukselle ja analysoinnille syntyi yrityksen halusta kehittää nykyistä valmistusprosessia.

Kartoituksesta ja analysoinnista selvisi, että molemmat valmistusprosessit pitävät sisällään vahvuuksia toisiinsa nähden, kun prosesseja verrattiin keskenään. Nykyinen käytössä oleva valmistusprosessi tuotti valuja nopeammin, mutta koneistusvaihe vei enemmän aikaa. Vaihtoehtoinen valmistusprosessi sisälsi enemmän arvoa lisääviä toimintoja ja vähemmän vaadittavia työvaiheita laakeriholkin valmistuksessa. SPC -tutkimus ei osoittanut valutavan erolla olevan mitään vaikutusta lopputuotteen laatuun. Ainoat laatuerot nähtiin mittaustulosten hajontana, joka oli seuraus sorvilla ajon aikana tehdyistä muutoksista.

Opinnäytetyön tulosten perusteella tehtiin kaksi jatkotoimenpide-ehdotusta. Yritys halutessaan voisi tehdä uuden SPC -tutkimuksen valmistusprosesseihin, jossa koneistusvaiheessa ei tehtäisi mitään muutoksia sorville ajojen aikana. Näin saataisiin todellista tietoa siitä, kuinka koneistusparametrit käyttäytyvät ajon aikana. Yritys voisi halutessaan myös ottaa Six Sigman osaksi organisaatiotaan. Six Sigman avulla ei pelkästään voitaisi vähentää hajontaa ja vaihtelua laakeriholkin valmistusprosessissa, vaan kaikissa muissakin yrityksen prosesseista.

Asiasanat: valmistusprosessit, kartoitus, analysointi

ABSTRACT

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In this thesis, two manufacturing processes used to produce the same bearing bush were mapped and analysed at Oy Johnson Metall Finland Ab. The goal for this thesis was to produce visual representations of the manufacturing process's workflow, attributes and the capability to produce quality. The thesis was implemented by examining the currently used manufacturing process and an alternative manufacturing process by using flowcharts, value analyses, value stream maps and SPC. The need for the mapping and analysing came from the company's desire to improve the currently used manufacturing process.

The mapping and analysing revealed that both manufacturing processes had strengths over each other when they were compared together. The currently used manufacturing process had an ability to produce cast faster, but the machining phase required more time. The alternative manufacturing process included more value adding activities and fewer required stages in producing the bearing bush. The SPC study did reveal that there were small differences on quality, but this had no significant impact on the overall quality. The only distinctions noticed quality wise were minor variations in the measuring results that were caused by adjustments made at the lathe during the machining.

Based on the results of the thesis, two suggestions were made for follow-up actions. If the company is willing, a new SPC study could be made for the manufacturing processes in which no adjustments would be made on the lathes during the machining phase. By doing this, actual data on how the machining parameters act during the machining would be gained. The company could also adapt Six Sigma as a part of its organization. Six Sigma would not only reduce the variation inside the bearing bushes manufacturing process, but in all the other processes the company uses.

Key words: manufacturing processes, mapping, analysing

SISÄLLYS

ABBREVIATIONS AND TERMS

SPC	Statistical process control
ERP	Enterprise resource planning

1 INTRODUCTION

The subject of this thesis was given by Oy Johnson Metall Finland Ab. The goal for this thesis was to provide the company with two flowcharts and value analyses, made from two of the company’s manufacturing processes. Both manufacturing processes are designed to produce the same product, a bearing bush. One of the processes is the currently used in production and the other is an alternative process. With the results that this thesis provides, the company can make a comparison between the two manufacturing processes and design improvements based on the results.

This thesis is a quantitative research and it is implemented by gathering data from the manufacturing processes, then processing the data with statistical and analytical methods. The gathered and processed data will be presented visually in forms of flowcharts and analyses. Theoretical sources and personnel of the company are used as an assist in gathering and processing the data.

The work related to this thesis is executed by getting acquainted with the two manufacturing processes under examination. All stages inside the process that the bearing bush goes through to become a finished product, is followed and mapped as the product-to-be moves from one stage to the another. Every stage included in the chain of manufacturing is mapped with all the necessary information regarding it. After all the necessary data is gathered, it is processed and analysed with statistical formulas and calculations.

The mapping and analysing of the manufacturing processes is done, because Oy Johnson Metall Finland Ab has a desire to improve the currently used process. By the company’s standpoint, it is worthwhile to understand the current state and capabilities of the process, before improving it. This way, the company reduces the chances of making costly and time taking mistakes in the improvement process. Also, in the alternative process, the casting technique is different than in the currently used process.

The technique has been used in the company before, but not for an outer diameter of this size. So, the results of this thesis will display the suitability of this method and the effect that it has on producing the product.

2 OY JOHNSON METALL FINLAND AB

Oy Johnson Metall Finland Ab is a company that is located in Pirkkala, Finland that manufactures slide bearings, bushings and other vital machine parts from copper base alloys. The company has a large clientele that consists for example from operators in maritime industry, mining industry and power plant industry. The company can produce products as a single production or as a mass production. The company had a net revenue of 15,9 million euros in 2018. Currently, the company employs 85 employees inside its organization.

Oy Johnson Metall Finland Ab offers its customers a complete chain of production, as its core processes are casting and machining. Everything that the product goes through on its journey from raw material to a complete product, is operated by the company. Casting techniques used by the company are centrifugal- and continuous casting. Casts produced by centrifugal casting can have a diameter up to 1800mm and weight 2000kg. Continuous casting can produce casts that have a length of 6000mm and a diameter of 300mm.

The machine stock of the company is able to manufacture finished products from even the largest casts produced inside the facility, up to a length of 2500mm. The company does not have a designing department of its own, so it manufactures products based on customer designs.

Oy Johnson Metal Finland Ab has committed on reducing the impact that its actions have on the environment. Good example of this commitment is that all the metal waste produced by machining, is melted and reused. This way, the company achieves efficiency in its material usage and does not encumber environment by shipping the waste to an outside operator for refinement.

3 BACKGROUND FOR THE MAPPING AND ANALYSING

The initiative to map and analyse the manufacturing processes for the bearing bush, came from the desire to improve the current process in use. Oy Johnson Metall Finland Ab has already taken the first step towards improvement by designing an alternative manufacturing process for the bearing bush. This process uses a different casting technique which results in a blank that has a smaller machining allowance, hence making the machining process quicker and reducing the overall throughput time of the manufacturing process.

What is unknown, is the capability that the alternative process has in producing quality. By doing a test batch of products using the alternative process, a comparison in quality can be drawn with the products produced by the current process. From the results in quality and throughput time, the company can make changes and adjustments and solidify a new better manufacturing process for the bearing bush. For this, both processes must be mapped and analysed.

The desire of improving the manufacturing process in the first place, comes from different factors. Oy Johnson Metall Finland Ab is a company that uses the continuous improvement process. Also, the market in which the company provides its products, is undergoing a constant price competition. The company has to continuously improve itself and pursue advantages over its competitors.

Mapping and analysing processes are commonly used methods in all fields of business. They are used for solving quality issues, process flaws and in creating foundations for improvement. For this thesis, mapping and analysing are chosen, as they are the best suitable methods to provide the company with the information that it requires.

4 STATISTICAL PROCESS CONTROL

SPC or statistical process control is a method based on measuring and statistics. All methods that provide some kind of statistical data and can be used controlling manufacturing processes, are considered to be a form of SPC.
(Salomäki 1999, 167.)

4.1 History of SPC

Walter Andrew Shewhart (1891-1967) can be considered as the father of statistical process control (SPC). He came up with the idea of SPC in the 1920's as he worked at Western Electrics. In 1924, he presented the first control card to his manager. (Salomäki 1999, 170.)

At Western Electrics, Shewhart got acquainted with a problem that quality control had discovered. A large group of inspectors inspected every single product that had been manufactured. The inspectors and their organization had a goal to improve the quality of the products, so less rejects would come from production. When a rejected product came out of the production, the inspectors investigated the origin of the reject and adjusted the processes. This had no effect, as the situation just got worse. Shewhart examined the results of process control using statistic methods and he observed that the results acted in a gaussian distribution. From this, he concluded that the problems came from the changes to the processes. As the processes were adjusted, they no longer could meet the quality requirements. Making adjustments to the process based on the quality of a single product just gave birth for more variation on quality. (Salomäki 1999, 170-171.)

Shewhart created the first control cards and proved that there are common and different reasons for problems. A faulty process does not improve if its adjusted based on a single rejected product, it just makes the situation worse. A process must be adjusted by the variations averages and the performance is to be measured by the wideness of the variation.

If the variation is too great, the process must be improved to a point that the variation fits inside requirements. (Salomäki 1999, 171.)

4.2 Concepts used in SPC

4.2.1 Universe, Entry

In SPC, the term universe, means the assortment under examination. For example, all the produced products to this day and the ones produced in future, make up the universe. Entry is a single cell of the universe, a single product. (Salomäki 1999, 178.)

4.2.2 Sample, Sample lot

When a sample is taken in SPC, it means that a single result is taken from a universe to examination. When more than one sample is taken, then the term sample lot is used. However, conclusion about a process cannot be made based on one sample or a single sample lot. It is advised to collect at least of 20 sample lots before conducting statistical inspection.
(Salomäki 1999, 178.)

4.2.3 Arithmetic mean

In SPC, an arithmetic mean is often used. Arithmetic mean is the result when all the measurement results are summed together and divided by the number of the results. Basically, the arithmetic means of sample lots are more towards gaussian distribution than those gotten from single samples.
(Salomäki 1999, 179.)

4.2.4 Range

Range portrays the difference between the biggest and smallest result taken from the inspected results. The number describing the range is always zero or a bigger positive number. (Salomäki 1999, 180.)

4.2.5 Standard deviation

Standard deviation is a mathematically defined key figure that indicates the spreading of results both side of the arithmetic mean. If the standard deviation is big, the results are also more spread. (Salomäki 1999, 180.)

4.2.6 Control card

A control card is a graphical ancillary that presents the measurement results of a process. Variation information and attribute information can be handled by using control cards. (Salomäki 1999, 183.)

4.2.7 Control limits

Control limits are divided between upper control limits and lower control limits. They are defined by the estimation of standard deviation. Usually, the control limits are placed symmetrically on both sides of the arithmetic mean, three times the distance of the estimation of standard deviation. This way, the range between limits cover 99,73% of all results. (Salomäki 1999, 183.)

4.2.8 Tolerance limits and desired value

Upper and lower tolerance limits are defined in specifications. If the product surpasses the upper limit or does not meet the lower limit, it will be rejected.

In some cases, the product can be modified afterwards to become accepted by the limits. Desired value is usually in the middle of the upper and lower limits. (Salomäki 1999, 183.)

4.2.9 Performance figure (C_p)

Performance figure describes the actual measurements gotten from processes and products in a statistical regarding to the tolerance requirements.It also describes the processes capability to produce products that meet the set requirements. (Salomäki 1999, 184.)

4.2.10 Normal distribution

Normal distribution (also known as Gaussian distribution) is a cardinal concept of SPC that examines the regularity of chance variation. The probability density functions graph of normal distribution is called the bell curve. (Salomäki 1999, 184)

4.3 Process control and SPC

The quality of a process can be measured by its capability of performing given tasks. The capability of a process can be measured by comparing its average performance to the requirements set by the products specifications. Variations inside the process should be supervised, because it gives a chance to detect anomalies and react to them, before they cause more harm to the process or the quality of products. (Salomäki 1999, 166.)

Goals of a process is to produce good quality products efficiently, economically and without interferences to the process. A process can produce the same product continuously, or in contrary, every product is different that the process produces. The performance of the process is not tied to the product or the variations of products, but the relative performance can change as the requirements for products change. (Salomäki 1999, 166.)

When defining the performance of a process statistically, it must be done with reliable data, collected from observations. These observations may come from measurements of products that are being completed or from their other attributes, but they always have to come from a quantity which describes the processes performance. When controlling the processes performance, a regular sampling for statistical control may be enough, even if the product quality is being monitored with a thorough inspection. (Salomäki 1999, 166-167.)

SPC has cemented its usage on controlling processes and the quality of the products that the process produces. When using statistical tools, reliable and provable conclusion can be done from examined subjects.
SPC examines the manufacturing processes capability of producing quality instead of focusing on a single product or its quality. SPC is used in trying to keep the process in a state that it cannot produce a product of poor quality. With SPC, probability of producing a product of poor quality can be calculated. Probabilities and statistical characteristics can be used in designing inspection methods.
(Salomäki 1999, 167.)

SPC can also be used on improving a process that meets all the requirements set to it by using continuous improving. SPC separates the genuine improvement from coincidence. SPC is designed for recurring processes. For nonrecurring tasks, like projects, SPC does not work. (Salomäki 1999, 167.)

4.4 Challenges and misconceptions of SPC

SPC cannot be adapted without the knowledge of certain statistical concepts. Without the knowledge, the results gathered can be misleading. Without theoretical knowledge, applying the results can result on economic losses in worst cases. Temptations of using applications and ready-made functions on computer softwares should be avoided if the basics of SPC are not understood.
(Salomäki 1999, 173-174.)

Essential misconceptions of the functions and values of SPC are being displayed by using the method incorrectly or seeking for the wrong results. For example, some users of the method may have a perception that SPC charts can indicate if a product will meet its specifications, and this is a misconception. As a matter of fact, the charts reveal when the production process has changed, and the results can be used for identifying and improving the cause to prevent an issue. (Wachs, n.d.)

The physical sampling for SPC is one of the activities that brings more challenges. If the samples are collected improperly, the chart based on them will provide a misleading picture. Some of the SPC charts require rational samples, but some require a whole different sampling plan. It has to be acknowledged that the proper sampling plan depends entirely on the type of SPC chart being used. (Wachs, n.d.)

There is also a belief among the process operators that the SPC charts are used to monitor them personally, rather than the process which they are a part of. They have a fear that when a chart identifies a change, they would be blamed for it or for not meeting production quotas, because of the effect the change had. (Wachs, n.d.)

5 SIX SIGMA

Six Sigma can be defined as a disciplined methodology of defining, analysing and improving. Its goal is to remove variational defects from a company's products, processes and transactions. To do so, it introduces a DMAIC process that has different variations for different needs. (Slack, Chambers & Johnston 2010, 554.)

5.1 History of Six Sigma

The first company to make Six Sigma popular was Motorola by setting its quality objective as gaining total customer satisfaction. The company explored what it would mean for their operations processes to gain this objective. The company concluded that if total customer satisfaction is to be gained, products must be delivered in time with no defects or no early-life failures and the product cannot fail excessively in service. To meet these requirements, Motorola initially focused on seeking and removing manufacturing defects. Nonetheless, the company realised soon that many of the problem causing defects came from the design of the products. The problems might not show up at first, but eventually could cause failure. There was only one way to eliminate these defects and it was by making sure that the design specifications were tight with narrow tolerances and the process was capable enough. (Slack, Chambers & Johnston 2010, 553.)

The name for Motorola's Six Sigma concept came from it requiring that, the natural variation of processes (± 3 standard deviations) should be half their specification range. The Greek letter sigma (σ) is commonly used as the indicator of standard deviation in a process, hence the label became Six Sigma. (Slack, Chambers & Johnston 2010, 553.)

5.2 The six ingredients of Six Sigma

Pande, Neuman and Cavanaugh have defined the six ingredients below as the key to achieve Six Sigma capability:

1. Genuine focus on the customer
2. Data- and fact driven management
3. Process focus, management and improvement
4. Proactive management
5. Collaboration without boundaries
6. Driving for perfection, but tolerating setbacks

The things listed above are nothing new and most companies already use some of these ingredients in their organization. The way that Six Sigma compiles all these together to form a coherent program, is something new. (Pande, Neuman & Cavanaugh 2002, 11.)

5.2.1 Genuine focus on the customer

Customer focus is one of the highest priorities in Six Sigma. All improvements made by Six Sigma are defined by the impact from customer satisfaction and by the value they add for the customer. First tasks in Six Sigma is to define the customer requirements and the processes that are to meet them. (Pande, Neuman and Cavanagh 2002, 8-9.)

5.2.2 Data- and fact driven management

Six Sigma instructs that important decisions should not be made by gut-level hunches, but rather based on key measurements regarding the subject process. From the data collected from the process being analysed, understanding of key variables and process drivers can be obtained. (Pande, Neuman and Cavanagh 2002, 9.)

5.2.3 Process focus, management, and process improvement

When designing a new product, measuring performance or improving customer satisfaction, Six Sigma centralizes the process as the key mean to meet customer requirements. One of the most impressive impacts of Six Sigma is the ability to convince leading managers to master and improve processes. It is essential to do so, because it allows to deliver real value to the customer and gain competitive advantage. (Pande, Neuman and Cavanagh 2002, 9.)

5.2.4 Proactive management

Proactive can be seen as acting ahead of events. In business world, proactive can be seen as making a habit of setting ambitious goals, establishing distinct priorities and challenging the way of how things are being done instead of defending the old ways. Proactive management can reduce panicky decisions and quick fixes when a problem is detected by instructing creative thinking. Quick fixes resulted from hastily decisions, can cost a lot of money. Six Sigma offers the tools and practises for proactive management. (Pande, Neuman and Cavanagh 2002, 9.)

5.2.5 Collaboration without boundaries

Collaboration without boundaries can be defined as smashing the barriers inside organizations. Inside a company, different departments can have conflicts with one another over who does what and who is responsible for what. This blocks the flow of ideas and actions which could assist in the one goal that all the departments have in common, providing the customer with value. Six Sigma focuses on increasing collaboration. Everyone has to have a role in the big process picture and learn what is their relationship with the external customer. By placing the customer at center of business focus, Six Sigma demands an understanding of that processes are used to benefit everyone, not just one or two departments. (Pande, Neuman and Cavanagh 2002, 10.)

5.2.6 Driving for perfection, but tolerating setbacks

Six Sigma urges to drive for perfection and to make sustainable results happen within a useful business time frame. Sometimes there might be questions like, is spending two weeks to collect data worth of the effort and time? Or, can it be afforded to change the process and creating possibly more problems in the short term, while the bugs are being worked out? Spending time on collecting data can seem risky, but it often results in better decisions. Not improving and changing a process does not give better results of it, because it stays in the current state. Any company that is willing to adapt Six Sigma must be ready to learn from setbacks and mistakes. (Pande, Neuman and Cavanagh 2002, 10.)

5.3 Three ways to Six Sigma

Six Sigma is driven by customer knowledge and effective measures with three basic parts, process improvement, process design/redesign and process management. The linkage of these three parts together can be considered as one of the most important innovations in Six Sigma. The DMAIC process and its variations are used in each of the three ways (Pande, Neuman and Cavanagh 2002, 13.)

5.3.1 Process improvement

Process improvement alludes to a strategy of coming up with solutions on how to eliminate the root causes of performance problems in processes that are already in existence and in use. Actions taken with process improvement seek to eliminate the cause of variations inside the process and doing it in a way that leaves the basic process intact. In Six Sigma terms, process improvement finds the critical X’s that are the causes which creates the defects, or Y’s that are produced by the process. The five-step process that process improvement uses is labelled as DMAIC. (Pande, Neuman and Cavanagh 2002, 14.)

The abbreviation comes from:

- **D**efining the problem and customer requirements
- **M**easuring the defects and process operations
- **A**nalysing the data and discovering the causes of defects
- **I**mproving the process to remove causes of defects
- **C**ontrolling the process and to make sure that defects do not recur

5.3.2 Process design/redesign

The DMAIC process suits for vast range of different business situations, but there are scenarios when it is not the best choice as in its basic state. Three examples of these scenarios could be:

- When a company decides to replace, rather than repair, one or more of the core processes
- When it is discovered that improving an existing process will not deliver the quality that customers are demanding
- When an opportunity is identified to offer an entirely new product or service

These are scenarios when a company has to design or redesign its core processes. In process designing, Six Sigma principles are used to create new processes, goods and services built around customer requirements. These new creations are then validated by collecting data and by doing test runs. Process designing adapts DMAIC to make a version more suited for it. This version is labelled DMADV and the abbreviation comes from:

- **D**efining customer requirements and goals for the process/goods/services
- **M**easuring and matching performance to customer requirements
- **A**nalysing and assessing process/goods/services
- **D**esigning and implementing new processes/products/services
- **V**erifying results and maintaining performance

Process design is usually a longer time taker than process improvement. It also has a greater risk of failure, because it involves the creation and implementation of a new process.

Failure can be prompted by the lack of understanding in designing goals and with participants without the skills and knowledge for the task. (Pande, Neuman and Cavanagh 2002, 16-17.)

5.3.3 Process management

Third application of the DMAIC-based process, process management, introduces changes to the culture and management throughout the organizations. Process management has to make sure that the Six Sigma efforts are done in full power. Process management is considered to be the most challenging of the three Six Sigma strategies to master. It is a vital part of the methodology, because without it, a company's Six Sigma adaption can be a one-and-done experience. Process managements version of DMAIC is the following:

- Defining processes, key customer requirements and process "owners"
- Measuring performance to customer requirements and key process indicators
- Analysing data from which to enhance measures and refine the process management mechanisms
- Controlling performance with ongoing monitoring of inputs/operations/outputs and quickly responding to problems and to variations in the process

Process management is a tool for business leaders to improve their processes in managing the business. It can take years to transform from a traditional reactionary outfit to an organization that is proactive in managing its processes and its equipment, with the same precision on both. (Pande, Neuman and Cavanagh 2002, 19-20.)

6 PROCESS MAPPING

Process mapping is a method used to describe a process in terms of how different activities inside the process relate to each other. Process mapping also reveals the flow of materials and information through the different activities within the process. (Slack, Chambers & Johnston 2010, 97)

Process mapping uses different symbols to classify the different activities within the process. These symbols are arranged in an order as in series or parallel to describe the process. (Slack, Chambers & Johnston 2010, 97)

6.1 Using process mapping to improve a process

In most organizations, a single person is unable to describe the series of actions that are required to transform a customer's request into a product. At least, not in the details of an organizational performance. This gap in understanding can be seen as the problem that leads to making improvements on one functional area, but at the same time, creating problems in other areas. This can result on good-willing companies to implement costly solutions that result little-to-no solution to problems or improve customer experience. (Osterling & Martin 2013, 1.)

A general rule of improving is that it is mandatory to know the current state of things. If there is no knowledge on how the process looks and operates today, the task of improving it successfully will be difficult or near impossible. Documenting a process by mapping it for example, should always be the first step of any improving activities. (Andersen 2007, 38.)

Process mapping improves the understanding of a complex process by covering all the steps. By using process mapping, ways can be found to simplify, streamline or redesign processes, hence improvement of process is gained. With knowledge and control of the inputs in a process, it is possible to reduce variation inside the process and this will lead to continuous process improvement.
(CItoolkit, n.d)

6.2 Flowchart as a process mapping tool

Flowcharts are representations of how a process works, done to a visual form. Flowcharts always depict the starting and ending points in a process, activities that are performed, decisions made and direction that material flows. (Kloppenborg & Petrick 2002, 2.)

Flowcharts are used to identify problems, defining process scopes, documenting the process itself and analysing the processes for simplification and improvement. Sometimes, flowchart can be used just as a discussion tool to uncover differences in how people perform the process steps. (Pande, Neuman & Cavanaugh 2002, 260-261.)

7 VALUE ANALYSIS

Value analysis is a value engineering process that aims to reduce costs or prevent all unnecessary costs. It is defined as eliminating all costs that do not contribute to the value or performance of the product. In value analysis, a chosen pack of elements are subject to thorough examination, by analysing their function and cost. After examination, similar components that could do the same operation at a lower cost, are searched. (Slack, Chambers & Johnston 2010, 129.)

7.1 Conducting a value analysis

The value analysis process follows a certain path in which the process advances. First task is to identify and map the process that is to be analysed. Flowchart can be used in mapping. After this, each step of the process is categorized as value adding or non-value adding. After categorization, the proportion of activities are counted to define the balance between value adding- or nonvalue adding activities. Next step is to create a check sheet that describes all the process steps and how much time is spent of each step. The last step on the analysis is to determine of what percentage of the process time adds value to the customer based on the previous steps. With the results, improving can be focused on the steps that do not add value or to those that are more time consuming. (Pande, Neuman & Cavanagh 2002, 265-266.)

7.1.1 Value adding activities

Activities that add value to the product are functions that contributes transforming raw material into a finished product. In a workshop level for example, all the casting, milling and assembling add value to the product. These actions physically shape the product to the desired form. From the customers point a view, these value adding activities are the services that they are paying for.

So for the manufacturer, these activities must be done correctly on the first try, because the customer does not pay for failed products. (Beels 2019.)

7.1.2 Non-value adding activities

Every manufacturing process has activities in it like moving the product from one stage to the next, inspecting the product at certain stages of manufacturing and waiting between the stages. These activities might be necessary for the product to become complete, but they are the type that do not add any value to the end product. (Beels 2019.)

8 VALUE STREAM MAP

Value stream mapping is a crude, but efficient way to learn how flow of products and information progress through a process and how value is added to it. It is a visual mapping from beginning to the end of the path a product goes through. It records all the activities done to the product during the path and depicts the flow of information that occurs as the product is being produced. (Slack, Chambers & Johnston 2010, 437)

As the name refers at, the value stream map focuses on the value adding activities and separates the value adding activities from non-value adding activities. It is similar to process mapping but uses a wider range of information and is better in identifying where to focus future improvements. (Slack, Chambers & Johnston 2010, 437)

Value stream map concentrates on working and improving on the whole manufacturing process instead of an individual process within the manufacturing process. Value stream map is considered to be the starting point on searching for waste and identifying the causes for it. (Slack, Chambers & Johnston 2010, 437)

The value stream mapping is a four-step process. The steps are the following and done in the order:

1. The value stream is identified from the process which is to be mapped
2. The process is mapped physically with the information flow
3. The problems found are diagnosed and suggestions made to solve them. After that, a new map is made which depicts the improved version of the process
4. The changes made based on suggestions are implemented and the process is adjusted to be like the improved version

The type of data collected into the value stream maps vary, but all value stream maps compare the total throughput time (or lead time) with the amount of value adding time. (Slack, Chambers & Johnston 2010, 437) Value stream maps can also depict a phase's change over time, uptime and amount of work hours available.

9 MAPPING AND ANALYSING

9.1 Selected manufacturing processes for mapping and analysing

The manufacturing processes that were mapped and analysed, were selected by Oy Johnson Metall Finland Ab. Both manufacturing processes are designed to produce the same bearing bush. One of the processes is the currently used in production and the other is an alternative process designed to produce the same product. The company selected these processes for mapping and analysing, because they have a desire to improve the currently used manufacturing process.

The basic principles of both manufacturing processes are introduced in this chapter. The manufacturing processes are later opened up in the flowcharts that give a more detailed view of both processes.

9.1.1 The currently used manufacturing process

The currently used manufacturing process is the one that the company has used to produce the bearing bushes so far. In figure 1, the manufacturing process is presented plainly.

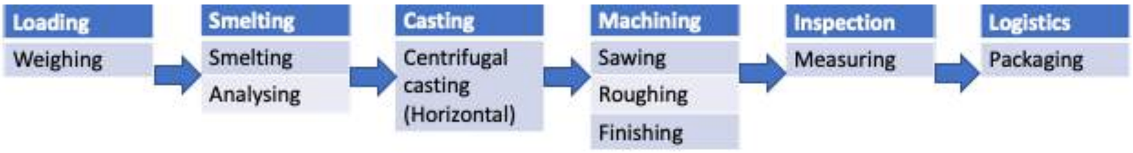


FIGURE 1. The phases of the currently used manufacturing process.

The currently used manufacturing process consists of six different phases. Same phases are in the alternative manufacturing process, but some of the manufacturing techniques used in them differ.

The manufacturing process begins with the loading of the raw materials. The materials used for the cast are loaded into a tipper and weighed to ensure that the load is the right size.

The raw materials are dried for a day in the tipper while storing them at the melting bridge. The drying is done, because the raw material mixture can include moist chips brought from the machinery for refinement.

The next phase is to smelt the raw material into a molten state in a furnace. When the material is completely melted, its temperature is measured with a dip-thermometer. Also, an analysis is taken from the molten alloy to ensure it consists of correct materials.

After analysis is completed, a crucible is filled with a portion of the molten material and it is taken into the centrifugal casting machine. The molten material is then poured into the casting machine. Mold rotates in the centrifugal casting machine until metal is solidified and an open cylindrical cast is produced. Nine products can be manufactured from a single cast. This casting method results in a graphite coating on the outer surface of the cast. Before the cast can undergo the machining phase, it is washed to remove some of the graphite coating.

After the washing, the cast is sawed into three smaller pieces. These pieces are then roughed on a lathe to reduce the outer and inner diameters and to remove the rest of the graphite coating. The pieces are now blanks (figure 2) that can be machined into finished products. Three products can be machined from a single blank. The blanks are then machined into products using a different lathe.

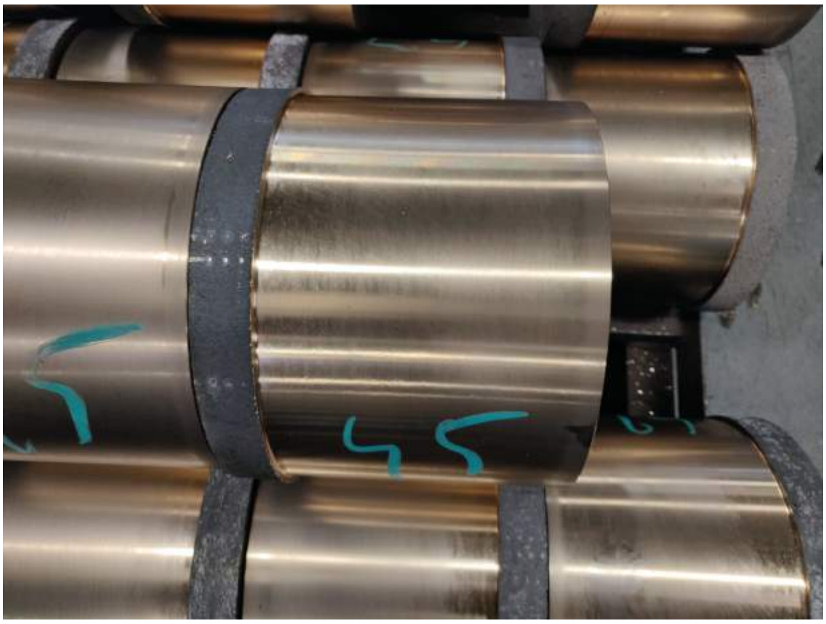
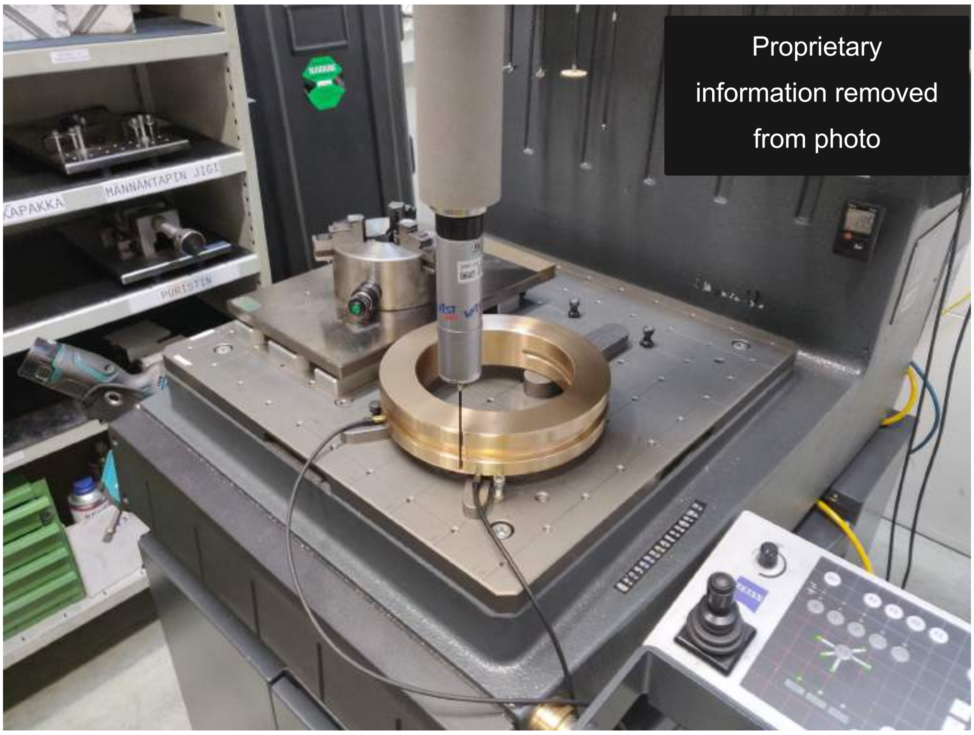


FIGURE 2. The blanks after sawing and roughing

After the machining phase, the bearing bushes are inspected and measured by using a coordinate measuring machine to ensure all specifications are met. After measuring, the finished products undergo logistical operations like packing and sending off to the customer.



Proprietary information removed from photo

FIGURE 3. A finished product undergoes measuring

9.1.2 The alternative manufacturing process

The alternative manufacturing process was designed to be an alternative method to produce the bearing bushes as the name indicates. The manufacturing process is presented plainly in figure 4.

FIGURE 4. The phases of the alternative manufacturing process.

This manufacturing process begins in the same way as the currently used does. The first two phases are done in a similar manner. The difference between the two manufacturing processes begins at the casting phase.

The casting phase begins as molten material is poured into the continuous casting machine. The machine is capable of producing as much of cast as material is poured into it, hence the name continuous casting. The casts in this manufacturing process are sized to hold material enough for 34 products each. Also, the casts produced with the continuous casting technique do not have the graphite coating on the outer surface like the ones produced with centrifugal casting. The machining allowance is also lower in these casts at the inner and outer surfaces.

After casting, the machining phase begins as the cast is sawed into smaller blanks. Like in the currently used manufacturing process, three products can be machined from a single blank. There is no washing or roughing on a different lathe, because there is no graphite coating. The blanks are machined into products after the sawing.

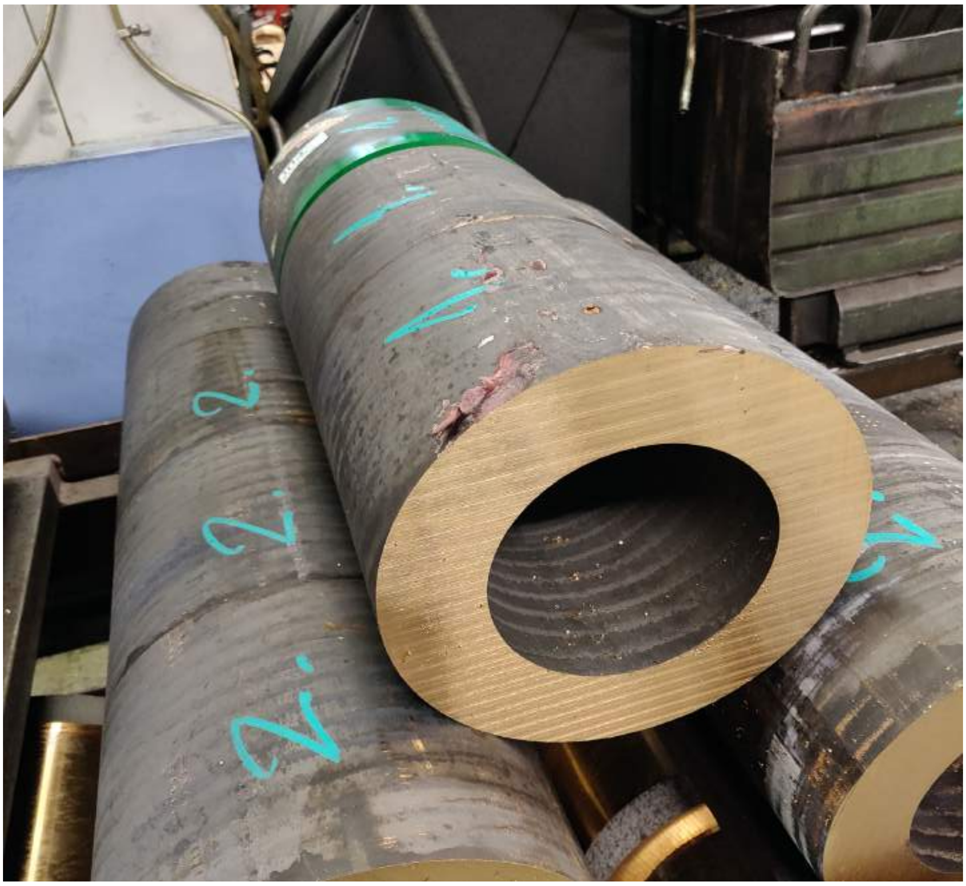


FIGURE 5. Blanks after sawing

The phases after machining are also the same as in the currently used manufacturing process. The products are inspected and packaged and sent off.

9.2 Mapping the manufacturing processes

9.2.1 The flowchart

The mapping of manufacturing processes was implemented by using a flowchart. Both manufacturing processes were mapped on to their own flowcharts (attachments 1 & 5) that also included a sub-flowchart of the machining process (attachments 2 & 6) and a technical drawing of the product. The flowcharts were done by using Microsoft Excel. As a spreadsheet with wide vary of functions and tools, Excel is a common tool used in creating flowcharts.

Flowchart was chosen as the mapping tool, because it is an easy concept to understand and can provide a very visual presentation of a manufacturing process. Flowcharts can be modified to include all the necessary information that is required from processes. Oy Johnson Metall Finland Ab also had previous experience of using flowchart in process mapping, so there was no point to use a different method for this thesis.

The information required to be included in the flowchart are the following:

- Phases of the manufacturing process divided into their own sections
- Material flow must be drawn on the map
- Each stage of the manufacturing process must be marked on the flowchart
- Description of what is done on each of the stages
- Different symbols for each type of operation in the manufacturing process
- Equipment used on a stage
- Possible technical instructions or specifications that are used on the stage
- Possible measuring instruments used on a stage
- What quality attribute is controlled on the stage
- Control frequency of the quality
- How the quality and procedure reporting is done if a stage includes them
- Additional notes and observations

9.2.2 Implementing the process mapping

The process mapping was implemented by following the manufacturing processes at the company’s production facility. As a preparation for the mapping, first task was to get familiar manufacturing processes in overall. This was done by overviewing the manufacturing processes few times to get an idea of the big picture of how the bearing bushes are being manufactured and how the different parts of the organization contribute to it.

After getting familiar to the manufacturing processes as a whole, the next task was to begin the mapping by conducting detailed walkthroughs of the different stages of the manufacturing processes and gathering data from them. All of these stages were mapped in the same order as they occur in the manufacturing processes. Personnel from the company who supervise and contribute to these different stages were assisting in the mapping.

Most of the mapping was done by observing the transformation of raw material to a finished product as it moved from one stage of manufacturing to an another and filling the flowchart with all the information regarding these stages. No throughput time measurements were made of the smelting, casting, inspection and logistical stages.

The only stage included in both of the manufacturing processes that was mapped and had its processing time measured during the mapping was the machining stage. This was done to get reliable data on the differences between the different casts machining-wise. This stage was mapped and created as a sub-flowchart inside the main flowchart. The sub-flowcharts have the machining programs divided into subroutines and the work time of each of the subroutines is measured in it. The sub-flowcharts also display the order in which the machining subroutines are executed, parameters they use and what geometrical feature of the product they are machining.

The flowcharts created were used as a basis for the next phases of this thesis. It was important that they are accurate as possible and describe all the operations within the manufacturing processes.

9.3 Value analysis

The value analysis that was conducted for both of the manufacturing processes was derived from the flowcharts created in the mapping process. The flowcharts already had the manufacturing processes compartmentalized in stages, so the next step was to divide the stages into value adding and non-value adding activities.

The value analysis examined the chain of manufacturing from raw material stock to the end product stock. All the stages within the chain had its value and processing time defined. The goal was to gain knowledge of the relation between non-value adding and value adding activities within the examined section. Logistics were not covered in the value analyses.

9.3.1 Defining value

The analysis process began by creating new spreadsheets with Microsoft Excel, one for both manufacturing processes. To these spreadsheets, all the stages within the manufacturing processes were copied from the flowcharts. Each stage was then defined as value adding or non-value adding based on the guidelines mentioned in chapters 7.1.1 and 7.1.2. When all the stages were defined correctly, a relation between value adding and non- value adding activities was calculated for both manufacturing processes.

9.3.2 Defining process times

The next phase of the value analysis process was to examine the times inside the manufacturing processes. Each stage inside both of the manufacturing processes had its processing time defined. Before the defining itself, the first task was to select dimensions in which the times would be portrayed. The dimensions needed to be selected on the basis that the stages process through different amounts of material when functioning.

This means that for example, the smelting and casting stages can process enough material for tens of products by functioning once, but one function of the inspection stage only processes a single product. Because of this, three dimensions were used to portray the times. By using the dimensions listed in TABLE 1, the times could be converted to display values for a stage, casting load or a single product. This was done to solve the challenge that the stages opposed by processing different amounts of material. A single dimension would not have worked for these manufacturing processes.

Different types of processing times were also used for the stages. This was done to separate the value adding time from the non-value adding time. Furthermore, the non-value adding processing time was separated into four different categories. In table 2, the used time types are listed and explained.

TABLE 1. The dimensions used to represent the process times.

Time taken by function	This is the time that it takes for a stage to function once. This was the first dimension used in defining the process times. The two other dimensions listed below were derived from the values defined for this dimension.
Time per full casting load	This is the time that it takes for the stage to process through the full casting load. It was defined by multiplying the time taken by function to match the full casting load.
Time per one product	This is the time it takes for a stage to process through a single product. This dimension was defined by dividing the time taken by function to indicate portion of a time that a single product requires.

TABLE 2. The different types of processing times used

Value adding time	Value adding time is all the time that is necessary to use for producing the product.
Wait time (Non-value adding)	Wait time describes how long the product waits between stages but is not in an actual storage.
Storage time (Non-value adding)	Storage time describes how long the product sits in an actual storage shelf.
Inspection time (Non-value adding)	Inspection time describes the time spent on measuring and inspecting the product.
Transfer time (Non-value adding)	Transfer time describes how long it takes to move the product from a stage to another.

The time taken by function -dimension portrays the time it takes for a stage to function once regardless of how many products are being processed. This dimension includes the setup and work time of a stage.

The time per full casting load -dimension was used to portray the time a stage requires to process through a full casting load. The casting loads chosen for the value analyses were 4.4 tons for the currently used manufacturing process and 4 tons for the alternative manufacturing process. These amounts are enough to produce 270 products with the currently used manufacturing process and 340 with the alternative. The difference in the raw material usage comes from different dimensioned casts. The alternative manufacturing process produces casts that have smaller machining allowances, hence the casts have less waste material. As a result, the alternative manufacturing process is able to produce more casts from less amount of raw material.

The time per one product -dimension displays the time it takes for a stage to process through a single product. The times defined for this dimension are mostly theoretical as many of the stages are not designed or used to process just a single product.

The time definition was done together with personnel who work on and supervise the stages within the manufacturing processes. The time taken by function was the first dimension that was defined for every stage.

The time per full casting load and per single product dimensions were derived from the time taken by function -dimension. Simply dividing and multiplying the time taken by function, the two other dimensions got a theoretical time that they would require for their respective amounts.

Some averages were also used in the time defining. For example, the waiting times for the currently used manufacturing process are calculated averages. This was done, because the waiting time rarely is the same on different runs of the same manufacturing process. The averages were calculated from four different waiting times that were recorder in the company’s ERP. The average value gives a good theoretical value that what the waiting time could be. For the alternative manufacturing process, averages could not be calculated. The manufacturing process was only used once, so the waiting times defined are the actual ones that occurred during the single run.

9.4 Value stream map

Value stream maps were created from both of the manufacturing processes in order to get even more visual representation of both of the manufacturing processes and further examine their value. The process times collected previously were exploited, as they were used as a basis in defining the value stream maps. The value stream maps were created by using Microsoft PowerPoint.

The value stream maps were scoped to examine the value stream that begins from the raw material stock and ends to the end-product stock. Every phase of manufacturing that occurred between these two stocks was mapped to the value stream map. Each of the phases had their cycle times calculated and a total lead time was derived from the cycle and storage times.

The relation between value adding time and total lead time was also included into the value stream maps. The information flow in the chain of manufacturing was also mapped.

The dimensions used on the value stream maps were the previously full casting loads. All the cycle times were calculated on the basis of these cast loads.
The calculation was done by summing all the process times inside a phase together. Storage time between the phases was also mapped into the value stream maps.

The total lead time was calculated for both of the manufacturing processes by summing together the cycle times of the phases and adding the storage time to the calculations. From the total lead time, value adding time was separated and a timeline was created which displays the amount of value adding time on each phase. Total lead time was presented in days, hours and minutes, but value adding time only in hours and minutes.

In addition, information flows that occur in the manufacturing processes were mapped into the value stream maps. These information flows display how the information moves inside the chain of manufacturing. Changeover time and uptime were also defined for each phase if possible.

9.5 SPC study

The last phase of the thesis work was to examine the quality producing capabilities that both of the manufacturing processes have. The measuring was implemented by doing a SPC study on both of the manufacturing processes. The SPC study was done by using a statistical process control software Minitab. It is a software that produces charts and capability reports based on the data that is fed to it.

The goal for this study was to reveal the possible differences that the two manufacturing processes might have qualitywise. Both processes use a different casting technique and the machining phases differ also between the two.

So, all the possible impacts that these different manufacturing techniques have on the capability of producing quality should be observable from the results.

9.5.1 Sampling for the SPC study

For conducting the SPC study, two geometric dimensions were chosen from the product to measure the qualitywise capability of both manufacturing processes. The dimensions chosen were the outer diameter and the sleeve thickness between the outer and inner surfaces. The outer diameter is dimensioned at 206mm and the sleeve thickness at 32,92mm. These particular dimensions were chosen, because they are crucial for the products functionality and have tight tolerances.

The sample lots were acquired by measuring product batches produced by both of the manufacturing processes. Both geometrical dimensions were measured from single points on the outer surface and inner surface.

The products were measured with a coordinate measuring -machine that ran the standardized measurement pattern. The measured batch produced with the currently used manufacturing process included 30 products and they were taken from the end-product stock. The batch that was produced with the alternative manufacturing process included 41 products and it came straight from the production.

The sample lots were gathered from the measurement reports. All the measurement results for the two geometrical dimensions were separated from the report to an empty spreadsheet and organized into a correct order.

9.5.2 The charts

The charts were created by feeding data to Minitab. The data included the geometrical dimensions, their tolerances and the previously gained measurement results. The software processed the data into requested charts. This chapter presents all the made charts. Some of the charts have a circled sample in them.

It indicates that the sample was removed from the SPC data. By removing the circled sample, the rest of the sample lot is in a normal distribution. The removed samples are the result of something out of ordinary occurring during the machining processes. Hence, fixed SPC data was used in this study.

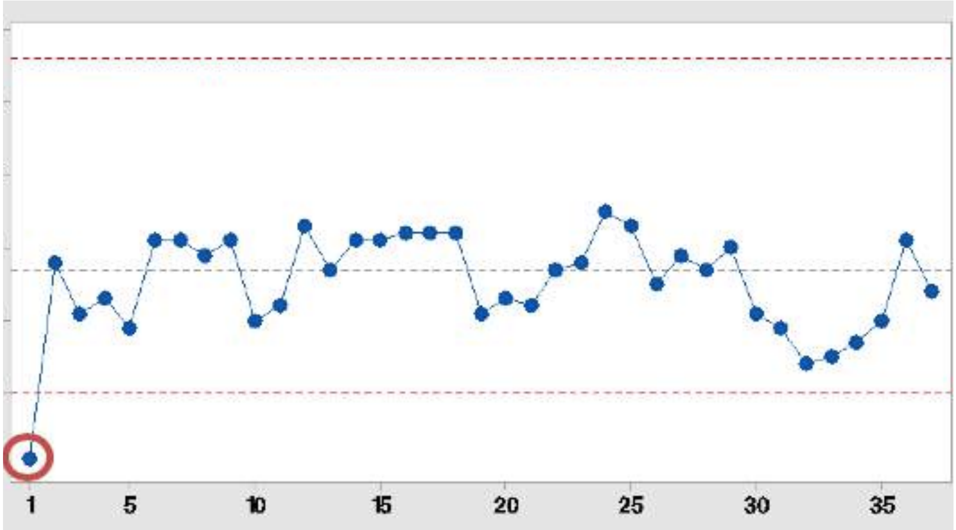


FIGURE 6. A run chart created from the outer diameter results

The run chart (figure 6) depicts the measurement results gained from outer diameters of bearing bushes produced with the alternative manufacturing process. The first result which is circled, has been removed from the SPC data as it alludes to adjustments made in the beginning of the machining process.

The bar chart (figure 7) depicts the same outer diameter measurement results. Examining the bar chart shows that the results do not spread in normal distribution. This affects the C_p values and makes them not reliable.

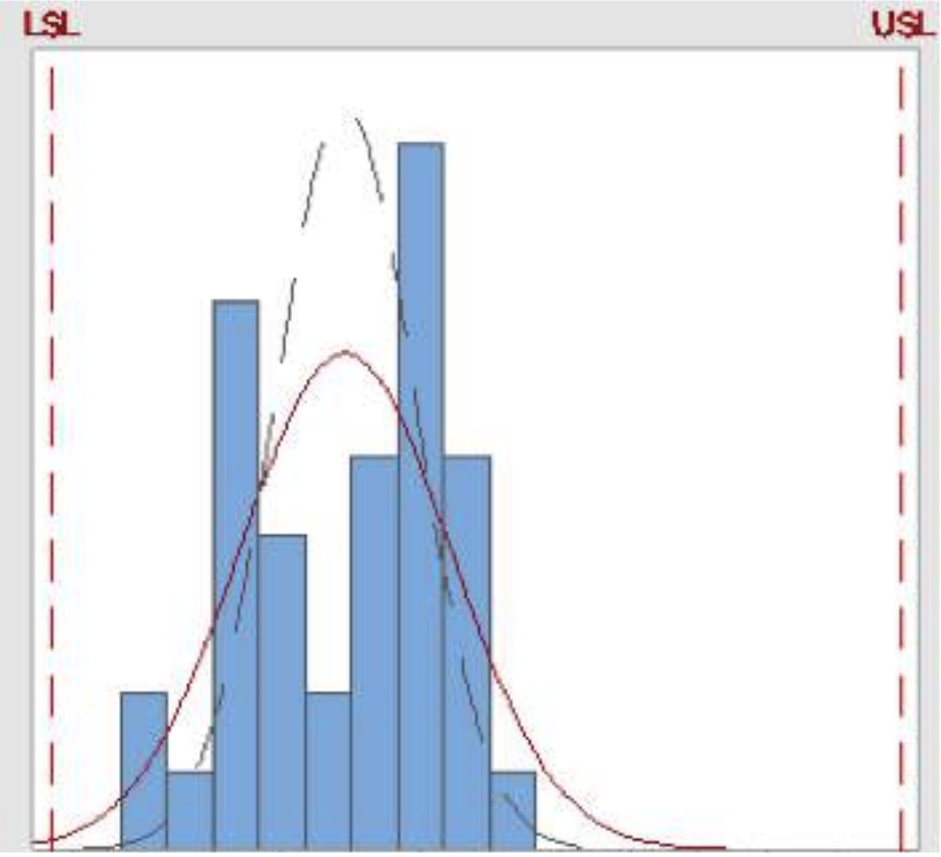


FIGURE 7. A bar chart made from the outer diameter measurements

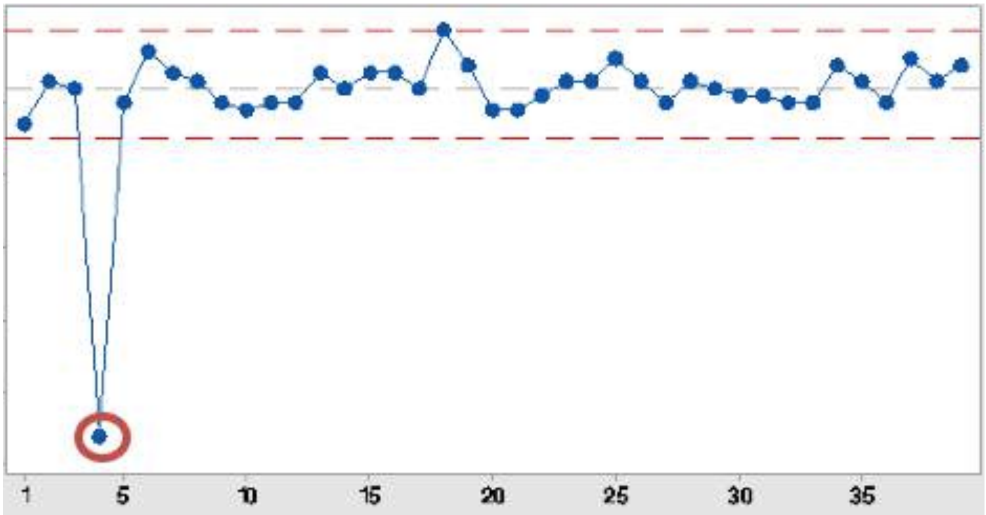


FIGURE 8. Run chart created from the sleeve thickness measurement result

The run chart (figure 8) depicts the measurement results gotten from the sleeve thickness of bearing bushes produced with the alternative manufacturing process. The fourth sample that is circled, was removed from the SPC data to change it towards normal distribution. The centred distribution is shown at figure 9. These results are in normal distribution which means that the C_p values are reliable.

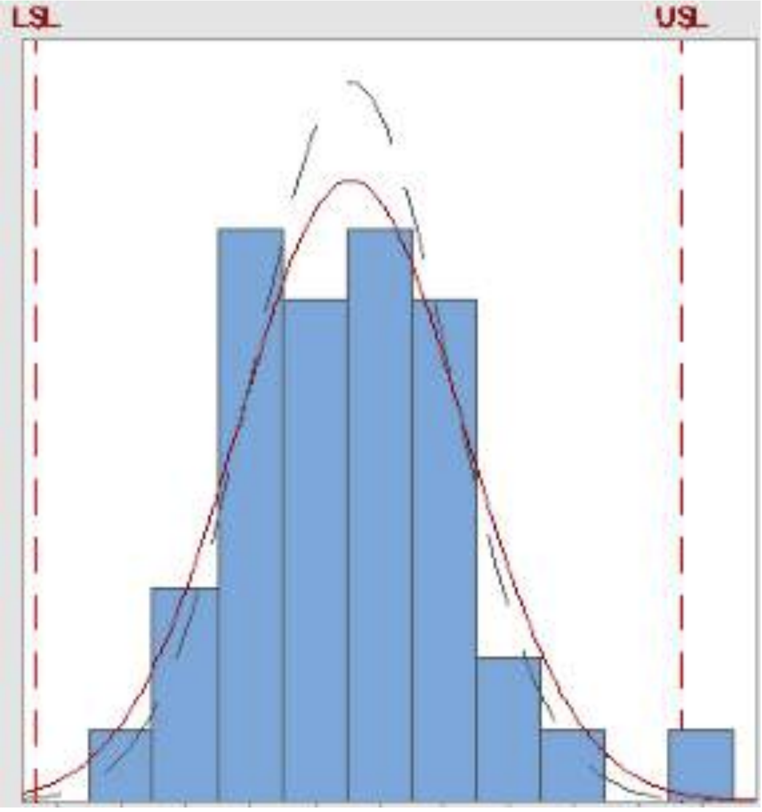


FIGURE 9. A bar chart created from the sleeve thickness measurement results

The probability plot (figure 10) and bar chart (figure 11) begin the charts made for the measurement results gotten from bearing bushes produced with the currently used manufacturing process. They examine the results gotten from the outer diameter. Both of the charts depicts that the results are in normal distribution, so the C_p values are reliable. However, the bar chart shows more spread compared to the bar chart from outer diameter results examined for the alternative manufacturing process.

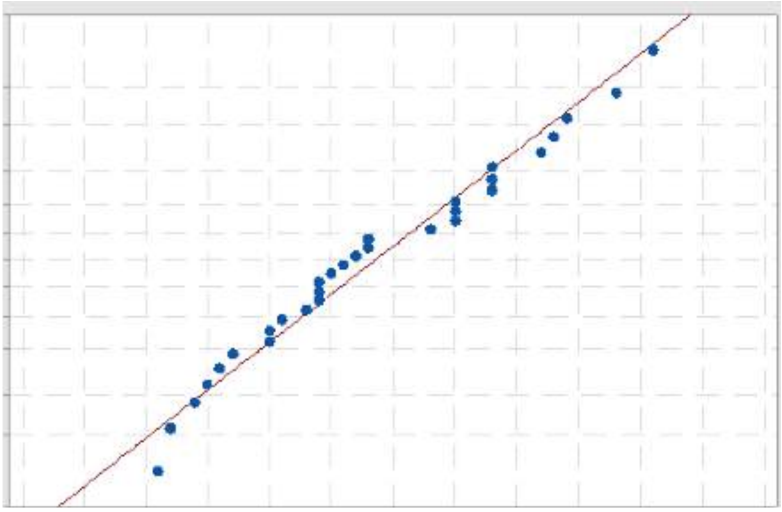


FIGURE 10. Probability plot depicting the outer diameter results

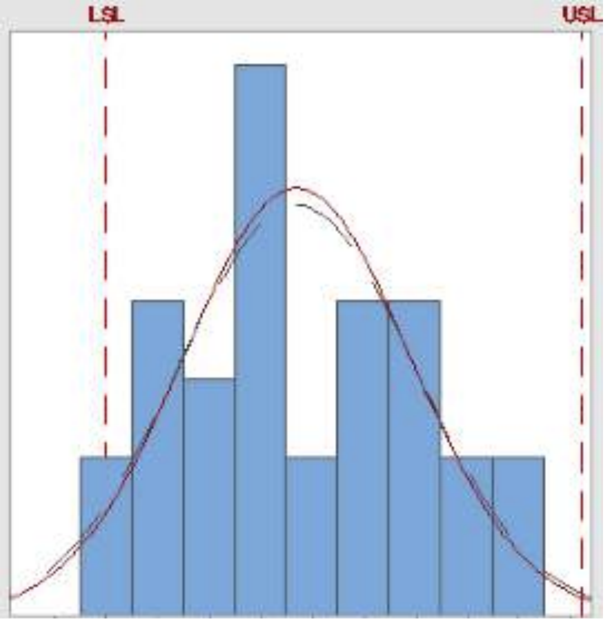


FIGURE 11. A bar chart created from the outer diameter results

The last charts depict the sleeve thickness measurement results for the currently used manufacturing process. The probability plot (figure 12) and the bar chart (figure 13) had a single sample removed to make them act in normal distribution. These results also gave a reliable C_p value. The spread of samples is very narrow, but the charts show a concentration near the upper tolerance.

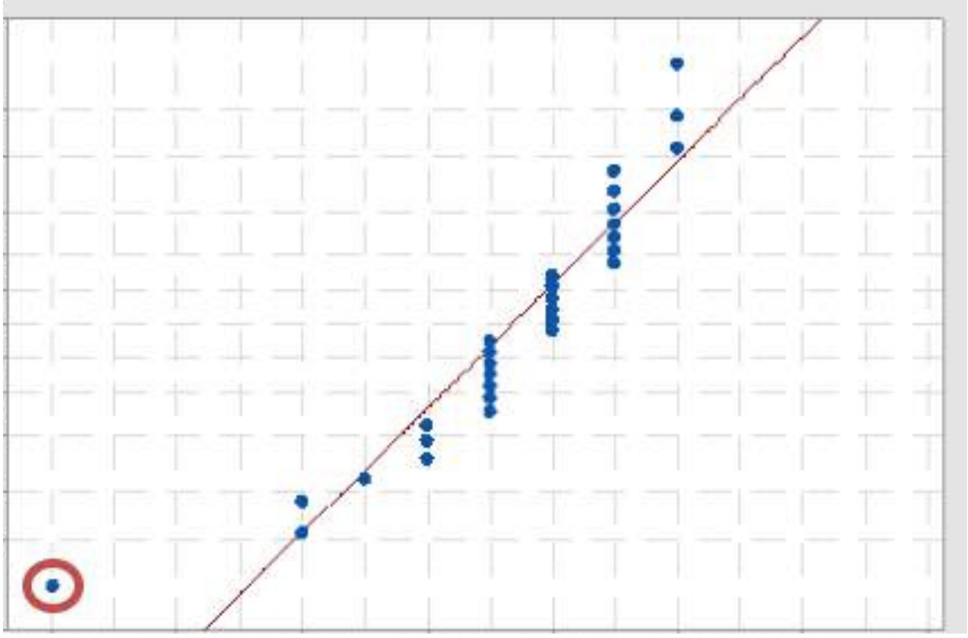


FIGURE 12. The probability plot created from the sleeve thickness results

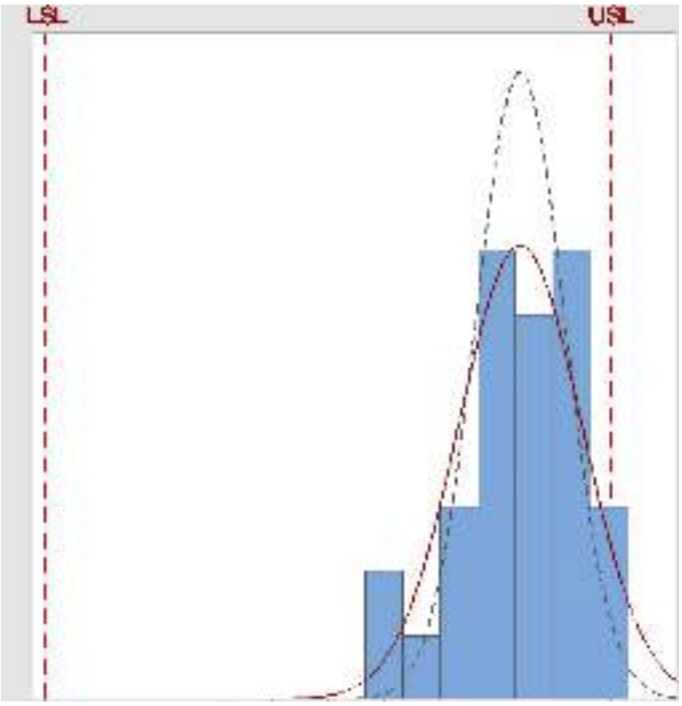


FIGURE 13. The bar chart created from the sleeve thickness results

9.6 The results

This chapter presents the results gathered from the mapping and analysing. Both manufacturing processes are addressed individually, and a comparison is made between them. SPC charts are excluded, because they are already presented in the chapter 8.5.2.

9.6.1 The currently used manufacturing process

The flowchart (attachment 1) created from the manufacturing process depicts that there are 39 necessary stages to produce the bearing bush. These stages are divided into 6 different phases. The flowchart also depicts the flow through the whole manufacturing process. The machining stages were mapped into a sub-flowchart (attachment 2) which depicts the subroutines in the machining program and parameters used.

The value analysis (attachment 3) created from the manufacturing process depicts the value distribution inside the process.

The value analysis revealed that 39% of the stages inside the manufacturing process are value adding and 61% non-value adding. The reason for this distribution can be found from the many internal transfers and waiting periods that the product has to go through during the manufacturing process. They plainly eclipse the value adding stages with their amount. Reducing the waiting periods and internal transfers oppose a challenge, as they are necessary or inevitable. As the production is spread around the facility, internal transfers must be made to gain progress in the manufacturing process. And as other products are being manufactured in the company, the production capacity is not always available immediately as the previous stage is completed.

The processing times of the stages included in the value analysis were separated into five different types and their relation calculated in comparison to the total process time. The result (table 3) shows that waiting periods take the major share based on defined processing times inside the manufacturing process.

The waiting times were defined from an average calculated from waiting times occurred during earlier runs with the process, but the waiting time is a variable subject to change.

TABLE 3. The separation of the total process time

Value adding time percentage	24%
Waiting time percentage	72%
Storage time percentage	3.5%
Inspection time percentage	0.3%
Transfer time percentage	0.2%

The value stream map (attachment 4) created from the manufacturing process depicts a timeline and value stream for producing 270 products. Based on the defined processing times from it was created, the machining phase has the longest cycle time. The cycle time makes up for 75% of the total lead time of the manufacturing process and 87% of the value adding time is made by the phase. This is understandable, because the machining phase includes the use of three different machines and the cycle time consists not only from the actual machining, but also the waiting times between the usage of these different machines.

The waiting time can be a result of limited capacity as other products are being manufactured parallel to the bearing bush on the same machines.

The loading and smelting phases make up to only 6% of the total lead time and a major part of that portion is made by the one day drying time the raw material load undergoes before smelting.

The casting phase makes up for 1% of the total lead time. The centrifugal casting technique produces casts in a fast pace and the phase has no waiting times. The casts go to a storage after the casting phase to cool down and this cooling time makes up to 4% of the total lead time.

The inspection phase is not considered to be a value adding phase. With the current inspection strategy, the phase makes up for 14% of the total lead time.

The SPC study made from the manufacturing process revealed that measurement results differed in spread. It could be the results of making more adjustments to the other dimension.

The outer diameter results depicted in figure 11, show that the distribution is concentrated in the middle of the range, but there is a lot of spread. This spread indicates that adjustments has been made to the machining parameters for the outer diameter. Based on C_p value, the process would not be able to continuously produce products that meet the requirements. However, because of the adjustments made during the machining, the C_p value is not reliable. The bar chart does not depict the reality of the condition in which the process is.

The sleeve thickness depicted in figure 12 shows that the measurement results are concentrated to the upper tolerance area. However, the spread is narrow, and the data is in a normal distribution after a single sample is removed. The removed sample is visible in the probability plot (figure 13).

The centrifugal casting technique can be excluded as a suspect that causes the spread. The cast itself has a lot of machining allowance so possible rugged sections in the outer surfaces would be removed in the roughing phase of machining

9.6.2 The alternative manufacturing process

The flowchart (attachment 5) created from the manufacturing process depicts that 34 stages are required to manufacture the bearing bush. The flowchart is similar to the one made of the currently used manufacturing process and includes the machining sub-flowchart (attachment 6).

The value analysis (attachment 7) depicts that 44% of the stages are value adding and 56% non-value adding. This is the result of less internal transfers and waiting periods occurring inside the manufacturing process. Having less of the previously mentioned activities turn the ratio toward a more positive figure.

The processing times included in the value analysis for the stages in this manufacturing process, were also separated to five different types. The results (table 4) depicted that the major share of the total process time came from the storage. However, the storage time that was defined based on a single run of the manufacturing process, so the odds of it being the same on the next run are low. It is a variable that is a subject for changes on each run.

TABLE 4. Separation of total process time

Value adding time percentage	19.5%
Waiting time percentage	24%
Storage time percentage	56%
Inspection time percentage	0.4%
Transfer time percentage	0.1%

The value stream map (attachment 8) created from the manufacturing process depicts a timeline and value stream for producing 340 products.

Based on the defined processing times it was created from, the machining phase has the largest cycle time of the whole manufacturing process. It makes up to 28% of the total lead time and 86% of the total value adding time. The storage time mentioned in the previous graph has an impact on the value analysis as it makes up for 56% of the total lead time. If the manufacturing process would be improved based on the results of value stream map, reducing the storage time would be an obvious choice.

Loading and smelting phases make for a 4% of the total lead time. The casting technique does not influence the time it takes for the loading and smelting processes. This can be seen in the percentage on the currently used manufacturing process, as it is similar.

The casting phase makes up for 1% of the total lead time. It is the same that the centrifugal casting makes from the currently used manufacturing processes lead time. This is a low percentage when considering that the casting phase produces enough cast for 340 products. The storage time after casting makes up for 1% of the total lead time.

Inspection phase makes up for 10% of the total lead time. Once again, this phase is not considered to add any value.

The SPC study made from the manufacturing process made a case that the continuous casting technique does not affect the outer diameter or the sleeve thickness in a negative way. There would be a possibility that if the cast had a rugged surface, the machining phase could not chip it “clean”, but in this study this was not the case.

The results for the outer diameter (figure 7) were not in a normal distribution. This made the C_p value obsolete as it would not be reliable in this case. However, all the measurement results are inside the tolerance limits.

The results for the sleeve thickness (figure 9) depicts that the machine process is well concentrated in relation to the geometrical dimension.

Spread can be seen as a negative factor in the chart, but the results all are between tolerance requirements. The C_p values indicate that the process is capable of producing products that meet specifications, but there is room for improvement.

9.6.3 Comparison

Based on the results presented in the previous chapter, the manufacturing processes have differences and can be compared. The loading and smelting phases are excluded from the comparison, as they are the same in both of the processes and differ only in the amount in pouring molten material in the crucible. Inspection is excluded also, because it is also the same for both of the manufacturing processes.

The first comparable feature of both manufacturing processes is the casting phase. Based on the value stream map, the currently used manufacturing process is able to cast the full casting load in 55% of the time the alternative manufacturing process requires. But the casts produced with the currently used manufacturing process have larger machining allowances compared to the alternative manufacturing process and also include a graphite coating.
The casts in the currently used manufacturing process must be washed before the machining phase to remove some of the graphite.

The second comparable feature is the machining phase. The value stream map indicates that the alternative manufacturing is able to complete the whole machining phase in 52% of the time that currently used manufacturing process would require. In addition, the phase time calculated for the alternative manufacturing process covers the machining of 340 products, whereas the phase time for the currently used manufacturing process covers only 270 products.

The currently used manufacturing process requires more capacity in machining, because it uses three different machines to complete the process, whereas the alternative manufacturing process uses just two. The reason behind the use of an extra machine is the graphite coating.

The turning of graphite produces an abrasive dust that can damage the machines, so it’s more sensible to do the roughing on designated machines and not on those which are used to finish the products. This however creates more waiting periods inside the currently used manufacturing process as the casts wait for the roughing and after that wait again for finishing. These waiting periods make a large contribution to the phase time. The alternative manufacturing process has also a better ratio on value adding activities to non-value adding activities in its machining phase. The currently used manufacturing has a faster casting phase, but it makes more duration to the machining phase. The duration is larger than the difference between the two casting techniques.

The alternative manufacturing process uses the casting load more effectively, as it is able to transform a 4t load into 340 products. In comparison, the currently used manufacturing process is able to transform a 4.4t load into 270 products. The machining allowances in the currently used manufacturing process bind more raw material than the allowances on the alternative manufacturing process. With a larger machining allowance, more material needs to be removed to get to the target diameters. The casts of the currently used manufacturing process have 20mm or more of machining allowances compared to the casts produced in the alternative manufacturing process. This makes the difference on how the manufacturing processes use the casting load.

The third comparable feature is the ratio between value adding and non-value adding. The value analysis depicted that the currently used manufacturing had 24% of value adding time compared to the 19.5% that the alternative manufacturing process had. Percentagewise, the alternative manufacturing process has 44% of its activities adding value, and the currently used manufacturing process 39%.

Calculating the ratio between value adding time to the total process time if waiting and storage times are not taken into account, the currently used manufacturing process has 96.9% of the total time adding value. The respective amount for the alternative manufacturing process is 97.2%. The results show that if theoretically there would be no waiting and storages in both manufacturing processes, the alternative manufacturing process would have the most of value adding time.

The fourth comparable feature is the quality that the manufacturing processes produce. The different casting techniques did not make any major differences in the SPC study.

The spreads seen in the charts were cause most likely by machining parameters and adjustments made to them by the machinists during the machining. No conclusion cannot be made based on the SPC study results that which one is the better manufacturing process qualitywise.

The fifth comparable feature is the amount of required stages that the manufacturing processes have in producing the bearing bushes. The flowcharts indicate that the alternative manufacturing process has 5 stages less inside it. This is a result of lacking the graphite coating, as it adds extra stages to the currently used manufacturing process.

10 Conclusions

10.1 Examining the results

The goal for the thesis was to provide data for Oy Johnson Metall Finland Ab from two of its manufacturing processes. The company had a desire to improve other of the manufacturing processes, so it required concrete data from which seek potential targets of improvement. This thesis used mapping and analysing to examine all the aspects and characteristics of the manufacturing processes and presented the gathered data in a visual form. In overall, the thesis has fulfilled all the demands that were set to it. All the defined deadlines were met, and the content required was gathered.

The results of this thesis depicted that both manufacturing processes have pros and cons in them. The currently used manufacturing process can produce casts in a fast pace, but the machining phase will last longer, because of the attributes of the cast. The alternative manufacturing process works in a reversed way, it takes more time to produce casts, but makes up for it in the machining phase. Qualitywise, both of the manufacturing processes have a similar capability based on the results of the SPC study. In value adding attributes, the alternative manufacturing process has a slight edge over the currently used manufacturing process. The alternative manufacturing process also has less stages in it.

In the theoretical section of the thesis, Six Sigma and SPC were examined. They were selected to be the sources for this thesis, because they represent the importance of gathering concrete data and analysing it before doing any improvements or adjustments. Six Sigma is a very common statistical improvement tool used in a large range of industries and business, so sources for it were available in large amounts. The flowcharts, value analyses and value stream maps all were made with guidelines provided by Six Sigma sources. Six Sigma can be utilized even if the company would not identify as a Six Sigma -user. SPC examines variations inside processes and like Six Sigma, it uses statistical data and it is considered to be a subset of Six Sigma.

SPC was a harder subject to find theoretical sources, but the ones found provided enough information to use in examining the results.

The reliability of the gathered data is hard to define. It was mostly gathered together with personnel of the company, but there is always a chance for human error and misunderstandings when something is measured or analysed. The possible errors in the thesis could be in the SPC study, as many different individuals have contributed to it, so this creates more causes for variation in the study. However, the flowcharts, value analyses and value stream maps should depict both of the manufacturing processes realistically and provide valuable information.

10.2 Suggestions on follow-up actions

10.2.1 Making adjustments to the machining programs

Based on the results gained on this thesis, the company should do a few adjustments to the machining programs used in both manufacturing processes.

In the currently used manufacturing process, a subroutine in the finishing program meant to rough the outer surface does not remove any actual chips. The blank has already a smaller outer diameter than the subroutine is meant to chip, hence the cutting tool just moves in the air without doing any chipping. This flaw was discovered while mapping the machining stage. Removing the subroutine would make the actual machining process a little faster.

Another adjustment that could be made to the finishing machining program in the currently used manufacturing process is to take a 0.007mm deeper chip in the finishing subroutine of the inner surface. As seen in figure 14, the measurement results are concentrated at the upper tolerance area. Taking a slightly deeper chip could bring the concentration more to the middle of the tolerance range.

In the alternative manufacturing process, the finishing subroutine for the outer diameter could be adjusted to take a 0.01mm lower chip. As seen in figure 8, the measurement results are concentrated in the lower tolerance area. The reduced chip could bring the concentration more to the middle of the tolerance range.

10.2.2 Conducting a more thorough SPC study

The SPC study made for this thesis did not reveal the real full capability of the manufacturing processes. Some of the results in the study display a spread that is caused by adjustments made while machining the products. These adjustments fight against the principle of SPC which is that adjustments should never be made based on single products. In this case, there is a possibility that adjustments were made after each machined product.

Oy Johnson Metall Finland Ab should examine the capability again by executing a thorough SPC study on the manufacturing processes. Test batches of minimum 30 products should be produced with both manufacturing processes. In the beginning of the machining phase, all the machinist should be informed not to do any adjustments while machining the test products. All the products should be measured in the order they were manufactured, and the results used for the study in the same fashion they were used in this thesis.

The results of the SPC study could reveal how the machining parameters act as the products are machined without doing any adjustments.
A pattern could be found and interpreting it could result on finding the correct parameter corrections. The modern lathes can be programmed to do automatic corrections after a certain amount of driven products and the study could help to reveal them.

As this thesis showed, the casting technique does not affect the quality of the products as much as the process times. So, the key for better quality for this product should be found from the machining phase.

After the new SPC study, the decision on which manufacturing process should be used in future should be made based on which manufacturing process has the more controllable machining phase.

10.2.3 Adapting Six Sigma

As a third suggestion that is made for the company based on this thesis, is to adapt Six Sigma as a solid part of its organizational actions. This suggestion would only not cover the manufacturing the bearing bushes, but the way the whole organization works towards reducing the variations inside all of its processes.

Some of the ingredients of Six Sigma that are examined in chapter 5.2 can be already seen in Oy Johnson Metall Finland Ab. The company has a genuine focus on its customers and by improving its processes, the company aims to add more value to the customer. It operates on a market in which the customer has to be kept satisfied and this requires constant actions from the company, like continuous improvement which the company does.

In addition, the company is fact and data driven as this thesis shows. It wants to get concrete data from which to seek the right targets to improve. This is a feat that might be the most important in Six Sigma, the will to use time to get the all necessary and required data. Based on the two ingredients previously mentioned, the company should have a good basis on adapting Six Sigma.

The adapting could be done by selecting the best fitting personnel whom have the traits and interest to learn Six Sigma. These personnel would undergo education and training where they would learn to utilize the tools and methods of Six Sigma. After the training, a Six Sigma -team could be formed in the company that would aim to reduce variations from the processes.

An adaption of Six Sigma would require time and create costs as the training for it would need to come from outside sources.

And there is always a chance that Six Sigma just does not fit in the organization, but the results might be worth of the risk if the company would want to go all-in on improving the quality it produces.

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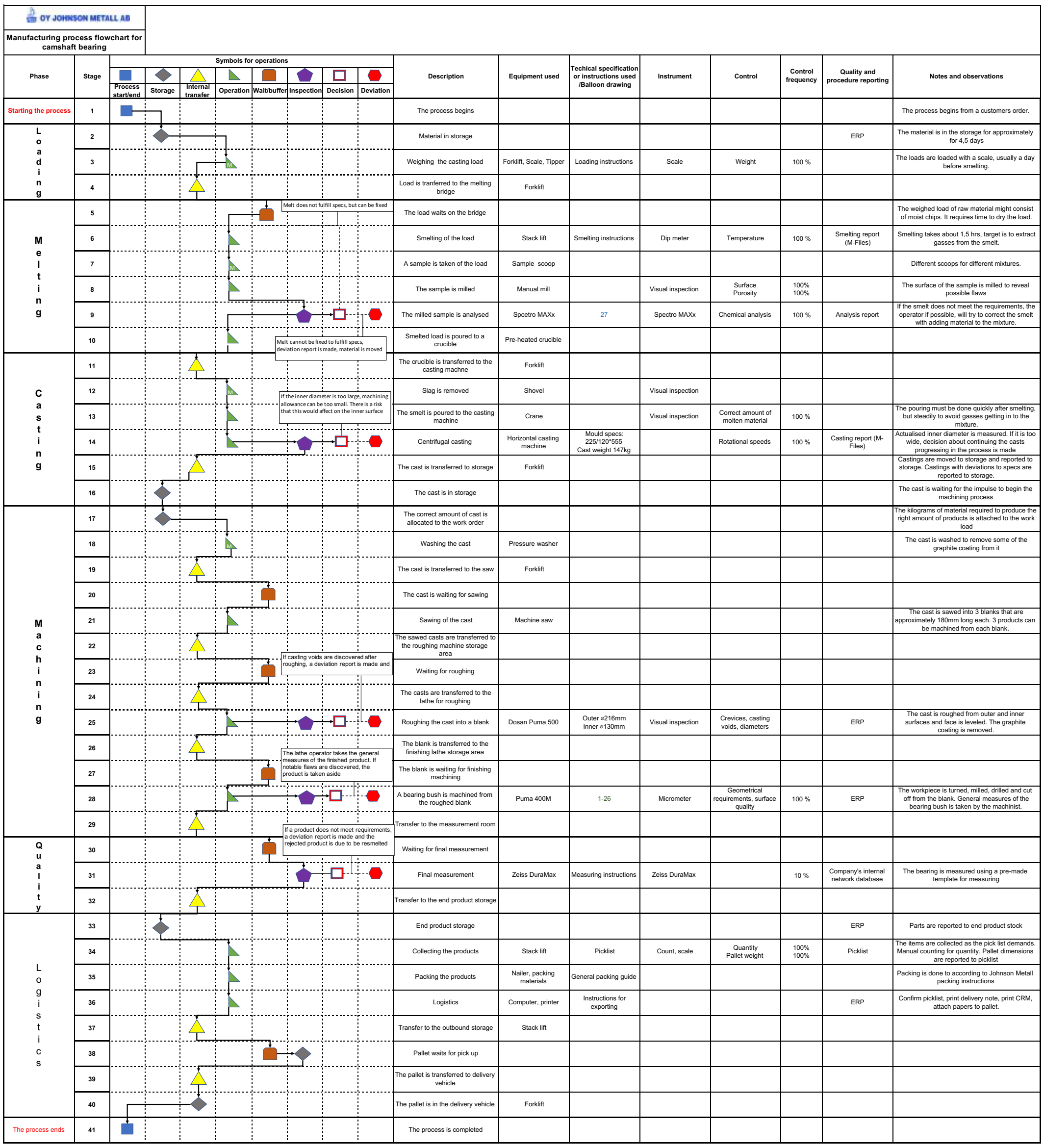
ATTACHMENTS

Attachment 1. Flowchart created from the currently used manufacturing process



OY JOHNSON METALL AB

Manufacturing process flowchart for camshaft bearing

Phase	Stage	Symbols for operations								Description	Equipment used	Techical specification or instructions used /Balloon drawing	Instrument	Control	Control frequency	Quality and procedure reporting	Notes and observations
		■ Process start/end	◆ Storage	▲ Internal transfer	◣ Operation	🟧 Wait/buffer	⬟ Inspection	□ Decision	⬣ Deviation								
Starting the process	1	■								The process begins							The process begins from a customers order.
Loading	2		◆							Material in storage						ERP	The material is in the storage for approximately for 4,5 days
	3				◣ M					Weighing the casting load	Forklift, Scale, Tipper	Loading instructions	Scale	Weight	100 %		The loads are loaded with a scale, usually a day before smelting.
	4			▲						Load is tranferred to the melting bridge	Forklift						
Melting	5					🟧				The load waits on the bridge							The weighed load of raw material might consist of moist chips. It requires time to dry the load.
	6				◣					Smelting of the load	Stack lift	Smelting instructions	Dip meter	Temperature	100 %	Smelting report (M-Files)	Smelting takes about 1,5 hrs, target is to extract gasses from the smelt.
	7				◣ M					A sample is taken of the load	Sample scoop						Different scoops for different mixtures.
	8				◣					The sample is milled	Manual mill		Visual inspection	Surface Porosity	100% 100%		The surface of the sample is milled to reveal possible flaws
	9						⬟	□	⬣	The milled sample is analysed	Spcetro MAXx	27	Spectro MAXx	Chemical analysis	100 %	Analysis report	If the smelt does not meet the requirements, the operator if possible, will try to correct the smelt with adding material to the mixture.
	10				◣					Smelted load is poured to a crucible	Pre-heated crucible						
Casting	11			▲						The crucible is transferred to the casting machne	Forklift						
	12				◣ M					Slag is removed	Shovel		Visual inspection				
	13				◣					The smelt is poured to the casting machine	Crane		Visual inspection	Correct amount of molten material	100 %		The pouring must be done quickly after smelting, but steadily to avoid gasses getting in to the mixture.
	14				◣		⬟	□	⬣	Centrifugal casting	Horizontal casting machine	Mould specs: 225/120*555 Cast weight 147kg		Rotational speeds	100 %	Casting report (M-Files)	Actualised inner diameter is measured. If it is too wide, decision about continuing the casts progressing in the process is made
	15			▲						The cast is transferred to storage	Forklift						Castings are moved to storage and reported to storage. Castings with deviations to specs are reported to storage.
	16		◆							The cast is in storage							The cast is waiting for the impulse to begin the machining process
Machining	17		◆							The correct amount of cast is allocated to the work order							The kilograms of material required to produce the right amount of products is attached to the work load
	18				◣ M					Washing the cast	Pressure washer						The cast is washed to remove some of the graphite coating from it
	19			▲						The cast is transferred to the saw	Forklift						
	20					🟧				The cast is waiting for sawing							
	21				◣					Sawing of the cast	Machine saw						The cast is sawed into 3 blanks that are approximately 180mm long each. 3 products can be machined from each blank.
	22			▲						The sawed casts are transferred to the roughing machine storage area							
	23					🟧				Waiting for roughing							
	24			▲						The casts are transferred to the lathe for roughing							
	25				◣		⬟	□	⬣	Roughing the cast into a blank	Dosan Puma 500	Outer ⌀216mm Inner ⌀130mm	Visual inspection	Crevices, casting voids, diameters		ERP	The cast is roughed from outer and inner surfaces and face is leveled. The graphite coating is removed.
	26			▲						The blank is transferred to the finishing lathe storage area							
	27					🟧				The blank is waiting for finishing machining							
	28				◣		⬟	□	⬣	A bearing bush is machined from the roughed blank	Puma 400M	1-26	Micrometer	Geometrical requirements, surface quality	100 %	ERP	The workpiece is turned, milled, drilled and cut off from the blank. General measures of the bearing bush is taken by the machinist.
	29			▲						Transfer to the measurement room							
Quality	30					🟧				Waiting for final measurement							
	31						⬟	□	⬣	Final measurement	Zeiss DuraMax	Measuring instructions	Zeiss DuraMax		10 %	Company's internal network database	The bearing is measured using a pre-made template for measuring
	32			▲						Transfer to the end product storage							
Logistics	33		◆							End product storage						ERP	Parts are reported to end product stock
	34				◣					Collecting the products	Stack lift	Picklist	Count, scale	Quantity Pallet weight	100% 100%	Picklist	The items are collected as the pick list demands. Manual counting for quantity. Pallet dimensions are reported to picklist
	35				◣					Packing the products	Nailer, packing materials	General packing guide					Packing is done to according to Johnson Metall packing instructions
	36				◣					Logistics	Computer, printer	Instructions for exporting				ERP	Confirm picklist, print delivery note, print CRM, attach papers to pallet.
	37			▲						Transfer to the outbound storage	Stack lift						
	38					🟧	◆			Pallet waits for pick up							
	39			▲						The pallet is transferred to delivery vehicle							
	40			◆						The pallet is in the delivery vehicle	Forklift						
The process ends	41	■								The process is completed							

Melt does not fulfill specs, but can be fixed

Melt cannot be fixed to fulfill specs, deviation report is made, material is moved

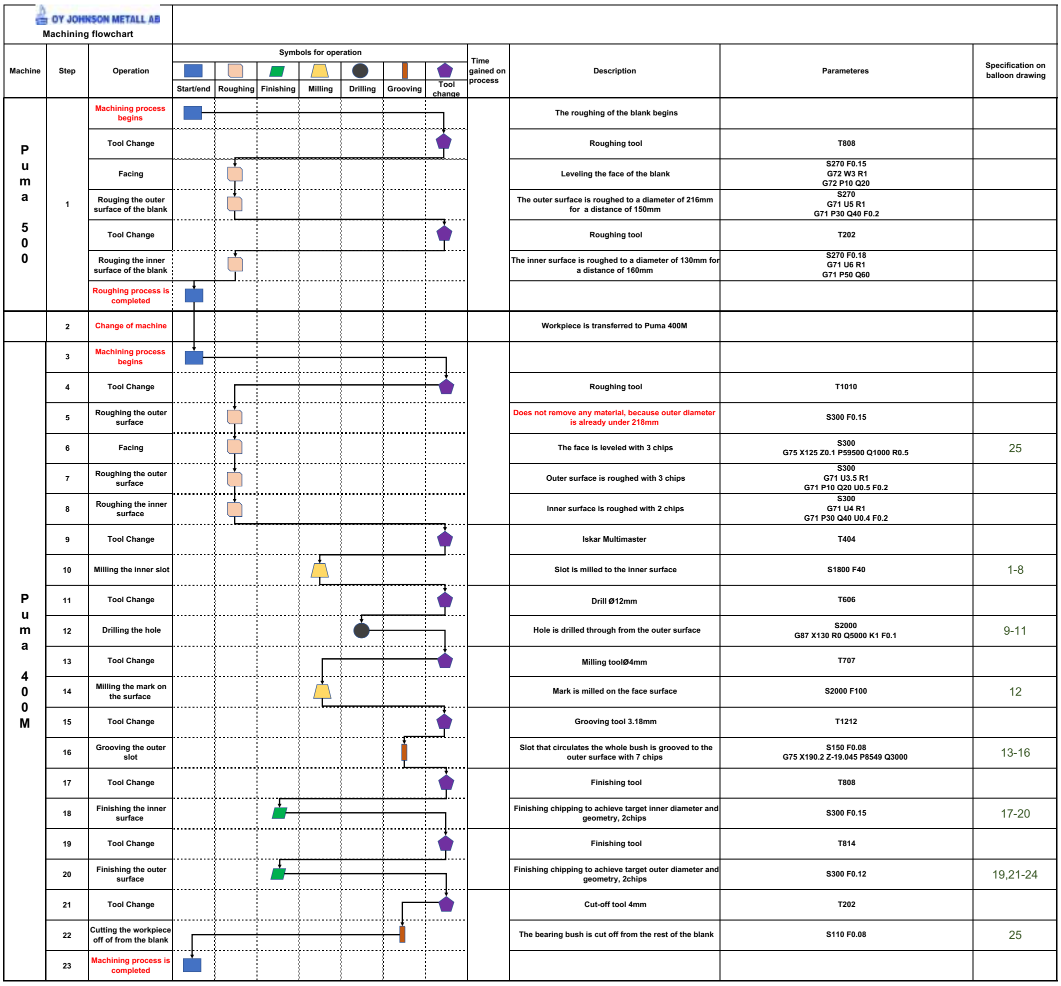
If the inner diameter is too large, machining allowance can be too small. There is a risk that this would affect on the inner surface

If casting voids are discovered after roughing, a deviation report is made and

The lathe operator takes the general measures of the finished product. If notable flaws are discovered, the product is taken aside

If a product does not meet requirements, a deviation report is made and the rejected product is due to be resmelted

Attachment 2. The sub-flowchart for the machining stages (currently used)



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Machining flowchart

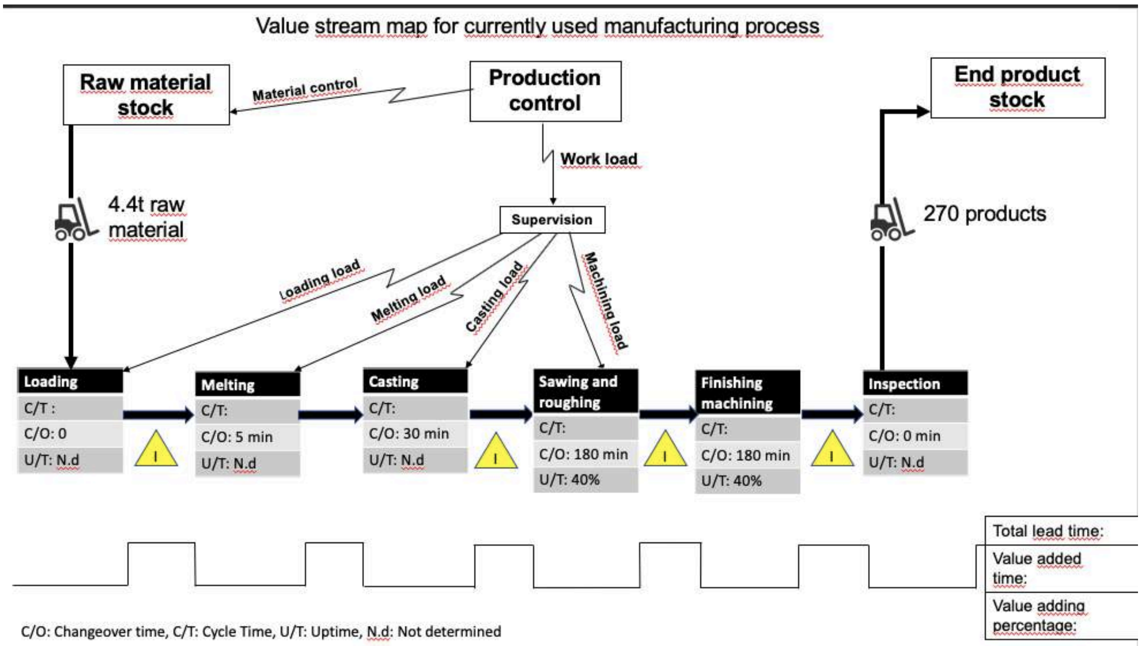
Machine	Step	Operation	Symbols for operation							Time gained on process	Description	Parameteres	Specification on balloon drawing
			■	▢	▱	⏢	●	▮	⬟				
			Start/end	Roughing	Finishing	Milling	Drilling	Grooving	Tool change				
Puma 500	1	Machining process begins	■								The roughing of the blank begins		
		Tool Change							⬟		Roughing tool	T808	
		Facing		▢							Leveling the face of the blank	S270 F0.15 G72 W3 R1 G72 P10 Q20	
		Rouging the outer surface of the blank		▢							The outer surface is roughed to a diameter of 216mm for a distance of 150mm	S270 G71 U5 R1 G71 P30 Q40 F0.2	
		Tool Change							⬟		Roughing tool	T202	
		Rouging the inner surface of the blank		▢							The inner surface is roughed to a diameter of 130mm for a distance of 160mm	S270 F0.18 G71 U6 R1 G71 P50 Q60	
		Roughing process is completed	■										
	2	Change of machine									Workpiece is transferred to Puma 400M		
Puma 400M	3	Machining process begins	■										
	4	Tool Change							⬟		Roughing tool	T1010	
	5	Roughing the outer surface		▢							Does not remove any material, because outer diameter is already under 218mm	S300 F0.15	
	6	Facing		▢							The face is leveled with 3 chips	S300 G75 X125 Z0.1 P59500 Q1000 R0.5	25
	7	Roughing the outer surface		▢							Outer surface is roughed with 3 chips	S300 G71 U3.5 R1 G71 P10 Q20 U0.5 F0.2	
	8	Roughing the inner surface		▢							Inner surface is roughed with 2 chips	S300 G71 U4 R1 G71 P30 Q40 U0.4 F0.2	
	9	Tool Change							⬟		Iskar Multimaster	T404	
	10	Milling the inner slot				⏢					Slot is milled to the inner surface	S1800 F40	1-8
	11	Tool Change							⬟		Drill Ø12mm	T606	
	12	Drilling the hole					●				Hole is drilled through from the outer surface	S2000 G87 X130 R0 Q5000 K1 F0.1	9-11
	13	Tool Change							⬟		Milling toolØ4mm	T707	
	14	Milling the mark on the surface				⏢					Mark is milled on the face surface	S2000 F100	12
	15	Tool Change							⬟		Grooving tool 3.18mm	T1212	
	16	Grooving the outer slot						▮			Slot that circulates the whole bush is grooved to the outer surface with 7 chips	S150 F0.08 G75 X190.2 Z-19.045 P8549 Q3000	13-16
	17	Tool Change							⬟		Finishing tool	T808	
	18	Finishing the inner surface			▱						Finishing chipping to achieve target inner diameter and geometry, 2chips	S300 F0.15	17-20
	19	Tool Change							⬟		Finishing tool	T814	
	20	Finishing the outer surface			▱						Finishing chipping to achieve target outer diameter and geometry, 2chips	S300 F0.12	19,21-24
	21	Tool Change							⬟		Cut-off tool 4mm	T202	
	22	Cutting the workpiece off of from the blank						▮			The bearing bush is cut off from the rest of the blank	S110 F0.08	25
	23	Machining process is completed	■										

Attachment 3. Value analysis of the currently manufacturing process

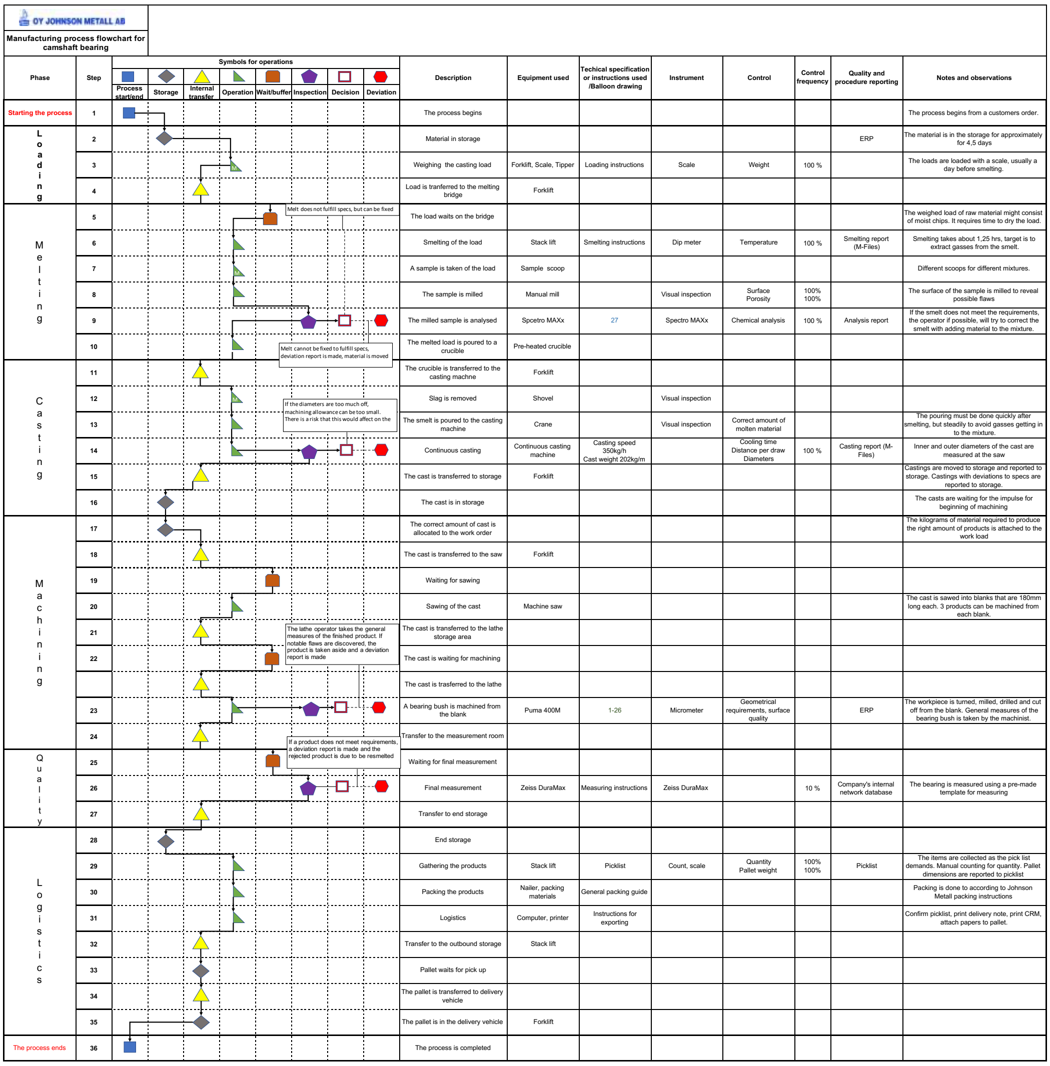
The current manufacturing process
Dimensions= Two-shift, 4.4t of raw material, 270 produced products

Phase	Operation	Value definement	Time taken by operation	Time per full casting load (4.4t)	Time per 1 product	Description for time taken	Time type
Loading	Material in storage	**Non-value adding**				Copper is ordered 40 x 10 ton shipments each year. This is not calculated into analysis or vsm	Storage time
	Weighing the casting load	**Value adding**				The time it takes to weigh the raw material for a single 440 kg load.	Value adding time
	Load is tranferred to the melting bridge	**Non-value adding**					Transfer time
Melting	The load waits on the bridge	**Non-value adding**				The raw material might consist of moist chips and needs time to dry before melting	Wait time
	Melting of the load	**Value adding**				The total time it takes to melt the 440kg load. 440kg of material is enough to produce 3 casts. One cast weights approximately 147kg.	Value adding time
	A sample is taken of the load	**Value adding**					Value adding time
	The sample is milled	**Value adding**					Value adding time
	The milled sample is analysed	**Value adding**					Value adding time
	Smelted load is poured to a crucible	**Value adding**				The crucible contains material for a single cast. The single cast contains material for 9 products	Value adding time
Casting	The crucible is transferred to the casting machne	**Non-value adding**					Transfer time
	Slag is removed	**Value adding**					Value adding time
	The smelt is poured to the casting machine	**Value adding**				The total time taken to produce one cast.	Value adding time
	Producing a blank by centrifugal casting	**Value adding**					Value adding time
	The cast is transferred to storage	**Non-value adding**					Transfer time
	The cast is in storage	**Non-value adding**					Storage time
Machining	Washing the cast	**Non-value adding**					Non-value adding time
	The casts is transferred to the saw	**Non-value adding**					Transfer time
	Waiting for sawing	**Non-value adding**				Calculated average from sampling of 4 different waiting times	Wait time
	Sawing the cast to smaller pieces	**Value adding**				The time it takes to saw one 550mm long cast into three blanks.	Value adding time
	The sawed cast is transferred to the roughing machine storage area	**Non-value adding**					Transfer time
	Waiting for roughing	**Non-value adding**				Calculated average from sampling of 4 different waiting times	Wait time
	The blank is transferred to the lathe for roughing	**Non-value adding**					
	Roughing the blank into a blank	**Value adding**				The time it takes to rough one blank.	Value adding time
	The roughed blank is transferred to finishing lathe storage area	**Non-value adding**					Transfer time
	The blank is waiting for finishing machining	**Non-value adding**				Calculated average from sampling of 4 different waiting times	Wait time
	The blank is transferred to the lathe for finishing	**Non-value adding**					
	Machining a finished product from the roughed blank	**Value adding**				The time it takes to machine one finished product from the blank	Value adding time
	Transfer to the measurement room	**Non-value adding**				27 finished products	Transfer time
Quality	Waiting for final measurement	**Non-value adding**				Calculated average from sampling of 4 different waiting times	Wait time
	Final measurement	**Non-value adding**				10% of finished products undergo the inspection	Inspection time
	Transfer to end product storage	**Non-value adding**					Transfer time

Attachment 4. A value stream map of the currently used manufacturing process



Attachment 5. Flowchart created from the alternative manufacturing process



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Manufacturing process flowchart for camshaft bearing

Phase	Step	Symbols for operations								Description	Equipment used	Techical specification or instructions used /Balloon drawing	Instrument	Control	Control frequency	Quality and procedure reporting	Notes and observations
		🟦 Process start/end	◆ Storage	▲ Internal transfer	◢ Operation	🟧 Wait/buffer	⬟ Inspection	☐ Decision	⬣ Deviation								
Starting the process	1	🟦								The process begins							The process begins from a customers order.
Loading	2		◆							Material in storage						ERP	The material is in the storage for approximately for 4,5 days
	3				◢ M					Weighing the casting load	Forklift, Scale, Tipper	Loading instructions	Scale	Weight	100 %		The loads are loaded with a scale, usually a day before smelting.
	4			▲						Load is tranferred to the melting bridge	Forklift						
Melting	5					🟧				The load waits on the bridge							The weighed load of raw material might consist of moist chips. It requires time to dry the load.
	6				◢					Smelting of the load	Stack lift	Smelting instructions	Dip meter	Temperature	100 %	Smelting report (M-Files)	Smelting takes about 1,25 hrs, target is to extract gasses from the smelt.
	7				◢ M					A sample is taken of the load	Sample scoop						Different scoops for different mixtures.
	8				◢					The sample is milled	Manual mill		Visual inspection	Surface Porosity	100% 100%		The surface of the sample is milled to reveal possible flaws
	9						⬟	☐	⬣	The milled sample is analysed	Spcetro MAXx	27	Spectro MAXx	Chemical analysis	100 %	Analysis report	If the smelt does not meet the requirements, the operator if possible, will try to correct the smelt with adding material to the mixture.
	10				◢					The melted load is poured to a crucible	Pre-heated crucible						
Casting	11			▲						The crucible is transferred to the casting machne	Forklift						
	12				◢ M					Slag is removed	Shovel		Visual inspection				
	13				◢					The smelt is poured to the casting machine	Crane		Visual inspection	Correct amount of molten material			The pouring must be done quickly after smelting, but steadily to avoid gasses getting in to the mixture.
	14				◢		⬟	☐	⬣	Continuous casting	Continuous casting machine	Casting speed 350kg/h Cast weight 202kg/m		Cooling time Distance per draw Diameters	100 %	Casting report (M-Files)	Inner and outer diameters of the cast are measured at the saw
	15			▲						The cast is transferred to storage	Forklift						Castings are moved to storage and reported to storage. Castings with deviations to specs are reported to storage.
	16		◆							The cast is in storage							The casts are waiting for the impulse for beginning of machining
Machining	17		◆							The correct amount of cast is allocated to the work order							The kilograms of material required to produce the right amount of products is attached to the work load
	18			▲						The cast is transferred to the saw	Forklift						
	19					🟧				Waiting for sawing							
	20				◢					Sawing of the cast	Machine saw						The cast is sawed into blanks that are 180mm long each. 3 products can be machined from each blank.
	21			▲						The cast is transferred to the lathe storage area							
	22					🟧				The cast is waiting for machining							
				▲						The cast is trasferred to the lathe							
	23				◢		⬟	☐	⬣	A bearing bush is machined from the blank	Puma 400M	1-26	Micrometer	Geometrical requirements, surface quality		ERP	The workpiece is turned, milled, drilled and cut off from the blank. General measures of the bearing bush is taken by the machinist.
	24			▲						Transfer to the measurement room							
Quality	25					🟧				Waiting for final measurement							
	26						⬟	☐	⬣	Final measurement	Zeiss DuraMax	Measuring instructions	Zeiss DuraMax		10 %	Company's internal network database	The bearing is measured using a pre-made template for measuring
	27			▲						Transfer to end storage							
Logistics	28		◆							End storage							
	29				◢					Gathering the products	Stack lift	Picklist	Count, scale	Quantity Pallet weight	100% 100%	Picklist	The items are collected as the pick list demands. Manual counting for quantity. Pallet dimensions are reported to picklist
	30				◢					Packing the products	Nailer, packing materials	General packing guide					Packing is done to according to Johnson Metall packing instructions
	31				◢					Logistics	Computer, printer	Instructions for exporting					Confirm picklist, print delivery note, print CRM, attach papers to pallet.
	32			▲						Transfer to the outbound storage	Stack lift						
	33			◆						Pallet waits for pick up							
	34			▲						The pallet is transferred to delivery vehicle							
	35			◆						The pallet is in the delivery vehicle	Forklift						
The process ends	36	🟦								The process is completed							

Melt does not fulfill specs, but can be fixed

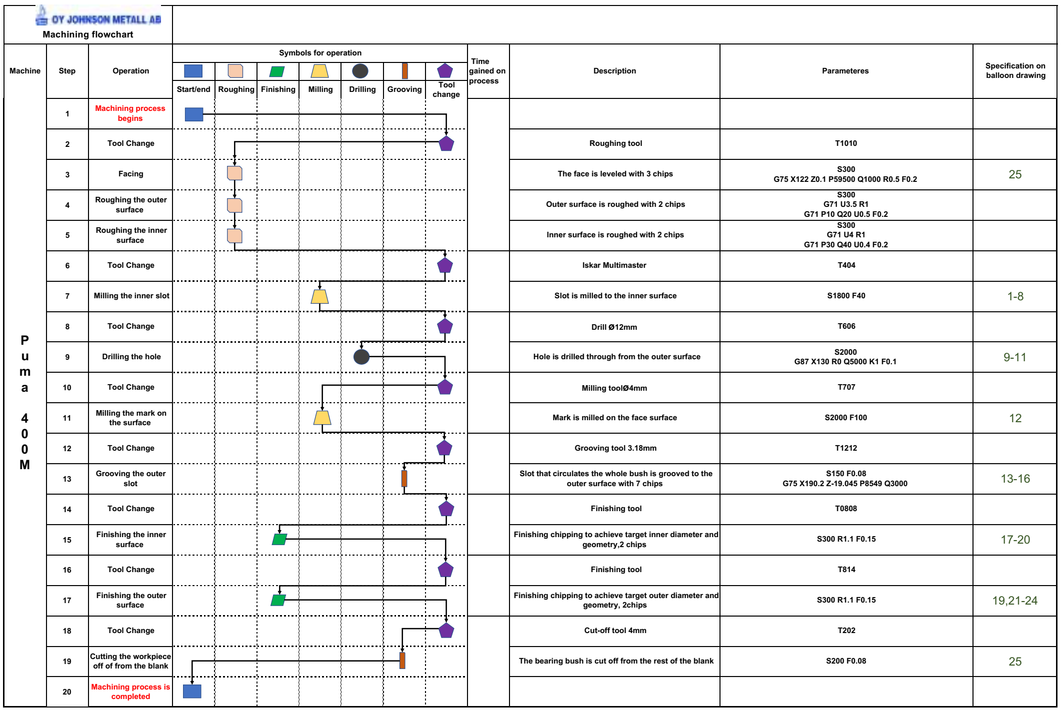
Melt cannot be fixed to fulfill specs, deviation report is made, material is moved

If the diameters are too much off, machining allowance can be too small. There is a risk that this would affect on the

The lathe operator takes the general measures of the finished product. If notable flaws are discovered, the product is taken aside and a deviation report is made

If a product does not meet requirements, a deviation report is made and the rejected product is due to be resmelted

Attachment 6. Sub-flowchart created from the machining stage (alternative)



OY JOHNSON METALL AB

Machining flowchart

Machine	Step	Operation	Symbols for operation							Time gained on process	Description	Parameteres	Specification on balloon drawing
			■	▢	▰	⏢	●	▮	⬟				
			Start/end	Roughing	Finishing	Milling	Drilling	Grooving	Tool change				
Puma 400M	1	Machining process begins	■										
	2	Tool Change							⬟		Roughing tool	T1010	
	3	Facing		▢							The face is leveled with 3 chips	S300 G75 X122 Z0.1 P59500 Q1000 R0.5 F0.2	25
	4	Roughing the outer surface		▢							Outer surface is roughed with 2 chips	S300 G71 U3.5 R1 G71 P10 Q20 U0.5 F0.2	
	5	Roughing the inner surface		▢							Inner surface is roughed with 2 chips	S300 G71 U4 R1 G71 P30 Q40 U0.4 F0.2	
	6	Tool Change							⬟		Iskar Multimaster	T404	
	7	Milling the inner slot				⏢					Slot is milled to the inner surface	S1800 F40	1-8
	8	Tool Change							⬟		Drill Ø12mm	T606	
	9	Drilling the hole					●				Hole is drilled through from the outer surface	S2000 G87 X130 R0 Q5000 K1 F0.1	9-11
	10	Tool Change							⬟		Milling toolØ4mm	T707	
	11	Milling the mark on the surface				⏢					Mark is milled on the face surface	S2000 F100	12
	12	Tool Change							⬟		Grooving tool 3.18mm	T1212	
	13	Grooving the outer slot						▮			Slot that circulates the whole bush is grooved to the outer surface with 7 chips	S150 F0.08 G75 X190.2 Z-19.045 P8549 Q3000	13-16
	14	Tool Change							⬟		Finishing tool	T0808	
	15	Finishing the inner surface			▰						Finishing chipping to achieve target inner diameter and geometry,2 chips	S300 R1.1 F0.15	17-20
	16	Tool Change							⬟		Finishing tool	T814	
	17	Finishing the outer surface			▰						Finishing chipping to achieve target outer diameter and geometry, 2chips	S300 R1.1 F0.15	19,21-24
	18	Tool Change							⬟		Cut-off tool 4mm	T202	
	19	Cutting the workpiece off of from the blank						▮			The bearing bush is cut off from the rest of the blank	S200 F0.08	25
	20	Machining process is completed	■										

Attachment 7. Value analysis of the alternative manufacturing process

The alternative manufacutring process (Based on one process run)
Dimensions= Two-shift, 4t of material, Cast weight: 202kg/m,Casting speed: 350kg/h, Products produced: 340pcs

Phase	Operation	Value definement	Time taken	Time per full casting load (4t)	Time per 1 product	Description for time taken	Time type
Loading	Material in storage	**Non-value adding**				Copper is ordered 40 x 10 ton shipments each year. This is not calculated into the value analysis or vsm	Storage time
	Weighing the casting load	**Value adding**				The time taken for weighing one load	Value adding time
	Load is tranferred to the melting bridge	**Non-value adding**					Transfer time
Melting	The load waits on the bridge	**Non-value adding**				The raw material might consist of moist chips and needs time to dry before melting	Wait time
	Melting the raw material	**Value adding**				The time it takes for a single melting process	Value adding time
	A sample is taken of the load	**Value adding**					Value adding time
	The sample is milled	**Value adding**					Value adding time
	The milled sample is analysed	**Value adding**					Value adding time
	Smelted load is poured to a crucible	**Value adding**					Value adding time
Casting	The crucible is transferred to the casting machne	**Non-value adding**					Transfer time
	Slag is removed	**Value adding**					Value adding time
	The smelt is poured to the casting machine	**Value adding**					Value adding time
	A blank is produced by continuous casting	**Value adding**				The theoretical time it takes to cast one 2m long cast. 34 products can be manufactured from a single cast	Value adding time
	The cast is transferred to storage	**Non-value adding**				One storage cage contains 1t of cast	Transfer time
	The cast is in storage	**Non-value adding**				The waiting time that occured during the only process run	Storage time
Machining	The cast is transferred to the saw	**Non-value adding**					Transfer time
	Sawing of the cast	**Value adding**				The time it takes to saw the whole cast into blanks	Value adding time
	The cast is transferred to lathe storage area	**Non-value adding**					Transfer time
	The cast is waiting for machining	**Non-value adding**				The waiting time that occured during the only process run	Wait time
	The cast is transferred to lathe	**Non-value adding**					
	Machining a finished product from the cast	**Value adding**				The time it takes to machine one product	Value adding time
	Transfer to the measurement room	**Non-value adding**					Transfer time
Quality	Waiting for final measurement	**Non-value adding**				The waiting time that occured during the only process run	Wait time
	Final measurement	**Non-value adding**				10% of finished products undergo the inspection	Inspection time
	Transfer to the ready-made storage	**Non-value adding**					Transfer time

Attachment 8. A Value stream map of the alternative manufacturing process