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IMPROVING PERFORMANCE OF TECHNICAL SUPPORT FUNCTION USING LEAN SIX SIGMA

Master's thesis

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Supervisor: Aleksandr Miina, PhD

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I hereby declare that I have compiled the thesis independently
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ABSTRACT

The qualitative and quantitative study is performed in a global company providing electrification, robotics and motion, industrial automation and power grids products and services. The focus function of this thesis is based in Estonia in one of the local factories providing everyday technical support to the production lines.

A qualitative study is performed in the form of unstructured interviews with the employees working in the technical support function and the internal customers who are using the service provided by that function. The qualitative study is then backed up with a quantitative study that uses data from the functions quality metrics.

The purpose of this research is to identify what is important for the internal customers in regard to the technical support function, understand and analyse the working principles and methods of the functions current state and find out how satisfied the internal customers are with the results. Where appropriate, implement new methods or suggest improvements.

Lean Six Sigma philosophy, principles and tools are used to identify the root causes, implement new working methods and make process improvements to reduce waste and focus on the topics with the biggest effect on customer satisfaction. Recommendations and solutions are given and implemented to increase the performance of the technical support function.

Research is based on a case study and looks into an international company's technical support function everyday work to answer the following study questions:

1. What are the current challenges of providing technical services?
2. What can be the solutions to improve the team's performance?
3. How can Lean Six Sigma be used to analyse and improve technical support function?

Keywords: Lean, Six Sigma, Lean Six Sigma, Statistical Process Control, Technical support function, Root Cause Analysis, Pareto principle

INTRODUCTION

Global competition for best products, services, efficiency and quality has forced business owners to continuously improve baseline results and seek new opportunities to increase the effectiveness of their business. This competition and strife for the best company, product and service shows that continuous improvement as a methodology, strategy and philosophy has been around for decades.

Different researches show that only a small percentage of all work done in a company is value adding from the customers perspective, but customer satisfaction is one of the most critical parameters that separates successful companies from unsuccessful. Lean and Six Sigma approaches are widely used in continuous improvement methodology to increase customer satisfaction by eliminating wastes from processes in manufacturing and service. Both of these methods have similarities and differences that improve each other when combined. In the theoretical chapter thesis author will illustrate how each methodology came to be, how they can be used and what are the similarities and differences of both mentioned principles. The chapter ends describing why are these philosophies nowadays tied under a combined approach of Lean Six Sigma.

The theoretical part is followed by a case study about a technical support function in a global company that provides electrification, robotics and motion, industrial automation and power grids products and services. This technical support function is developing and providing everyday support to the local Estonian factory where one of the core businesses is production.

The purpose of the case study is to show how Lean Six Sigma can be used to increase the performance of technical support function by identifying what is important for the internal customers and how satisfied they are with the service provided. Define and measure the underlying problems, analyse and understand the root causes and where appropriate, implement new methods or suggest improvements.

The performance of the technical support function is studied using qualitative and quantitative methods. A qualitative study is performed in the form of unstructured interviews with the internal customers who are using the service provided by that function. The qualitative study is then backed up with a quantitative study that uses data from the functions quality metrics.

The justification of this case study rises from the qualitative study indicating that internal customers in the studied company are not happy. The study shows that there are communication challenges, there’s no performance measurement system, the service provided by the technical support function has not been analysed, waste identified and removed.

Lean Six Sigma philosophy, principles and tools are then used to identify the root causes of poor customer satisfaction. Brainstorming sessions with employees working in the technical support function are made and all ideas plotted on Ishikawa diagrams. Cause and effect matrix and Pareto principle are used to define the most effective improvements. Action plans are made to implement new working methods and process improvements. Due to time constraints, not all improvements were made and instead some recommendations where given.

The final chapter gives an overview of recommendations and solutions that were implemented to increase the efficiency and effectiveness of the technical support function. With the new working methods, the technical writers creating assembly instructions have a standard process to follow and quality metrics to measure the results. Standardised templates, folder structures and methods were taken into use to reduce wasted time. Communication tool was implemented to remove barriers between engineering and production departments and new management principles agreed and implemented within the organisation to focus on long term developments that have an effect on company baseline results.

The goals for this thesis were of practical nature, to analyse the current status of the technical support team’s performance and find out the root causes of poor internal customer satisfaction. Based on these analyses make improvements and measurement system proposals and implement them where possible. These goals were met and the following chapters will illustrate how these results were achieved.

Study questions:

What are the current challenges for providing technical services?

What can be the solutions to improve technical support team performance?

How can Lean Six Sigma be used to analyse and improve technical support function?

1. THEORETICAL OVERVIEW

Continuous Improvement as a methodology, strategy and philosophy has been around for decades. Already in 2500 BC people where building pyramids using division of labour, standardization, one-piece flow, visual management and many other fundamentals of Continuous Improvement (CI). (Burton, 2014) The Arsenal of Venice was using standard parts in the manufacturing of warships as early as 1436. (Hopp & Spearman, 2008). The history of CI has been long, but the main growth and development happened during several industrial revolutions, over the past 200 years. Starting with the first Industrial Revolution, 1780 – 1880, by harnessing the power of water, steam and standardisation. Followed by the second Industrial Revolution, 1880 – 1980, with the birth of scientific management, integrated supply chains, electricity, progressive assembly lines, standard methods and waste reduction. The third Industrial Revolution, 1980 – 2010, introduced technological improvements that made electronics and computing available for masses and lead to program-based improvements like Lean and Six Sigma. Nowadays we are in the Fourth Industrial revolution with mass customization, adaptive systems and digitalization where everything is connected and data plays a key role. (Burton, 2014)

Development of continuous improvement methodologies has happened over time and the following chapters will give a general overview of some of the program-based CI methodologies used - Lean, Six Sigma and their combination Lean Six Sigma. In this chapter, the author will illustrate how each methodology came to be, give an overview of the theoretical framework, principles and general tools used in the case study.

1.1. Lean

The National Institute of Standards and Technology (NIST), through its Manufacturing Extension Partnership, defines lean as follows:

A systematic approach to identifying and eliminating waste (non-value-added-activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection. (Kubiak & Benbow, 2016)

Lean means doing more with less, using simplified and optimized processes to use fewer resources, less inventory, fewer workers, less space. The term was coined by James Womack and Daniel Jones to describe the Toyota Production System, widely recognized as the most efficient manufacturing system in the world. (Russell & Taylor, 2011) In the centre of lean thinking stands the idea of defining value from customers perspective to design or improve services and products eliminating all activities and features that don’t contribute to the customers' value. As a result, organizations improve on waste elimination, time reduction, improved quality, safety and morale. (Womack & Jones, 2003)

Lean is not merely a tool, it is important to understand the importance of lean thinking, concept and the philosophy around it. Lean expects managers not to think about possible short-term gains but focus on the future and make decisions accordingly. Businesses need to understand the importance of the philosophical aspects and long term thinking when implementing Lean (Liker, 2004)

The idea of Lean philosophy has been studied by numerous authors and they all agree that Lean needs to be viewed as a condition, state of mind or philosophy, rather than a process or package of improvement tools. (Bhasin, 2011) (Olexa, 2002) (Bateman, 2002) (Moore, 2001) (Laureani & Antony, 2011)

1.1.1. Roots of Lean

Toyota began it's innovative journey in 1949 when Toyota Kiichiro, president of Toyota, demanded that his company "catch up with the America in three years. Otherwise, the automobile industry of Japan will not survive" (Ohno, 1988) At the time, Japan's economy was shattered by the war, labour productivity was one-ninth that of the United States, and automobile production was at minuscule levels. (Hopp & Spearman, 2008)

In 1950 Taiichi Ohno, a Toyota pant manager then, was assigned to understand Ford's production. He visited U.S plants and benchmarked them. Also, he carefully studied Ford's book "Today and Tomorrow". (Liker, 2004) He recognized that the only way to become competitive with America would be to close the huge productivity gap between the two countries. This could be done only through waste elimination aimed at lowering costs. Unlike the American automobile companies, Toyota could not reduce costs by exploiting economies of scale in giant mass production facilities. The market for Japanese automobiles was simply too small. Thus, the managers of Toyota decided that their manufacturing strategy had to be to produce many models in small numbers. (Hopp & Spearman, 2008)

By 1970s Toyota instituted a host of procedures and systems for implementing just-in-time production and autonomation, which refers to machines that are both automated, so that one worker can operate many machines, and fool proofed, so that they automatically detect problems. From a systems perspective, they implemented initiatives to reduce setup times, improve worker training, vendor relations, quality control, and many other aspects. Toyota named this new way of operating its business Toyota Production System (TPS). While not all the efforts were successful, many where, and the overall effect was to raise Toyota from an inconsequential player in the automotive market in 1950 to one of the largest automobile manufacturers in the world by the 1990s. (Hopp & Spearman, 2008)

After Toyota rose to one of the biggest automobile manufacturers, managers discovered TPS, and different researchers, as well as practitioners in manufacturing companies tried to understand TPS (lean thinking) and define it.

The term "lean" was first used by MIT scientist John Krafcik, a researcher in the International Motor Vehicle Program to describe Toyota Production System in his master's thesis for MIT's Sloan School of Management and published in Sloan Managements Review. (Samuel, Found, & Williams, 2015)

Officially and extensively Lean was introduced in 1990, after 5-year MIT study of the automobile industry, a new term for Just In Time (JIT) – lean manufacturing – appeared in the book, The Machine That Changed the World (Womack, Jones, Roos 1990). This was followed in 1996 by a second book, Lean Thinking (Womack and Jones 1996) that outlined the lean "philosophy." (Hopp & Spearman, 2008)

The number of case studies and surveys about Lean implementation has increased over the last 25 years. This is an expected result as the Lean paradigm has attracted much attention after the publication of the book The Machine that Changed the World. (Amaro, 2019)

1.1.2. Lean Principles and Goals

Lean is doing more with less. Use the least amount of effort, energy, equipment, time, facility space, materials, and capital – while giving customers exactly what they want. (Womack & Jones, 2003)

This is achieved by focusing on five Lean Principles explained by Womack & Jones (2003). It is important to understand that Lean is not only about waste elimination. These five principles should be viewed as consecutive and explain the core of lean thinking and what the companies need to focus on.

1) **Specify Value –** value can be defined only by the ultimate customer and there should be no room for assumptions. This principle indicates that for every product or service there is a need that the customer wants to fulfil. The design of the service or product needs to focus on fulfilling the customer need or in other words businesses have to focus only on value-adding activities and eliminate everything that does not add any value from the customers perspective.

2) **Identify the Value Stream –** the Value stream is all the actions needed to bring a product or service to the customer. A value stream "map" identifies all activities needed to design, order and make a specific product or offer service. Each step is sorted into three categories: those that add value, those that add no value but are necessary because of regulations, and those that add no value whatsoever and can be eliminated. One example of non-value adding activity that is usually overlooked is quality inspection. For the end customer, this step does not add any value, the product needs to be made or service needs to be provided already with controlled quality that is desired by the customer. Womack & Jones (2003)

have a good example of the British grocery chain Tesco where the canned cola value stream has three hours of value-added activities that take 319 days to perform.

3) **Flow** – make the value-creating steps flow. This means that product, information or service should move through one value-adding activity to the next one without any delays. Womack & Jones (2003) have an exceptional example showing how five-sixths of a typical home-building schedule consists usually of waiting for the next set of specialist or reworking.
4) **Pull** - let the customer pull the product from you. Meaning that no one from the upstream process should produce or provide anything until the customer downstream asks for it. In this ideal state, there would be no buffers of goods in stock. A good example by Womack and Jones (2003) is that one-half of the books printed in the United States each year are shredded without ever finding a reader. A possible solution for that would be to print a book when the customer buys it.
5) **Pursue perfection** – there is no end to the process of reducing effort, time, space, cost and mistakes while offering a product or service which is even more nearly what the customer wants. Womack and Jones (2003) discuss that perhaps the most important spur to perfection is transparency, the fact that in a lean system everyone can see everything, and so it's easy to discover better ways to create value.

This is achieved by eliminating waste from processes and products. One of the main goals of Lean is to eliminate waste. Taiichi Ohno (1912-1990), a Toyota executive, identified seven types of waste found in any process: (Womack & Jones, 2003)

Following list of wastes is supplemented with ideas and examples from "Lean – Turn deviations into success!" by Petersson, P., Johansson, O., Broman, M., Blucher, D., & Alsterman, H.

1) **Transportation** – unnecessary or ineffective transportation of parts, information, people. This happens when transportation routes are not optimal. Can be caused by poor processes and layout. One example could be moving WIP from one place to another for rework purposes.
2) **Inventory** – Stacks of parts, information, work waiting to be processed or finished products, information waiting to be transferred. In service, it can be excess inventories that are not actually needed to provide services to customers. The money that is tied under

inventories could instead be used to generate value, in finance, it's measured as return on assets.

3) **Motion** – Unnecessary movement of people e.g. too many movements, reaching for parts etc. Can be caused by not optimal placement of tools or in IT sector making too many clicks to reach for required information caused by not standardised folder structures.

4) **Waiting** – Unnecessary waiting to begin the next step. Waiting for information, parts, tools, people etc. Time is not used in an efficient way that leads to idle processes. In service, it could be waiting for a taxi or people who show up late.

5) **Over-processing** – focusing too much on details, doing over quality job or product, giving too much information that the customer is not willing to pay for. One example could be using too much paint on a part, making it more expensive to produce, but at the same time not adding any value – more paint does not make it necessarily more corrosion resistant.

6) **Over-production** – producing services or products upfront. Producing more than the customer requires or faster than the next process needs. Sometimes referred also to produce overly large batches.

7) **Defects** – mistakes in the products, services, information provided. In production most common is to produce something not according to specification. In service, it can be entering wrong data, for example, wrong dimensions on technical documentation or bank information for invoicing.

Womack and Jones (2003) defined also eight type of waste

8) **Underutilization of intellect** – the full potential of people is not used. Can happen also when the voice of employees who are performing the actual work is not taken into consideration – not paying attention to ideas of employees, but only managers for example.

1.2. Six Sigma

Six Sigma has become the industry’s new strategy to increase profitability and enhance customer satisfaction. Senior company executives averse to other quality management initiatives have embraced Six Sigma as a proven way to decrease costs, grow profit margins, increase market share, and improve customer satisfaction. Six Sigma helps organizations to be high quality, low cost, and lean in everything they do. Six Sigma supplements an organization’s fundamental business process in a way that ensures the achievement of its long-term vision and objectives. (Watson, 2004)

The phrase “Six Sigma” has taken on several different meanings. It is more of a business strategy than a quality program. According to Gregory H. Watson, Six Sigma can be defined in several ways:

1) A philosophy of management – where is the direct linkage among numbers of product defects, wasted operating costs, and level of customer satisfaction with a company’s goods and services. It provides a framework that ties together business improvement and quality initiatives and aligns an organization to goals that are evaluated by their productivity, cost-effectiveness, and quality. (Watson, 2004)

2) A process-measurement methodology – where Six Sigma is a way to predict the probability that a process will produce results that meet customer expectations or stated requirements. Less process variation means better process-performance consistency. (Watson, 2004)

3) An analysis methodology – Six Sigma is a disciplined, data-driven methodology for decision making using statistical analysis. This methodology combines a step-by-step analytical approach called the DMAIC sequence (Define, Measure, Analyse, Improve, Control), to problem-solving, with statistical tools used in a specific sequence to expose and control sources of variation to optimize process output. (Watson, 2004)

4) A business culture – Six Sigma, like in many ways Lean, is a culture that motivates teams to work on a common problem to achieve higher levels of performance effectiveness and productivity at a lower cost. In Six Sigma culture, management by facts, root-cause analysis, and definition of problems according to the source of variation are part of the organisation’s business language. (Watson, 2004)

1.2.1. Roots of Six Sigma

Walter A. Shewhart successfully brought together the disciplines of statistics, engineering, and economics and became known as the father of modern quality control. The lasting and tangible evidence of that union, and for which he is most widely known, is the control chart, a simple but highly effective tool that represented an initial step toward what Shewhart called “the formulation of a scientific basis for securing economic control.” The control chart is nowadays widely used in Six Sigma methodology but was introduced to managers in his monumental work Economic Control of Quality of Manufactured Product, published in 1931. (Kubiak & Benbow, 2016)

W. Edwards Deming is the most widely known proponent of statistical quality control. In 1942 he suggested a short course in Shewhart’s methods to teach the basics of applied statistics to engineers and others. The influence of the courses on the individuals who formed the core of the statistical quality control movement in the United States and who founded the American Society for Quality (ASQ) is well known. In 1946 and 1948 he was sent to Japan to study agricultural production and related problems in the war-damaged nation. During these trips, Deming made contact with Japanese statisticians and convinced Kenichi Koyangi, one of the founding members of the Union of Japanese Scientists and Engineers (JUSE), of the potential of statistical methods in the rebuilding of Japanese industry. In 1950, Deming taught courses in statistical methods to Japanese industry and ever since has been described as a national folk hero in Japan for being one of the most influential person in the spectacular rise of Japanese industry after World War II. (Kubiak & Benbow, 2016)

In the 1970s, when the Japanese firm took over Motorola factory that manufactured Quasar television sets in the United States, they promptly set about making drastic changes in the way the factory was operated. Under Japanese management, the factory was soon producing TV sets with 1/20th as many defects as they had produced under Motorola’s management. They did this using the same workforce, technology, and designs and did it while lowering costs - making it clear that the problem was in Motorola’s management. Motorola’s own executives admitted that their quality was poor, but it took until nearly the mid-1980s before Motorola figured out what to do about it. (Pyzdek & Keller, 2010)

The early development of program-based improvement, Six Sigma, occurred during the years 1985- 1987 at Motorola. Six Sigma was conceived as a method for creating radically better products and processes that would enable Motorola to compete more effectively with the Japanese. In fact, the goal of Six Sigma was to reduce defects into the parts per million (PPM) range – orders of magnitude better than “typical” quality prevailing at that time. To achieve this, CEO Bob Galvin of Motorola insisted that product and service quality be improved by a factor of 10 every 2 years. This aggressive requirement became the impetus for an approach to reducing process variation that soon became known as the measure, analyse, improve, control methodology. This method quickly paid off for Motorola when it became one of the first recipients of the Malcolm Baldridge National Quality Award in 1988. (Hopp & Spearman, 2008)

Companies such as Asea Brown Boveri (ABB), Allied Signal (Honeywell), and General Electric (GE) pushed Six Sigma beyond what even Motorola has accomplished. In particular, Jack Welch of GE launched a companywide initiative in 1995 to transform his company from a “great business” into the “greatest company in the world.” He insisted that every aspect of business be brought under the umbrella of Six Sigma. Furthermore, Six Sigma training would be a requirement for a promotion. From a financial perspective, GE’s goals were fully realized, as illustrated on Figure 1 (Pyzdek & Keller, 2010); its annual reports during 1996 – 1999 estimate that savings from Six Sigma to be $1-2 billion per year. In the years following 1995, the value if GE stock increased four-fold. (Hopp & Spearman, 2008)

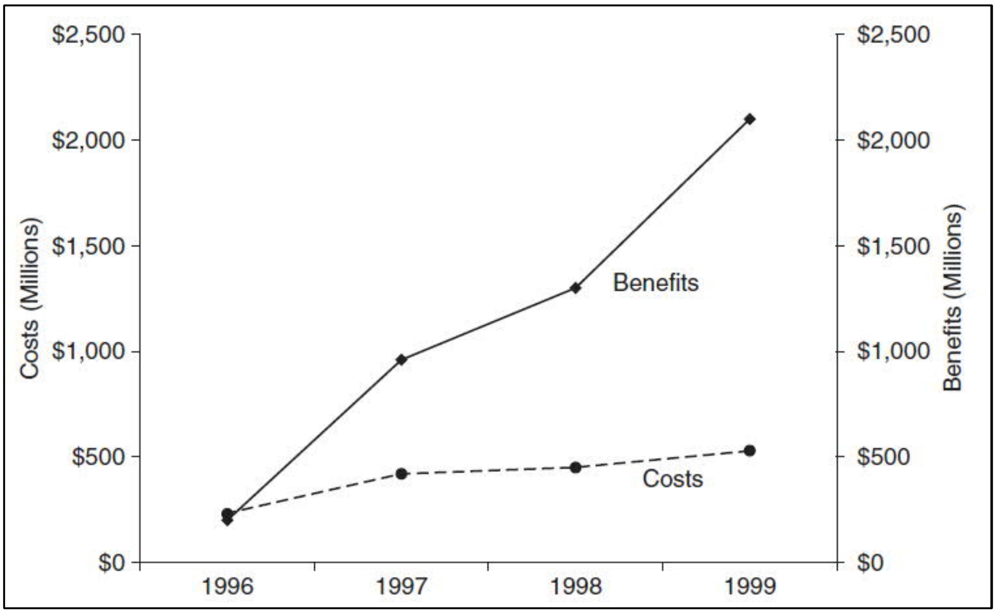


Figure 1. GE's recorded cost of Six Sigma versus benefits
Source: (Pyzdek & Keller, 2010)

By the turn of the millennium, Six Sigma had matured into a well-defined methodology know as DMAIC. While Companies in fields as diverse as health care, manufacturing, financial services, software development and home improvement adopted Six Sigma as the basis for their process improvement efforts. As Six Sigma grew and developed, it became what some practitioners consider to be a complete management system that was successful precisely because of its bottom-line orientation. (Hopp & Spearman, 2008)

1.2.2. Six Sigma Principles and Goals

Six Sigma methodology can be related to Greek letter sigma (S, s) that represents the statistical meaning of sum or measure of variability, standard deviation. (Pande, 2014) (Van Aartsengel, 2013) The relation comes from The Six Sigma movements that started from the need to reduce the variability caused by errors in a production environment. Understanding how variability degrades performance is key to improving manufacturing and service systems. (Hopp & Spearman, 2008)

Genichy Taguchi has pointed out that any departure/variation from the nominal or target value for a characteristic represents a loss and is described by his quality loss function. A quality loss function is a parabolic approximation of the quality loss that occurs when quality characteristic deviates from the target value. The quality loss function is expressed in monetary units. The cost of deviation from the target increases as a quadric function the farther the quality characteristic moves from the target. The formula used to quality loss function depends on the type of quality characteristic used. (Kubiak & Benbow, 2016)

The quality loss function is described in Figure 2, where m is a target value for a product or service, $m \pm \Delta_0$ represents the deviation at which functional failure of the product or service occurs, and in many cases is the specification limit of a product or service, and A0 is the cost of countermeasure, which for an average customer is product discarding, replacement or repairment. (Taguchi, Chowdhury, & Wu, 2004)

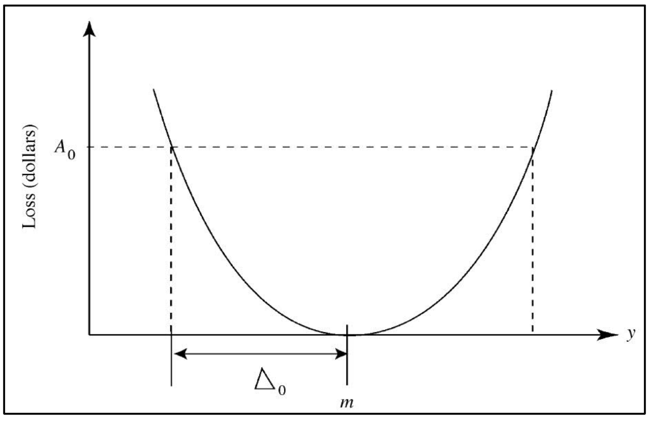


Figure 2. Taguchi’s quality loss function
Source: (Taguchi, Chowdhury, & Wu, 2004)

Six Sigma views all work as a process that can be defined, measured, analysed, improved and controlled (the DMAIC cycle). Processes require inputs and produce outputs, if you control the inputs, you control the outputs. This is generally expressed as the Y=f(x), outputs are the function of inputs, concept. (Kubiak & Benbow, 2016) With this concept in mind, control is ultimately achieved when companies can control the variation, more precisely the fewer variation inputs have, the more predictable the outcome of the process. This is where Six Sigma excels and a lot of focus is set on.

To control variation, in Six Sigma methodology, common cause and special cause variation are first distinguished. To define these, it is important to first understand the central limit theorem that states - Irrespective of the shape of the distribution of the population or universe, the distribution of average values of samples drawn from that universe will tend towards a normal distribution as the sample size grows without bound. (Pyzdek & Keller, 2010) The distinction between common cause and special cause variation is defined through the standard deviation and proportion of elements falling within and beyond three standard deviations from the central tendency illustrated in Figure 3 and Figure 4

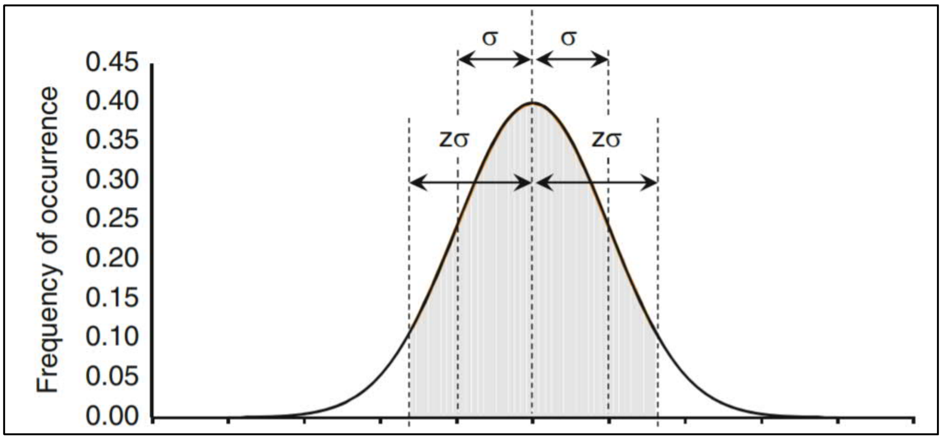


Figure 3. A plot of a normal distribution
Source: (Van Aartsengel, 2013)

The Normal Distribution is defined by a probability density function f(x) that resembles a bell-shaped curve illustrated in figure Figure 3 and with the following equation:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Where μ is the process mean indicating the centre of mass of the distribution, and s is the standard deviation, which indicates the spread.

The standard deviation for the population is found with the following equation

$$\sigma = \sqrt{\frac{\sum(X-\mu)^2}{N}}$$

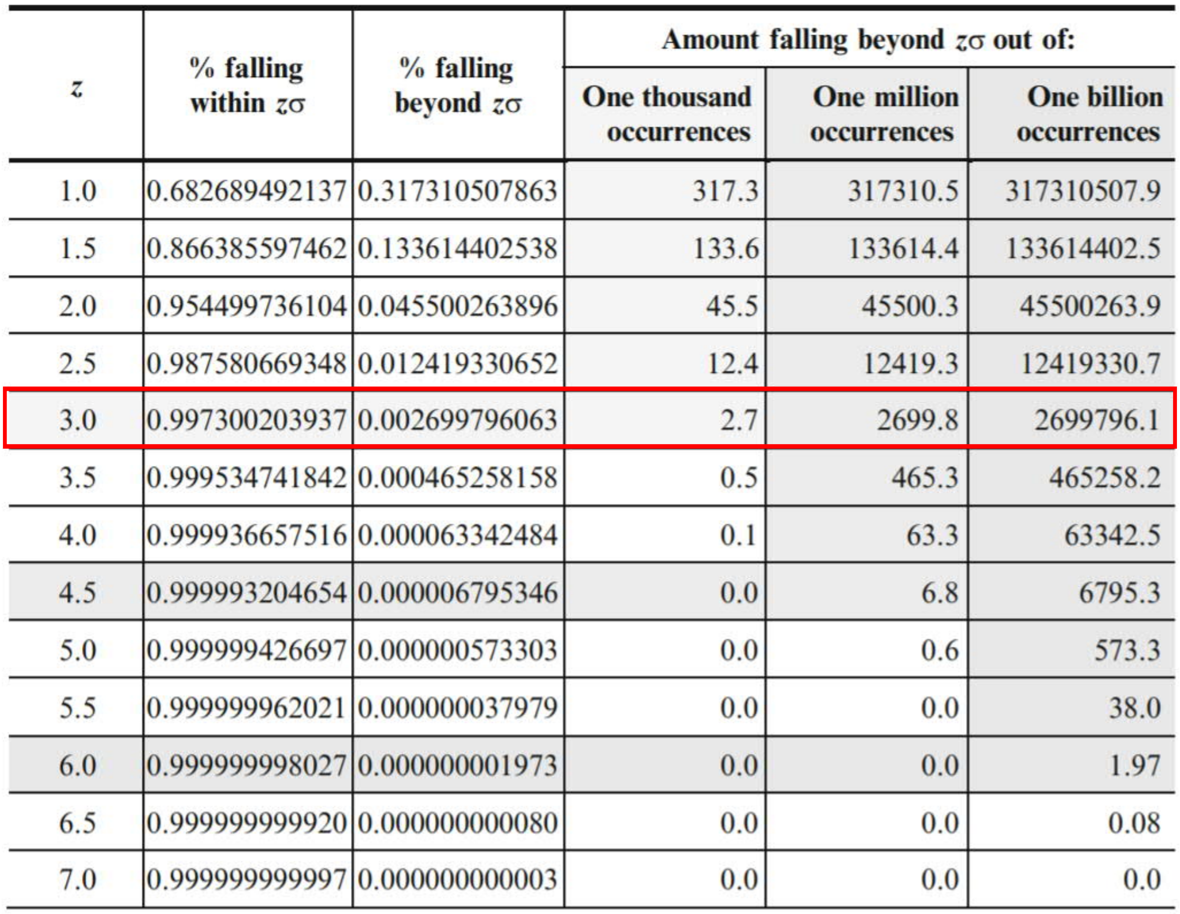
s – the standard deviation of the population

N – number of data points

μ – mean value of the population

x – observed value in the data set

The percentage of elements falling within and beyond z standard deviations of the central tendency are shown in Figure 4



z	% falling within $z\sigma$	% falling beyond $z\sigma$	Amount falling beyond $z\sigma$ out of: One thousand occurrences	One million occurrences	One billion occurrences
1.0	0.682689492137	0.317310507863	317.3	317310.5	317310507.9
1.5	0.866385597462	0.133614402538	133.6	133614.4	133614402.5
2.0	0.954499736104	0.045500263896	45.5	45500.3	45500263.9
2.5	0.987580669348	0.012419330652	12.4	12419.3	12419330.7
3.0	0.997300203937	0.002699796063	2.7	2699.8	2699796.1
3.5	0.999534741842	0.000465258158	0.5	465.3	465258.2
4.0	0.999936657516	0.000063342484	0.1	63.3	63342.5
4.5	0.999993204654	0.000006795346	0.0	6.8	6795.3
5.0	0.999999426697	0.000000573303	0.0	0.6	573.3
5.5	0.999999962021	0.000000037979	0.0	0.0	38.0
6.0	0.999999998027	0.000000001973	0.0	0.0	1.97
6.5	0.999999999920	0.000000000080	0.0	0.0	0.08
7.0	0.999999999997	0.000000000003	0.0	0.0	0.0

Figure 4. The proportion of elements falling within and beyond z standard deviations around the central tendency
Source: (Van Aartsengel, 2013)

Control is then defined by Shewhart - A process will be said to be in control when, through the use of past experience it is possible to predict, at least within limits, how the process may be expected to vary in the future. The critical point in this definition is that control is not defined as the complete absence of variation. Control is simply a state where all variation is predictable. (Pyzdek & Keller, 2010)

To understand whether the process is in control, statistical process control (SPC) methods are used. During Shewhart`s work on “Economic Control of Quality of Manufactured Product”, he created the control chart with 3 standard deviations around the central tendency as a performance permissible limit of variations. Shewhart’s use of 3-sigma limits, as opposed to any other multiple of sigma, did not stem from any specific mathematical computation. Rather, the choice of 3-sigma limits was seen to be an acceptable economic value, and it was also justified by “empirical evidence that it works.” (Van Aartsengel, 2013)

Knowing this, it is possible to define that any unknown random cause of variation is within 3-sigma range from the central tendency of population and is defined as common cause variation. At times, the variation is caused by a source of variation that is not part of the constant system creating systematic patterns or lying beyond 3-sigma range from the central tendency and is called special cause variation. Common cause and special cause variation are illustrated on Figure 5 where all data points above upper control limit (UCL) and below lower control limit (LCL) are deriving from special cause variation and everything between UCL and LCL are deriving from common cause variation.

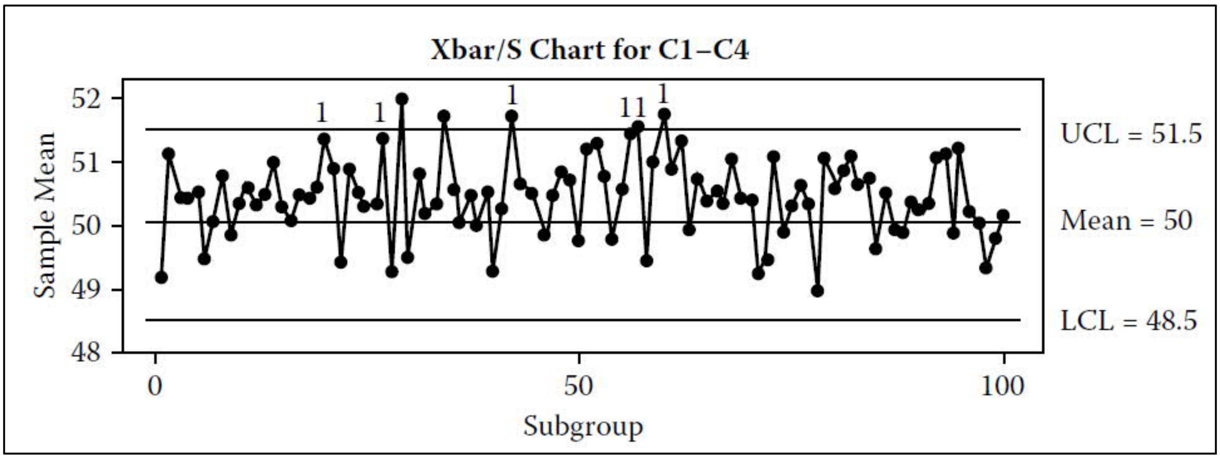


Figure 5. Control chart illustrating common cause and special cause variation
Source: (Levinson, 2010)

The basic rule of SPC is variation from common-cause systems should be explored "off-line" by looking for long-term process improvements, but special-cause variation should be identified and eliminated. (Pyzdek & Keller, 2010)

Depending on the data set type, distribution and subgroup size, practitioners of SPC can choose between different charts, the decision tree is illustrated in Figure 6, where n is the subgroup size. Because of the limitations and extent for this thesis, all different statistical process control charts are not going to be described and can be examined independently from (Pyzdek & Keller, 2010) book.

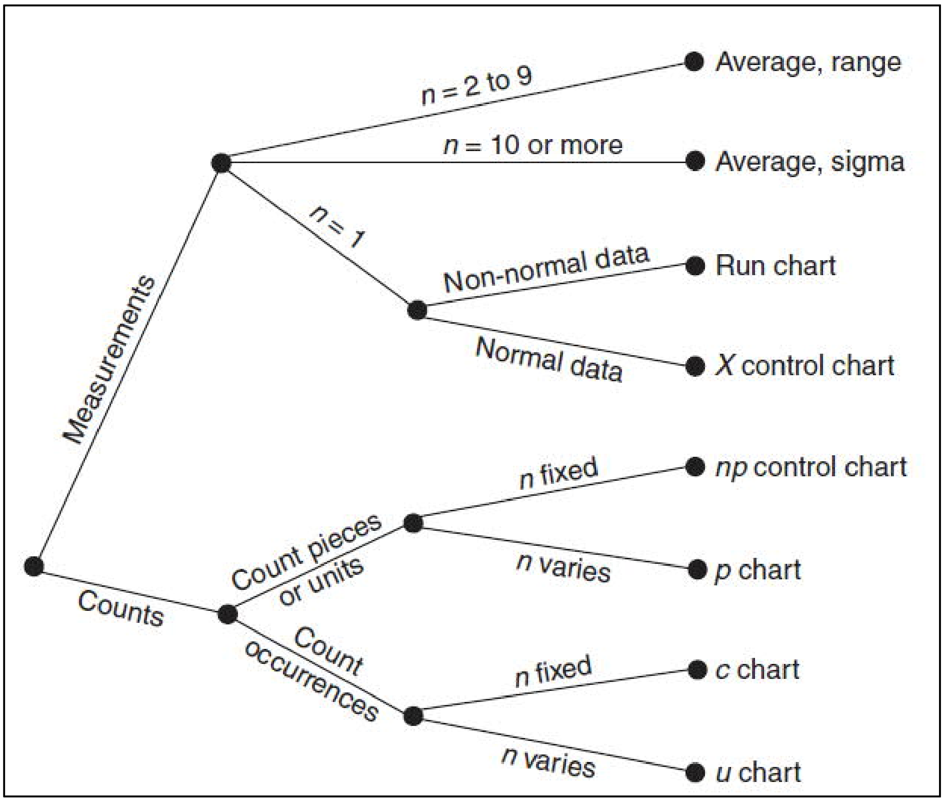


Figure 6. Control chart selection decision tree
Source: (Pyzdek & Keller, 2010)

Once special cause variation is understood and eliminated, processes are said to be stable. Practitioners of six sigma continue their study with the process capability analyses. The process capability analysis refers to a set of statistical methods designed to estimate the capability of a manufacturing/service process to meet a set of requirements or customer specification limits. The output of the analysis is typically an estimate of the percentage of items or service opportunities that conform to those specifications. If the estimated percentage is large enough, the process is said to be "capable" of producing a satisfactory product or service. (Polhemus, 2017)

Processes ability to meet specifications depends on two factors – variation and accuracy. Variation is process capability relative to the specification with, accuracy means that the process mean is at the nominal. In Six Sigma there are four common states to describe the process against the specification limits. Processes are divided into four categories:

1. In control and capable – low variation and accurate results

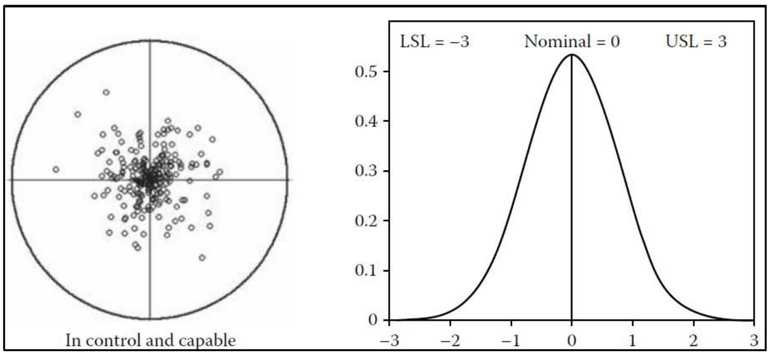


Figure 7. In control and capable process
Source: (Levinson, 2010)

2. In control but not capable – high variation but accurate results

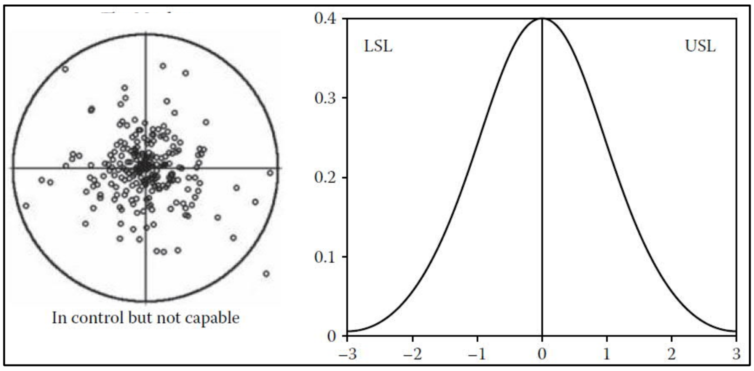


Figure 8. In control but not capable process
Source: (Levinson, 2010)

3. Out of control but capable – a process with low variation but not accurate results

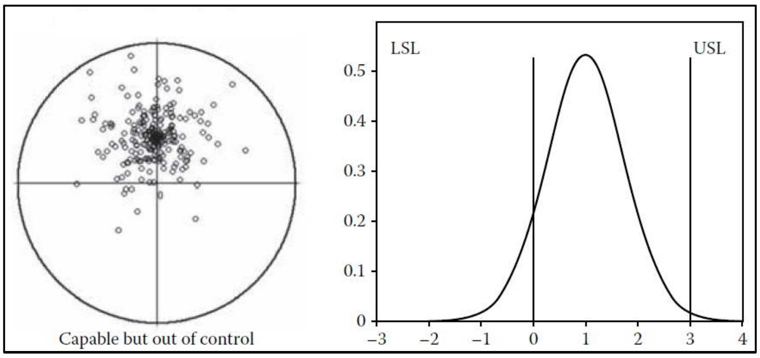


Figure 9. Out of control but capable process
Source: (Levinson, 2010)

4. Out of control and not capable – a process with high variation and not accurate results

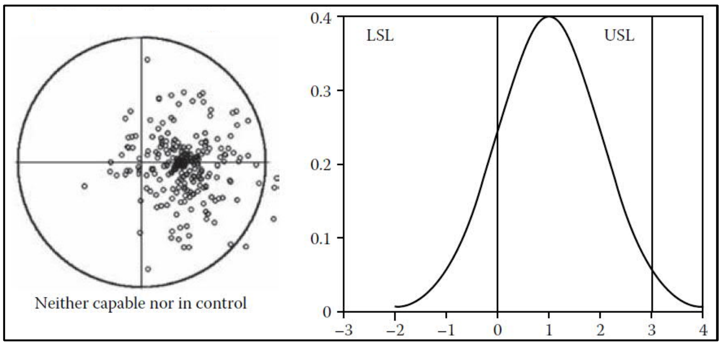


Figure 10. Out of control and not capable process
Source: (Levinson, 2010)

The acceptable proportion of nonconforming items depends strongly on the product or service being provided, the variable being measured, and the cost associated with the nonconformance. Six Sigma practitioners reserve the “world-class quality” for processes that generate no more than 3,4 defects per million opportunities (DPMO). (Polhemus, 2017)

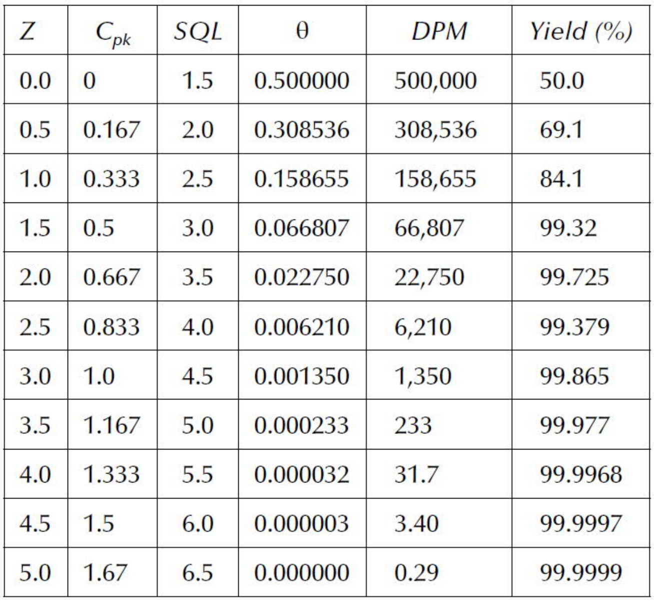
Frequently used statistic in determining the capability of meeting the customer specifications is the capability index Cpk, which in the case of a normal distribution divides the distance between the mean and the nearer specification limit by $3s$ (Polhemus, 2017)

$$C_{pk} = \frac{Z}{3}$$

Where, for normal distribution, Z quantifies as the number of standard deviations between the mean and the nearest specification limit.

Many organizations strive for Cpk = 1,33, which for the variable data ensures that the distance from the mean to the nearer specification limit is at least 4 standard deviations. (Polhemus, 2017)

Practitioners of Six Sigma define also “Sigma Quality Level” (SQL), which may be attached to any process. By their definition, a process that achieves an SQL of 6 or better is producing a product with “world-class quality”. The SQL can be calculated from Z according to SQL = Z + 1,5. The addition of 1,5 to Z comes from the assertion that the mean of most processes is not completely stable, but tends to vary around its long term level by approximately +-1,5 standard deviations. (Polhemus, 2017) Figure 11 shows various quality indices and their corresponding DPM and yield.



Z	C_{pk}	*SQL*	θ	*DPM*	*Yield (%)*
0.0	0	1.5	0.500000	500,000	50.0
0.5	0.167	2.0	0.308536	308,536	69.1
1.0	0.333	2.5	0.158655	158,655	84.1
1.5	0.5	3.0	0.066807	66,807	99.32
2.0	0.667	3.5	0.022750	22,750	99.725
2.5	0.833	4.0	0.006210	6,210	99.379
3.0	1.0	4.5	0.001350	1,350	99.865
3.5	1.167	5.0	0.000233	233	99.977
4.0	1.333	5.5	0.000032	31.7	99.9968
4.5	1.5	6.0	0.000003	3.40	99.9997
5.0	1.67	6.5	0.000000	0.29	99.9999

Figure 11. Relationship between quality indices
Source: (Polhemus, 2017)

Once the baseline, or in other words, the capability of the current process is known, measures are taken to reduce the common cause variation and make the process more capable. Because no special cause variation exists in the process Six Sigma practitioners use the Pareto principle to quantify the baseline problems that affect the underlying process or service output.

Reasons for failures are often found to conform to the 80/20 principle which says that 80% of the failures are generally caused by around 20% of the root causes. (Brook, 2014)

A Pareto chart is essentially a bar chart for categorical/contextual data, where the most frequent results are placed in order from the left-hand side of the chart. The cumulative frequency is also plotted and shows the reason codes combined from the left of the chart. (Brook, 2014)

An example of a Pareto chart for defect types is illustrated in Figure 12. Each defect type is graphed along the x-axis, and the height of each bar is proportional to the number of defects. The graph contains two y-axes. The left y-axis identifies the number of defects and is associated with the bar heights. The right y-axis represents the percentage of defects. The cumulative percentage of each defect type is graphed above the bars. The purpose of the Pareto chart is to separate the “vital few” causes from the “trivial many.” (Kubiak & Benbow, 2016)

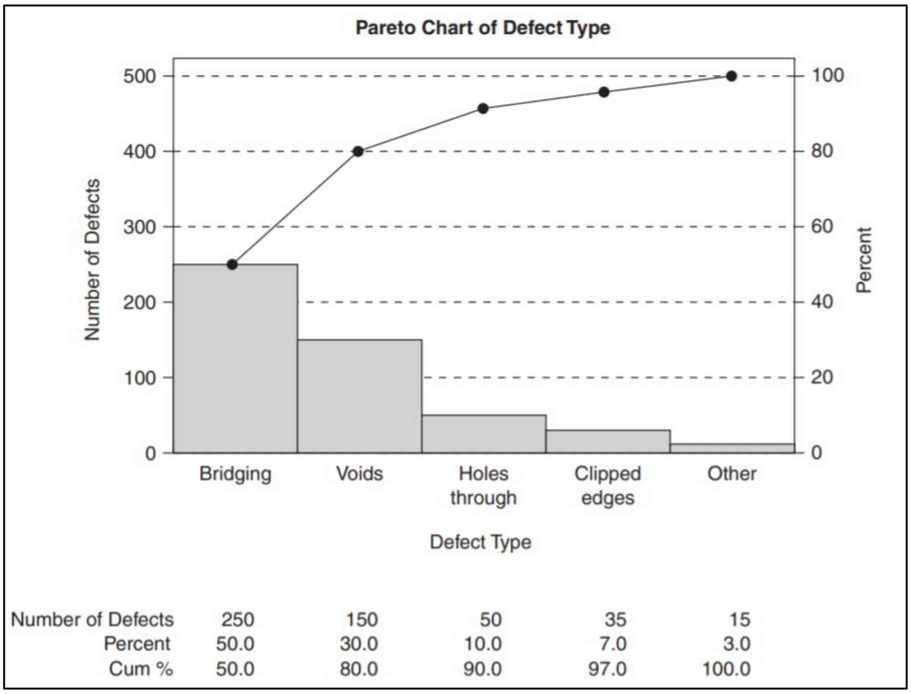
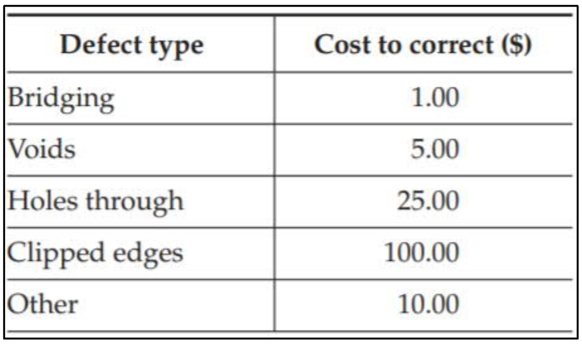


Figure 12. Example of a Pareto chart of defect types
Source: (Kubiak & Benbow, 2016)

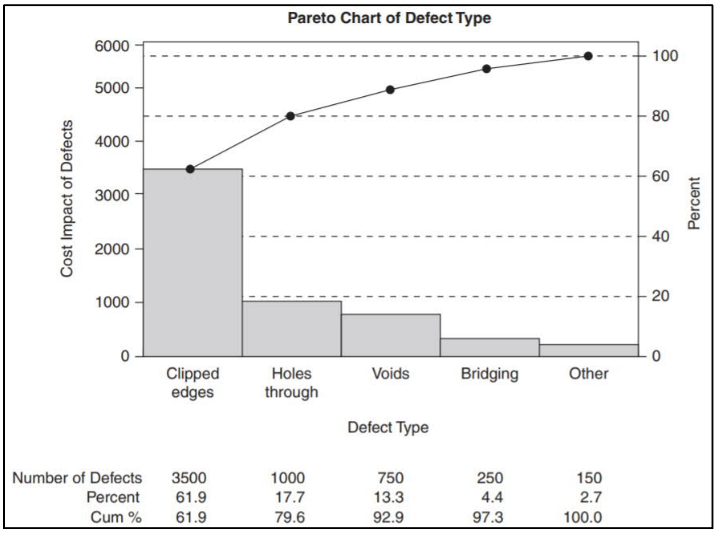
One drawback of Figure 12 is that it assumes all defects have an equal impact. However, if we quantify the cost of correcting each defect, we can weight each quantity of defect type by the cost of correction. This is quite common practice and can be also applied to other parameters. (Kubiak & Benbow, 2016)

An example of a quantified Pareto chart is illustrated using Figure 13 that indicates the cost of correcting each defect type and Figure 14 illustrates the end result and “vital few” that should be focused first hand.



Defect type	Cost to correct ($)
Bridging	1.00
Voids	5.00
Holes through	25.00
Clipped edges	100.00
Other	10.00

Figure 13. Cost of correcting each defect type
Source: (Kubiak & Benbow, 2016)



Number of Defects	3500	1000	750	250	150
Percent	61.9	17.7	13.3	4.4	2.7
Cum %	61.9	79.6	92.9	97.3	100.0

Figure 14. Example of a Pareto chart for defects weighted by the cost to correct
Source: (Kubiak & Benbow, 2016)

When the concepts of these ideas are put together - controlling the variation, knowing process capability, focusing on “vital few” root causes and understanding the Taguchi`s quality loss function, one can see that the underlying goal of Six Sigma is to control variation and make processes capable of meeting customer specifications, and through it reduce the cost illustrated by Taguchi’s quality loss function.

Thesis author has explained this concept in Figure 15 where the red hatched area illustrates the cost of variation before and after a process improvement.

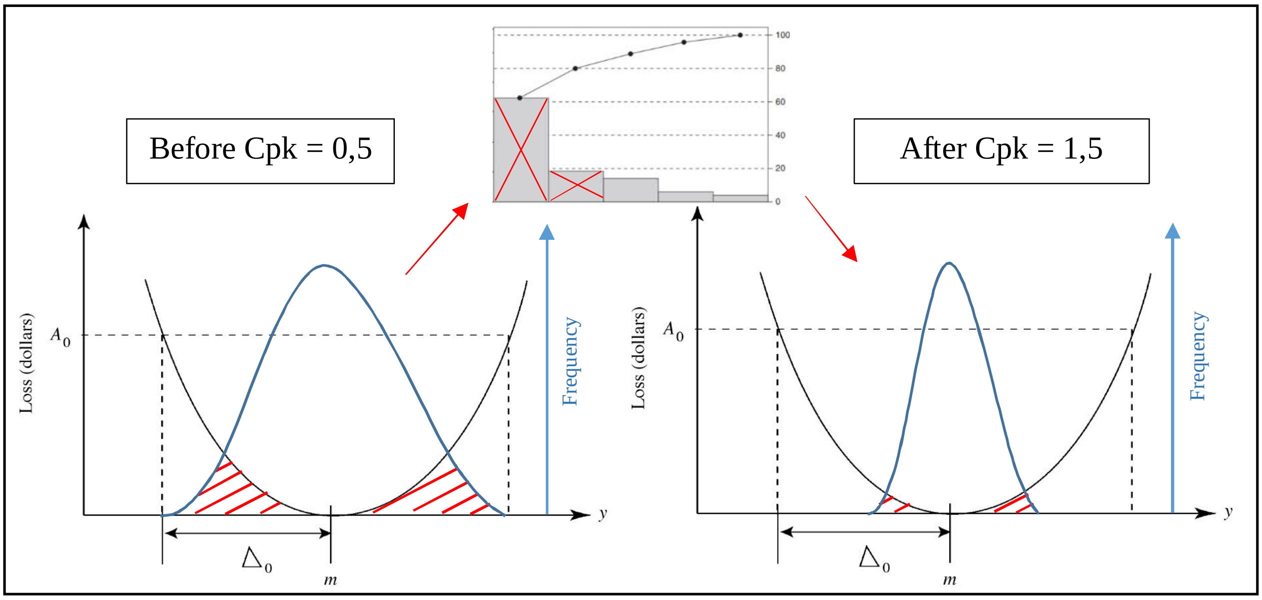


Figure 15. Cost of process variation
Source: (Taguchi, Chowdhury, & Wu, 2004) illustrations added by Author

All the tools mentioned above are part of the DMAIC or DMADV improvement cycles used by Six Sigma practitioners. These cycles are similar to widely known PDCA cycle that was first introduced by Deming and nowadays mostly known from the ISO 9001 standards, that uses it to describe the continuous improvement cycle and requires managers to commit to it. DMAIC and DMADV improvement cycles are illustrated in Figure 16.

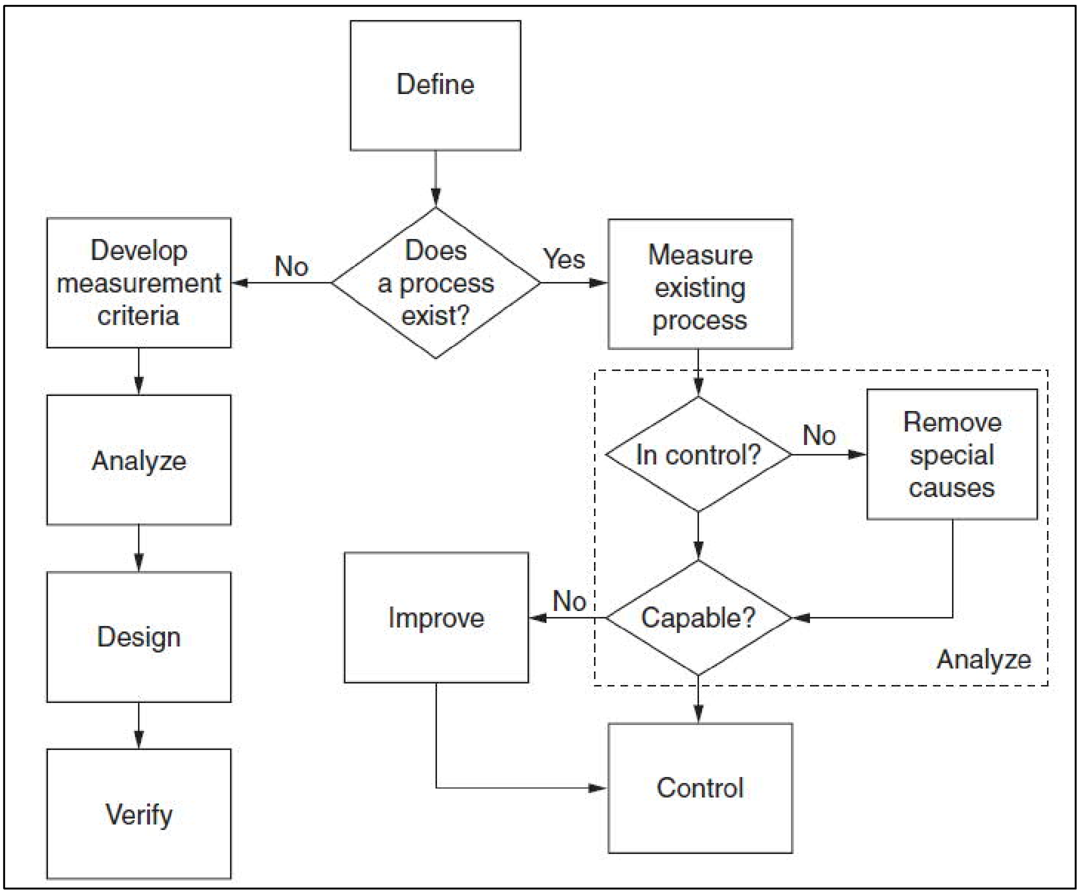


Figure 16. DMAIC and DMADV process cycle
Source: (Pyzdek & Keller, 2010)

When cost summaries on quality are made, a question arises – "what are the right costs?" Businesses are looking for a standard against which to compare their actual costs so that they can make a judgment on whether there is a need for action. In one published study, (Ittner, 1992) summarizes data on four categories for 72 manufacturing units of 23 companies in 5 industry sectors. Where three conclusions on cost data stand out: the total costs are higher for complex industries, failure costs are the largest percentage of the total, and prevention costs are the small per cent of the total. (Juran & Godfrey, 1998)

The study of the distribution of quality costs over major categories can be further explored using Juran`s model of optimum quality cost illustrated in Figure 18. The model shows three curves:

1. The failure costs – these equal zero when the product is 100 per cent good and rise to infinity when the product is 100 per cent defective.
2. The costs of appraisal plus prevention: These costs are zero at 100 per cent defective and rise as perfection is approached.

3. The sum of curves 1 and 2: this third curve is marked “total quality cost” and represents the total cost of quality per good unit of production.

Figure 18 suggests that the minimum level of total quality cost occurs when the quality of conformance is 100 per cent i.e. perfection. This model is backed by understanding that prevention and appraisal costs fall after each iteration/usage, thus perfection is not attained at finite costs. Also, the impact of quality failures on sales revenue must be quantified. When Taguchi’s quality loss function is taken into consideration, then the users and producers cost for not meeting the target value, further fuel to the conclusion that the optimum point is perfection. (Juran & Godfrey, 1998)

Six Sigma practitioners know that while perfection is obviously the goal for the long run, it does not follow that perfection is the most economic goal for the short run, or for every situation. In the short term, to evaluate whether quality improvement has reached the economic limit, practitioners need to compare the benefits possible from specific projects with costs involved in achieving these benefits. When no justifiable projects can be found, the optimum has been reached. (Juran & Godfrey, 1998) In the long term, knowledge from previous projects and designs can be reused as best practices to prevent failures from happening. Reusing these best practices is free, increasing prevention affect the need for appraisal thus in time, leading to lesser appraisal and prevention costs as illustrated on Figure 17, ultimately reaching to perfection as illustrated by Juran`s model of optimum quality Figure 18. As a conclusion, it can be said that the prospect is that the trend to 100 per cent conformance will extend to more and more goods and services of greater and greater complexity. (Juran & Godfrey, 1998)

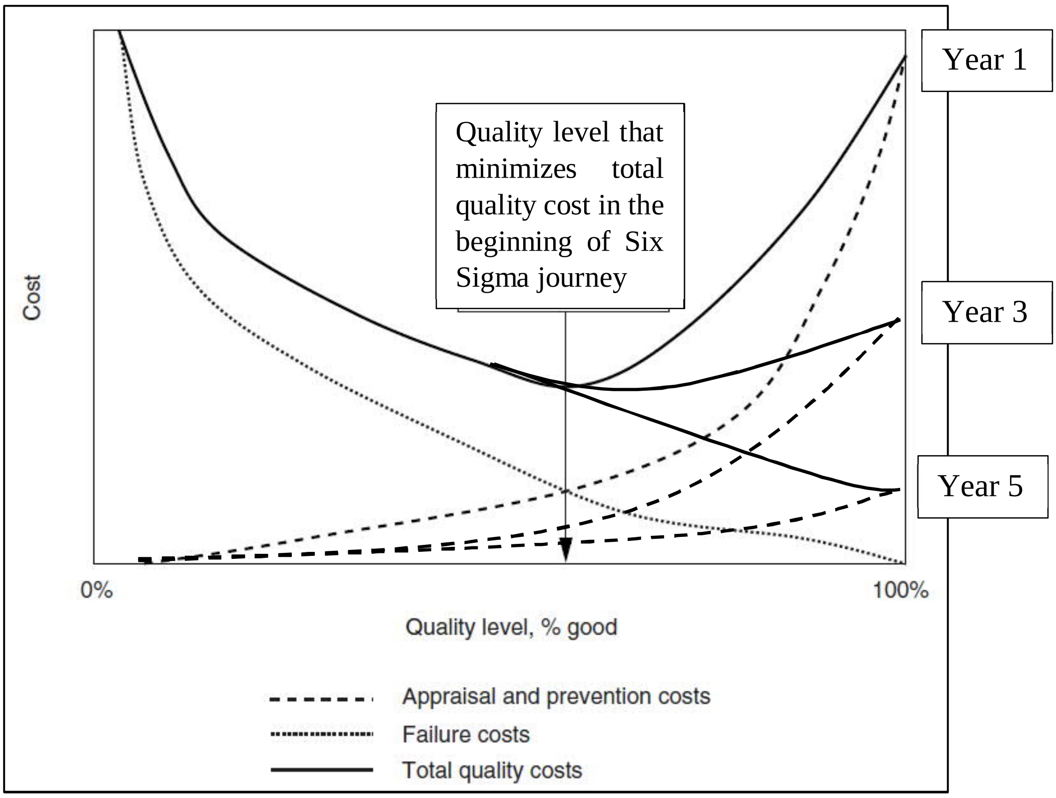


Figure 17. Traditional quality cost curves modified by the thesis author
Source: (Kubiak & Benbow, 2016)

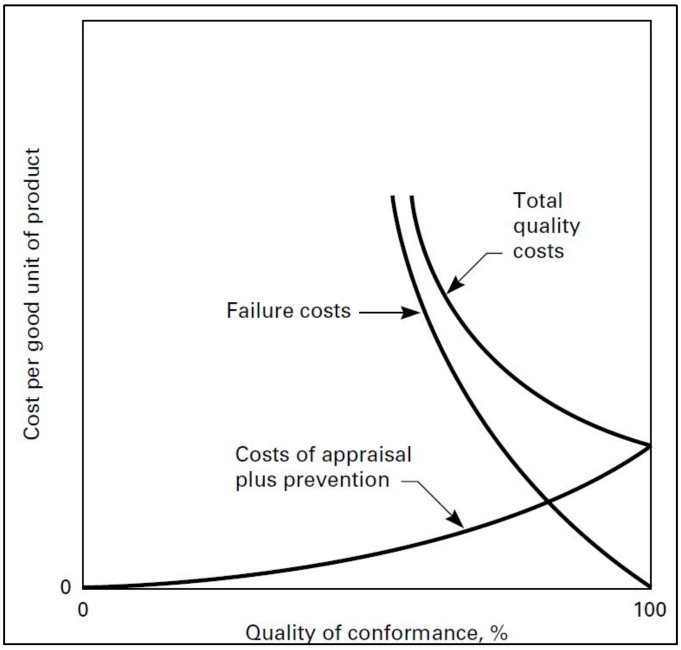


Figure 18. Model of optimum quality costs
Source: (Juran & Godfrey, 1998)

To sum it up, Six Sigma focuses on process variation, using several tools and principles to define, analyse and remove it. By removing the variation from processes, they get more predictable and lower the cost of quality.

Some key insights by (Pyzdek & Keller, 2010)

1) Six Sigma is not quality in the traditional sense, quality defined traditionally as conformance to internal requirements, has little to do with Six Sigma. Six Sigma focuses on helping the organization make more money by improving customer value and efficiency. (Pyzdek & Keller, 2010)
2) Linking this objective of Six Sigma with quality requires a new definition of quality: the value added by a productive endeavour. This quality may be expressed as a potential quality and actual quality. Potential Quality is the known maximum possible value added per unit of input. The actual quality is the current value-added per unit of input. The difference between potential and actual quality is waste. Six Sigma focuses on improving quality (i.e., reducing waste) by helping organizations produce products and services better, faster, and cheaper. (Pyzdek & Keller, 2010)
3) Six Sigma focuses on customer requirements, defect prevention, cycle time reduction and cost savings. Thus, the benefits from Six Sigma go straight to the bottom line. Unlike mindless cost-cutting programs which also reduce value and quality, Six Sigma identifies and eliminates costs which provide no value to the customers: waste cost. (Pyzdek & Keller, 2010)

Some key insights by (Hopp & Spearman, 2008):

1) A production system cannot be lean if it has poor internal quality i.e., products must be made right the first time. Likewise, a system cannot consistently produce a quality product unless it is quite lean i.e., it must have low WIP.
2) “If you don’t have time to do it right, when will you find time to do it over?” This aphorism succinctly captures the need for good quality in manufacturing systems.
3) Variability must be identified and reduced. The focus of Six Sigma is to identify and reduce variability by determining its root cause and eliminating it. The problem with Six Sigma is that many problems are not always directly related to variability but only indirectly.

1.3. Lean Six Sigma

A recent trend in quality management is Lean Six Sigma, that integrates Six Sigma and "lean systems." (Russell & Taylor, 2011)

Lean and Six Sigma have the same general purpose of providing the customer with the best possible quality, cost, delivery, and a newer attribute – nimbleness. There is a great deal of overlap, and disciplines of both disagree as to which techniques belong where. (Kubiak & Benbow, 2016)

Kubiak and Benbow point out that the most distinct characteristics between the two approaches are that Lean focuses on waste reduction, whereas Six Sigma emphasizes variation reduction. Lean achieves its goals by using less technical tools such as kaizen, workplace organization, and visual controls, whereas Six Sigma tends to use statistical data analysis, design of experiments, and hypothesis testing. (Kubiak & Benbow, 2016)

Over time the demarcation between Six Sigma and Lean has blurred. Process improvement requires aspects of both approaches to attain positive results. Six Sigma focuses on reducing process variation and enhancing process control, whereas Lean drives out waste and promotes work standardization and flow. Lean Six Sigma practitioners should be well versed in both. (Kubiak & Benbow, 2016)

The most successful users of implementations have begun with the Lean approach, making the workplace as efficient and effective as possible, reducing the eight wastes, and using value stream maps to improve understanding and throughput. When process problems remain, the more technical Six Sigma statistical tools may be applied. One thing both methodologies have in common is that both require strong management support to make them the standard way of doing business. (Kubiak & Benbow, 2016)

Kubiak and Benbow (2016) give Lean Six Sigma a combined definition:

Lean Six Sigma is a fact-based, data-driven philosophy of improvement that values defect prevention over defect detection. It drives customer satisfaction and bottom-line results by reducing variation, waste, and cycle time while promoting the use of work standardization and flow, thereby creating a competitive advantage. It applies anywhere where variation and waste exist, and every employee should be involved. (Kubiak & Benbow, 2016)

2. RESEARCH METHODOLOGY

This thesis is using mixed methods for research design. Mixed methods research is the branch of multiple methods research that combines the use of quantitative and qualitative data collection techniques and analytical procedures. More specifically concurred mixed method with a single phase of data collection and analysis is used. This allows both sets of results to be interpreted together to provide a richer and more comprehensive response to the research question. (Saunders, Lewis, & Thornhill, 2015)

Research is based on a case study; a case study is an in-depth inquiry into a topic or phenomenon within its real-life setting. (Yin, 2014) The “case” in case study research refers to a function in an international company that focuses on utilities, industry, transportation and infrastructure customers. Case study research sets out to understand the dynamics of a technical support function and ways of improving its performance.

The purpose of this research is to identify what is important for the internal customers in regard the technical support function, understand and analyse the working principles and methods for the current state, find out how satisfied the internal customers are with the results and where appropriate implement new methods or suggest improvements.

Research design is explained in more detail in the following chapter.

2.1. Research design

A qualitative study was performed in the form of unstructured interviews with the employees working in the technical support function and the internal customers who are using the service provided by that function. Unstructured interviews were chosen for the exploratory purpose to get in-depth knowledge in the general area in which this thesis is focused on. The unstructured method gives the interviewee the opportunity to talk freely about events, behaviour and beliefs in relation to the topic area. (Saunders, Lewis, & Thornhill, 2015) Interviews were conducted on a one-to-one basis between thesis author and a single participant. Using this method gave a good overview of the current status of the function and the customers' satisfaction with its results. Because of the multicultural and international characteristics of the studied company, interviews had to be carried out in several languages. The positive sides of this method are that it gives flexibility, broad applicability and ability to gather insight that is not possible to achieve through quantitative methods. (Saunders, Lewis, & Thornhill, 2015)

Saunders et al (2015) also point out that researchers using unstructured interviews must develop a sufficient level of competence and be able to gain access to the type of data associated with their use. This was handled by the fact that the thesis author has 8 years of experience in that field and is also working for the studied company.

The negative sides of this research method are the data quality issues related to reliability/dependability, forms of bias, cultural differences and generalizability/transferability. These may be overcome by careful preparation for conducting interviews to avoid bias that would otherwise threaten the credibility of gathered data. (Saunders, Lewis, & Thornhill, 2015) These negative sides were considered thoroughly by the author, and for overcoming these the interviews were held in different languages, focus groups were selected and conclusions were backed with quantitative studies where applicable.

Interviews were conducted with targeted focus groups in mind to get the whole picture of the function, its workers, customers, result and perspectives. People were grouped along the value chain to gather the voice of business, the voice of customers and the voice of the process (workers).

Based on the interviews quantitative data was gathered where appropriate and feasible. Quantitative data helped to back the conclusions drawn from interviews and helped to set focus and prioritize actions to be taken.

The goals for this research were to define the current status of the technical support function, its results and customer, business, worker satisfaction. Using qualitative and quantitative mixed methods gave the author a possibility to get close to the workers and customers, get their personal opinion and where feasible back the qualitative data with quantitative results.

2.2. Case company and function

The company is a pioneering technology leader in electrification products, robotics and motion, industrial automation and power grids, serving customers in utilities, industry and transport & infrastructure globally. With a history of innovation spanning more than 130 years, operating in more than 100 countries with about 147 000 employees.

The company is divided into four major business divisions

1. Electrification – offering a wide range of products, solutions and services from substations to sockets. Enables smart, safe and sustainable electrification Offerings encompass low and medium voltage products and services with digital and connected innovations like electric vehicle infrastructure, solar inverters, modular substations, distribution automation, power protection, wiring accessories, switchgear, enclosures, cabling sensing and control.
2. Industrial Automation – offering a broad range of solutions for process and hybrid industries, including industry-specific integrated automation, electrification and digital solution, control technologies, software and advanced services, as well as measurement & analytics, and marine, turbocharging offerings. Industrial automation is second in the market globally.
3. Motion – the largest supplier of drives and motors globally, providing customers with the complete range of electrical motors, generators, drives and services, as well as mechanical power transmission products and integrated digital powertrain solutions. Motion serves a wide range of automation applications in transportation, infrastructure and the discrete and process industries.
4. Robotics & Discrete automation – provides value-added solutions in robotics, machine and factory automation. Offerings include also integrated automation solutions and application expertise across a wide scope of industries.

The divisions are divided into business units. The business unit that is the focus of this case study is located in the Motion business division. Motion business is divided into three business units – Drives, Motors and Mechanical Power Transmission. The focus business unit is Drives serving customers from industries like food and beverage, marine and offshore, pulp and paper, water and wastewater, wind, mining and many others. The factory of this case study is in the Drives business unit and located in Estonia. Drives Estonia factory is a local unit of Estonian listed public limited company with a close co-operation with Drives in Helsinki, Finland.

Drives Estonia operates under the Group governance in the corporate, regional and local levels and toll manufacturing concept. Toll manufacturing concept means that the factory has specialised resources and provides service on behalf of the mother company using its materials and goods. The corporate governance contains topics applied at the Group level; examples of such topics include policies, values and strategy. Regional governance contains business-related topics. Local country-level governance includes topics related to business compliance with national laws and regulations (e.g. environmental laws), management of the quality management system certification, etc. All these areas are followed and managed through leadership, internal communication and reporting.

Factory focus is on producing power inverters and converters, low voltage AC drives and related accessories and subassemblies. Power range 3,3 - 4400kW and voltage 230-690V.

The black arrow on Figure 19 shows the main responsibilities of the Business Unit (BU) Drives' product group (PG) and the blue box lists the Local Management Unit Drives Estonia main responsibilities.

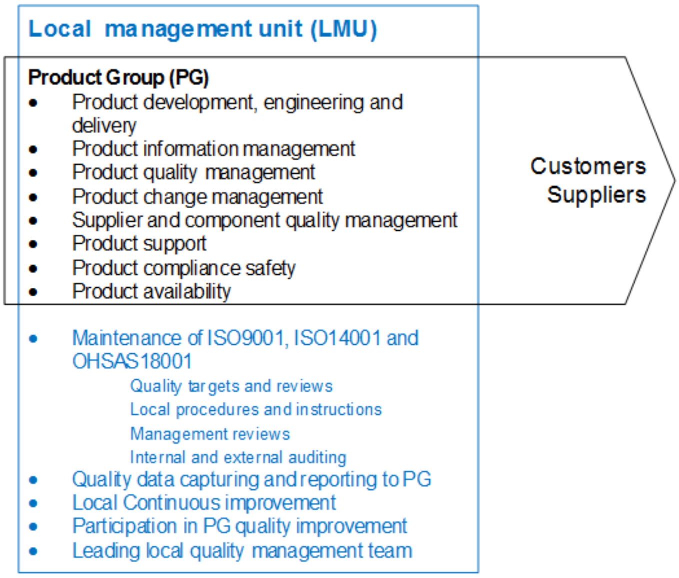


Figure 19. Division of responsibilities between the product group and the local management unit
Source: (Aun, 2019)

The core processes in Drives Estonia factory are the Production process and Product Development process. Interaction between core processes and support processes and functions are described in Figure 20. The focus areas of this thesis are highlighted with red.

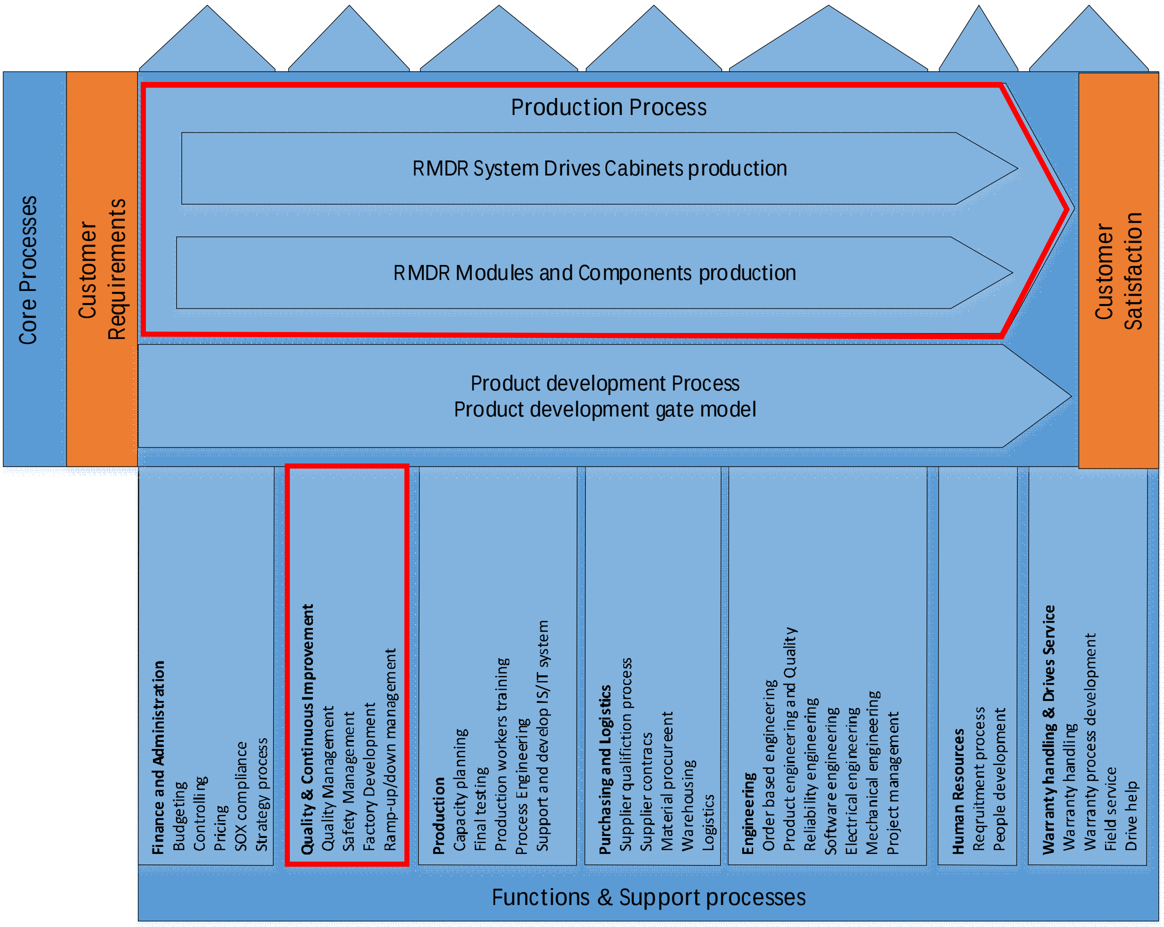


Figure 20. Core and support processes of the factory
Source: (Aun, 2019)

Because of the limitations to the extent of this thesis, only the core and support processes of the focus area will be described.

The core process of focus area is the production that is divided into cabinet, modules and components production. Annual volumes are around 120 000 pcs of accessories and components, 13 000 pcs of modules 3750 pcs of industrial cabinet drives and 535 pcs of wind converters. Factory production processes have to ensure that customers get the required products on time, in full and in quality. Final testing is part of the core process and ensures that products are correctly assembled, and they are fully functional before delivery to the customer. Continuous feedback and training of production workers is part of Final testing work. The owner of the Production process is respective Production Manager.

Support functions and processes help the core processes to fulfil the requirements of factory customers and other interest parties. Quality and Continuous Improvement is the focus support function of this thesis.

The task of Quality and Continuous Improvement function are following:

1. Manage and develop the factory's integrated quality management system
2. Coordinate and support safety, health and environmental aspects at factory
3. Coordinate and support continuous improvement on production lines
4. Project management of ramp-up and development projects
5. Provide support with 6S, electrostatic discharge, production tools & equipment including maintenance and calibration management
6. Responsible for the implementation of functional safety and ATEX quality management systems
7. Coordinate appropriate training for production workers.

The structure of Quality and Continuous Improvement function is described in Figure 21, where focus team of this thesis is highlighted with red.

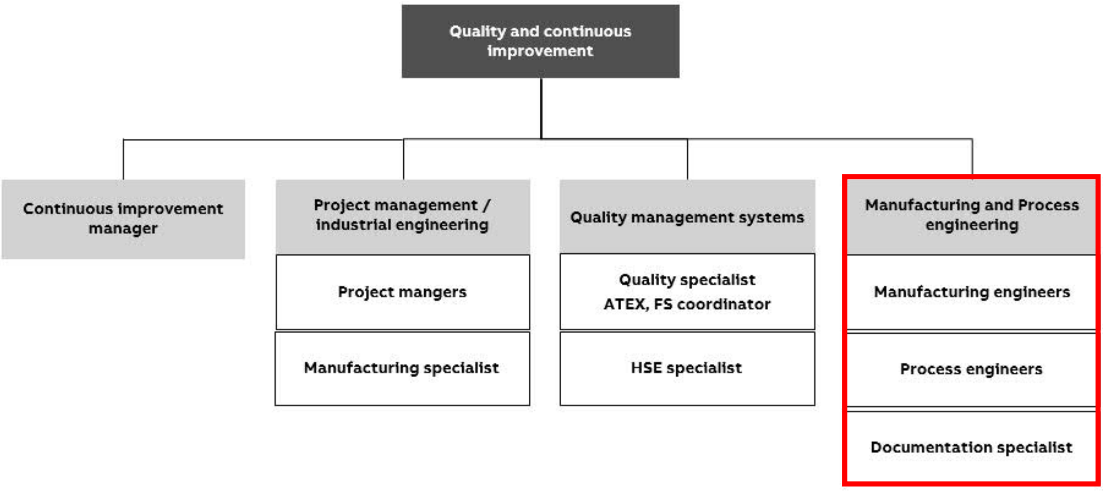


Figure 21. Structure of Quality and Continuous Improvement function
Source: (Miljand, 2019)

Drives Manufacturing and Process engineering team is providing everyday support and technical consultancy to the manufacturing unit. Work is based on production line key performance indicators, ensuring that processes are fully capable of meeting defined KPI’s (on-time delivery, quality, cycle times, safety and other). The main responsibility is to ensure that if technical challenges appear, they are solved in a fast manner so that the core processes can run smoothly. The team is also responsible for designing capable processes, working methods and for continual improvement of all production lines. Technical documentation specialists are responsible for creating work instructions and keeping them up to date for all production lines.

Each process and function in Drives factory has efficiency and quality targets based on the business and quality objectives of the profit centre and/or local country management tram and/or Drives Estonia.

The performance and status of the functions and processes versus set targets are continuously monitored, measured and analysed by process engineers. Corrective and preventive actions are made based on the observations.

The main theme of this thesis will be related to manufacturing and process engineering team service analysis and improvement possibilities. Process performance measurement system development and implementation.

2.3. Analysis of the current situation

The current tasks and targets were discussed in the previous chapter, the results and customer satisfaction will be the topic of this chapter.

The internal customers for manufacturing and process engineering team are the factory manager, production manager, line managers, foremen and the production workers. So far there has not been any processes in place to measure customer satisfaction with the support function daily work. The function has been getting feedback directly from the internal customers or department managers, but no systematic approach has been set in place.

Because the performance of many aspects for this service is not measured, customer feedback was gathered with the unstructured interviews. General customer satisfaction level was graded from poor to good and the results are shown in Table 1.

Customer	Team	Customer satisfaction	Customer feedback
Factory manager and Production manager	Manufacturing and Process engineering	Good but improvements needed	Would like to see more projects that increase the efficiency and effectiveness of the core process. Quality targets are not always met, root cause analyses are good, but we can’t see results.
Line managers	Manufacturing engineering	Good but needs improvements	The work division between process engineers and manufacturing engineers is unclear. Because of that, it takes too much effort and investigation whom to assign certain tasks. Priorities of the function are hard to understand.
	Process engineering		
Foremen	Manufacturing engineering	Medium	Depending on the production line, time to resolve certain challenges takes a lot of time. It’s unclear what are the exact priorities of the function and what are the projects being worked on. It’s hard to decide what tasks should be part of manufacturing or process engineering. The cooperation between production and engineering could be better.
	Process engineering	Medium	
	Technical writers	Poor	We do not know what the technical writers are working on and the end result is poor. There are too many old assembly instructions and it creates frustration and conflicts between final inspection and production workers.
Factory workers	Manufacturing engineering	Poor	Reaching engineers is difficult. First, we need to find the senior assembler who then calls engineers. Sometimes engineers are on meetings, sick leave or on vacation and then the senior assembler does not know whom to call. Then the problem is communicated to foremen. All this takes too much time. We don’t get any feedback on how long getting an answer will take, or what is the status of the problem. We don't have time to wait.
	Process engineering	Poor	
	Technical writers	Poor	Assembly instructions are not understandable, contain many mistakes, are not up to date and don’t follow the working principles used in the actual process.

Table 1. Internal customer feedback to Manufacturing and Process Engineering team
Source: Author’s table

For the next steps, the feedback of the internal clients should be backed with data. When investigating how to measure the performance of the team, it came out that there are not many measures in place to see the effectiveness of team output. Manufacturing and process engineers are keeping the daily work running, but there is no improvement project backlog to understand what projects are in the pipeline and how big of an effect they have on key performance indicators. Another key aspect of everyday work is to solve problems popping up in the core process, but again there is no overview of how many challenges there are and how fast are they solved. Because the measurement system is missing, resource management is complicated and done on personal intuition. Technical writers are given assembly instructions to work on, but there is no data about how work was planned out, how much time was put into each assembly instruction, how many mistakes there were etc. The estimation from the team is that it takes around 15 weeks for cabinets and 4 weeks for modules, and there are over 100 mistakes per assembly instruction that need to be reworked.

However, each production line has its key performance indicators (KPI) from which it is possible to estimate whether the work that has been put in has had any results. Figure 22 and Figure 23 illustrates the KPIs of one of the strategic production line. Altogether there are over 10 production lines where similar indicators are measured. Based on these measures it can be said that from a quality perspective not much has changed, although a lot of work has been put in to deliver goods on time.

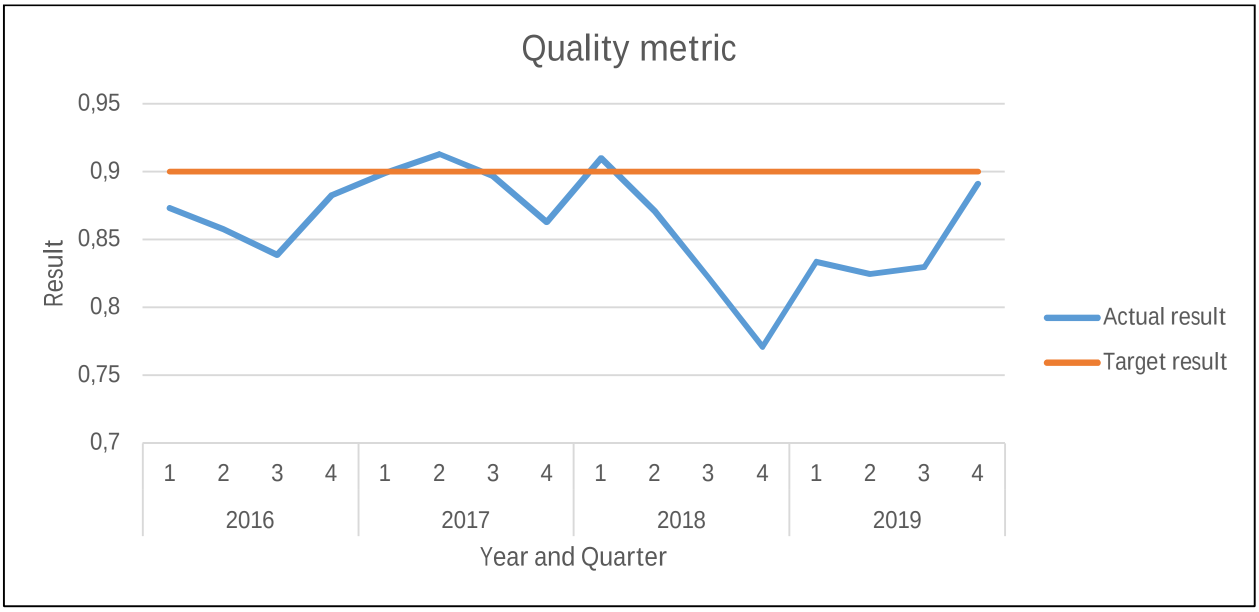


Figure 22. Quality key performance indicator of one of the strategic production lines
Source: Author’s chart

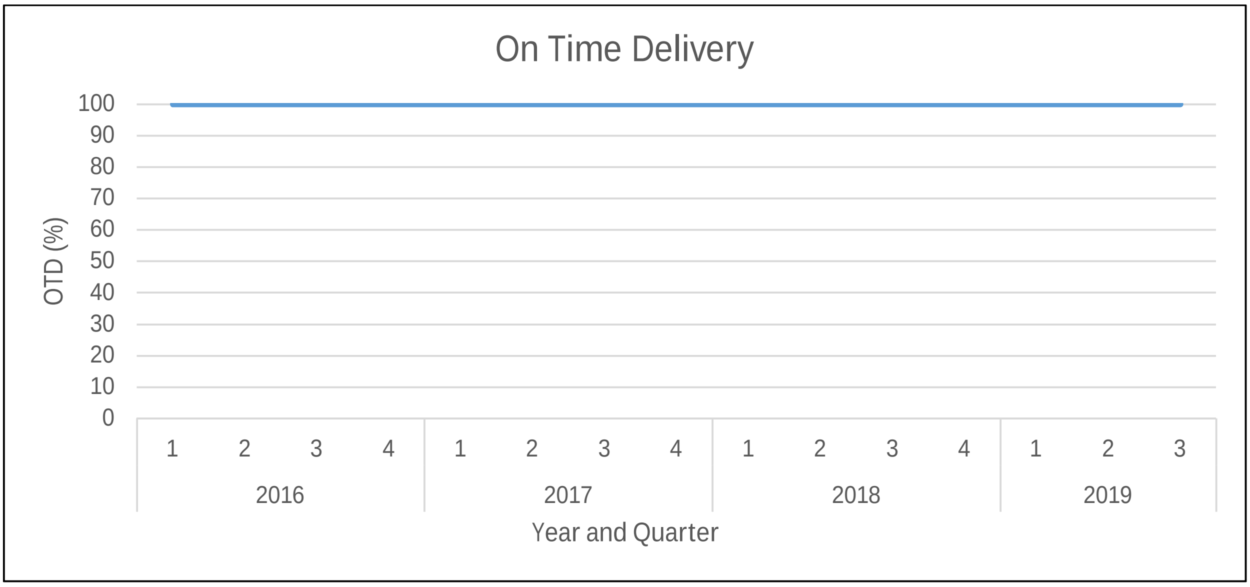


Figure 23. Delivery key performance indicator
Source: Author’s chart

2.4. Research methods

After the internal customer feedback is gathered, to understand the current situation, root cause analysis will be conducted using Lean and Six Sigma tools that are described in the following chapter.

2.4.1. Process mapping

First internal processes are mapped using swim lane flowcharts to learn and understand the daily works of the functions and create a mutual understanding of the processes that are going to be analysed and improved.

The flowchart is a pictorial or graphical representation of a process and is used to help understand, communicate, document, improve, and/or manipulate processes off-line. Various types of flowcharts exist, but the thesis author is using swim lane flowchart that is oriented horizontally. This method segments processes by functional groups providing visual clarity into the overall circuitous nature of the process. (Kubiak & Benbow, 2016)

The process mapping is using standard flow chart shapes defined in Microsoft Visio and illustrated in Figure 24.

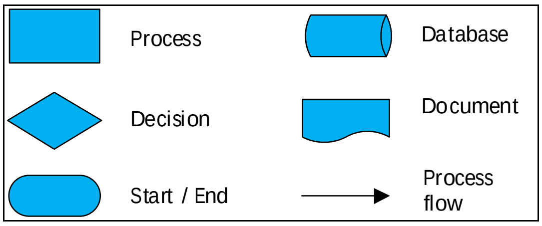


Figure 24. Microsoft Visio basic flowchart shapes
Source: Microsoft Visio 2016

2.4.2. Ishikawa diagram

After processes are mapped Ishikawa diagram, known as the cause and effect diagram, is constructed. Ishikawa diagram is using the "inputs are the function of outputs", Y=f(x), concept, where all possible root causes for possible symptoms are listed. The diagram traditionally divides causes into several general categories, known as the 6M's: (Kubiak & Benbow, 2016)

1. Materials (pats) – Parts / materials / documents / information that are consumed or transformed during a process. Some examples of such root causes could be obsolete information, instable incoming materials etc.
2. Methods (procedures) – How a process is performed, are they well or loosely defined. Examples of causes could be, wrong tool specified, improper procedure or failure to use specified tool or procedure.
3. Manpower (people) – human resources, their skills, knowledge and motivation. Examples of such causes could be lack of training, physical ability or motivation.
4. Measurement – how processes are measured, are the measurement systems capable and foolproof, are measurement systems giving the correct values? Examples of such causes could be measurement device is not calibrated or measurement system/procedures missing.
5. Machine (equipment) – machines or equipment needed to perform the underlying process. Examples of such causes could be old/slow PC, lack of accuracy and precision of a machine etc.
6. Mother nature (environment) – Variables of internal or external environment like temperature, humidity, atmospheric pressure, lightning, noise conditions, vibration, electronic emission

In practice, the diagram is used for brainstorming sessions to map all possible root causes. A diagram, illustrated in Figure 25 is drawn, where the rightmost box is the effect under investigation and other six boxes are the main categories. These general categories defined help people to look at the potential causes from several sides and generate all possible root causes that are then listed under these main categories.

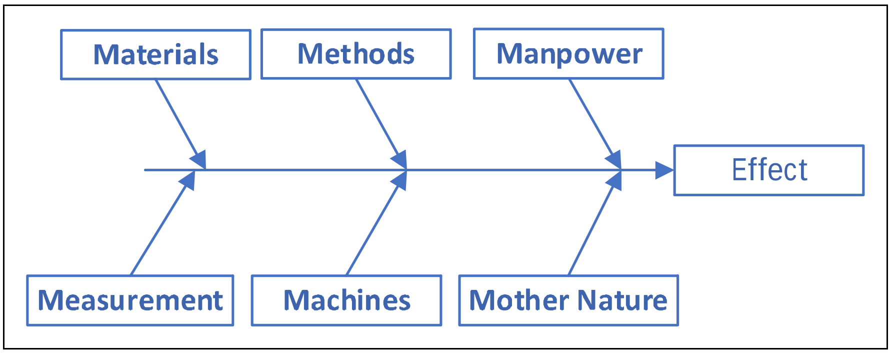


Figure 25. Example of blank Ishikawa diagram
Source: Authors illustration

2.4.3. Pairwise comparison

Once all root causes are listed pairwise comparison is used to understand what are the key parameters affecting the customer. For that, a survey is made to identify the Critical to Quality parameters and their raw and relative weight against each other. Parameters are ranked against each other in a matrix illustrated in Table 2, with predefined criteria illustrated in Table 3.

	Parameter 1	Parameter 2	Parameter n	Raw weight	Relative weight
Parameter 1	1				
Parameter 2		1			
Parameter n			1		

Table 2. Example of an empty pairwise comparison table
Source: (Watson, 2004)

Definition	**Index**	**Definition**	**Index**
Equally important	1	Equally important	1,00
Equally or slightly more important	2	Equally or slightly less important	0,50
Slightly more important	3	Slightly less important	0,33
Slightly to much more important	4	Slightly to way less important	0,25
Much more important	5	Way less important	0,20
Much to far more important	6	Way to far less important	0,17
Far more important	7	Far less important	0,14
Far more important to extremely more important	8	Far less important to extremely less important	0,13
Extremely more important	9	Extremely less important	0,11

Table 3. Assignment of scores for verbal descriptions of strength in the pairwise comparison
Source: Author’s table

Raw and relative weights are calculated with the following equations:

$$Raw\ weight_n = \sum_{i=1}^{n} parameter_i$$

Where n is the number of parameter values in a row

$$Relative\ weight_n = \frac{Raw\ weight_n}{\sum_{i=1}^{n} Raw\ weight_i}$$

Where n is the number of raw weights in a column

Relative weights are used later in cause and effect matrix to quantify the relative importance of each factor and thus give bigger weight on topics that have a higher impact on internal customer satisfaction.

2.4.4. Cause and effect matrix

After all possible root causes are mapped and important parameters for customer satisfaction known, cause and effect matrix is constructed. In the cause and effect matrix, all possible solutions for causes are listed.

Then Cause and effect matrix is used to rank causes and their possible solutions by taking into consideration evaluation criteria like frequency, time and the cost. Evaluation criteria are used to find the best and most effective solutions for listed root causes.

Example of one possible cause and effect matrix is illustrated in Table 4

		Outputs important for customers	Other important parameters			Results		
Causes / inputs	**Solution**	**Effect on Parameter n**	**Frequency**	**Amount of time to fix**	**Necessary Investment**	**Score**	**Running**	**Cum**
Cause 1	Solution 1							
Cause 2	Solution 2							
Cause n	Solution n							

Table 4. Example of an empty cause and effect matrix
Source: Author`s table

Where

$$Effect\ on\ Parameter_n = Relative\ weight\ of\ parameter_n * Cause\ effect\ on\ parameter_n$$

Table 5 is used to assign points to other important parameters like time, cost and frequency or other parameters that are relevant to the organization. In this example, frequency, amount of time and necessary investment are ranked based on Table 5. Practitioners have to keep in mind that each project can have its own evaluation parameters depending on the size and nature of a project. The main idea of the evaluation table is to reduce the subjectivity of verbal assessment.

1. Cause effect on parameter n	2. Frequency	3. Time to fix	4. Necessary investment
1 – 3p: For criteria 1	**1p:** 10% of time	**10 – 8p:** Less than one day	**10p:** No necessary investment
3 – 6p: For criteria 2	**2p:** 20% of time	**7 – 5p:** 1day – 7days	**9 – 7p:** 10 – 1k€
6 – 9p: For criteria 3	…	**4 – 2p:** 1week – 1month	**6 – 4p:** 1k€ - 10k€
10p: For criteria n	**10p:** 100% of time	**1p:** 1month..	**3 – 1p:** 10k€ - 100k€

Table 5. Example of Evaluation parameters for cause and effect matrix
Source: Author's table

The score of each cause and its solution is calculated by multiplying all the results from the columns of the matrix together, for example, the score for cause1/solution1 would be:

cause1/solution1 Score = effect on parameter n * frequency * amount of time to fix * necessary investment

After all causes and their solutions have been scored, they are ranked by the ascending order. Running percentage is calculated for each cause/solution by dividing each score with the sum of all scores. Based on this data, the cumulative percentage is displayed to construct a Pareto diagram and select a few solutions that have high implementation impact.

2.5. Problem statement and research questions

Problem statements arise from interviews with internal customers and quality results from previous years.

From production workers perspective the problem with Manufacturing and Process engineers is that it is hard to reach this department and see if the problems are solved. For department manager, it is hard to estimate how much time and resources it takes to resolve different everyday challenges? Finally, the effectiveness of department work does not reflect in quality baseline results and there is no evidence of improvement projects.

The problems with technical writers are related to the fact that assembly instructions are not understandable, contain many mistakes, are not up to date and don't follow the working principles used in the actual process. There is no clear and systematic way to tell when and who will produce new work instruction.

Study questions:

What are the challenges of providing technical services to internal customers?

What can be the best solutions to improve the technical support team's performance?

How can Lean Six Sigma be used to analyse and improve technical support function?

Justification:

Internal customers are not happy, there is no performance measurement system in place, the service provided by manufacturing engineering unit has not been analysed, waste identified and removed.

2.6. Goal statement

The first goal of this thesis is to analyse the current status of the team’s performance and find out the root causes of low performance. Based on these analyses the second goal is to make process improvements and measurement system proposals and implement them where possible.

2.7. Scope and boundaries

The work will be conducted according to Lean and Six Sigma principles, which means first the as-is process will be described, root causes defined and improvements proposed or made. The scope of the thesis will be related to the performance of technical writers, manufacturing and process engineering work provided to the core process. Only the most important root causes defined in the following chapters will be solved.

3. CASE STUDY

Following chapter is the empirical part of the thesis where the case company and case function are studied. The root causes are identified using Lean Six Sigma tools and principles introduced in theory and methodology chapters. This chapter ends with the demonstration of implemented solutions and further proposals.

3.1. Root cause analysis

Following chapter will demonstrate how Lean Six Sigma tools are used to identify root causes that are affecting work provided by the department and how to measure the effect/impact of these root causes.

3.1.1. Technical writers

First, the as-is process of creating assembly instructions was mapped using Microsoft Visio. This was necessary to create a mutual understanding of the process that is going to be analysed and how it is currently being performed. This method helps to get the project team on the same page and create a baseline of the current state of the analysed process. This as-is assembly instruction creation process is illustrated in Figure 42 in the appendix.

From this process mapping workshop, a conclusion was made that production and technical writing teams are not working together and that technical writing is an ad-hoc process to the core process. These two departments have different targets that force to work against each other, creating a lot of lost time and rework.

Next Ishikawa diagram was made with the team. Ishikawa diagram is using the “inputs are the function of outputs”, $Y=f(x)$, concept, where all possible root causes for possible symptoms are listed. On the diagram, the rightmost box is the symptom and other boxes are main categories under which root causes are listed. The output of this brainstorming session is illustrated in Figure 26 and Figure 27.

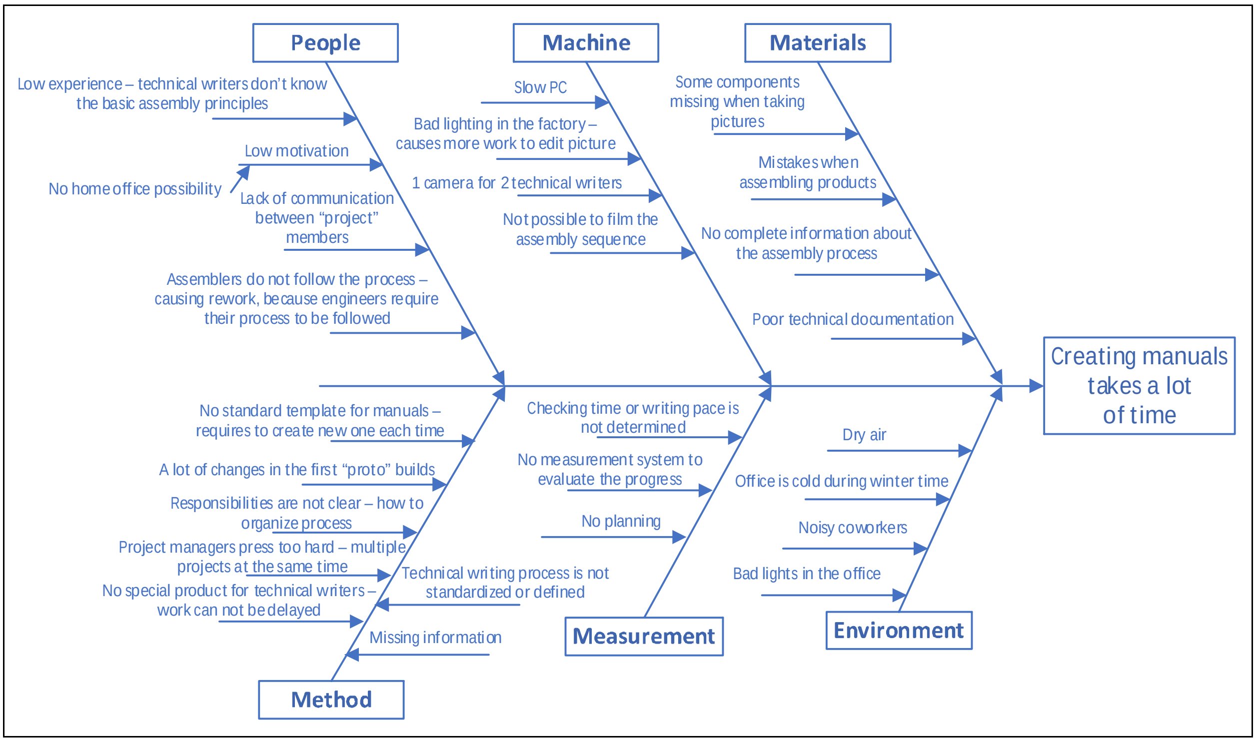


Figure 26. Ishikawa diagram "Creating assembly instructions takes a lot of time" - list of potential "x" factors
Source: Author's figure

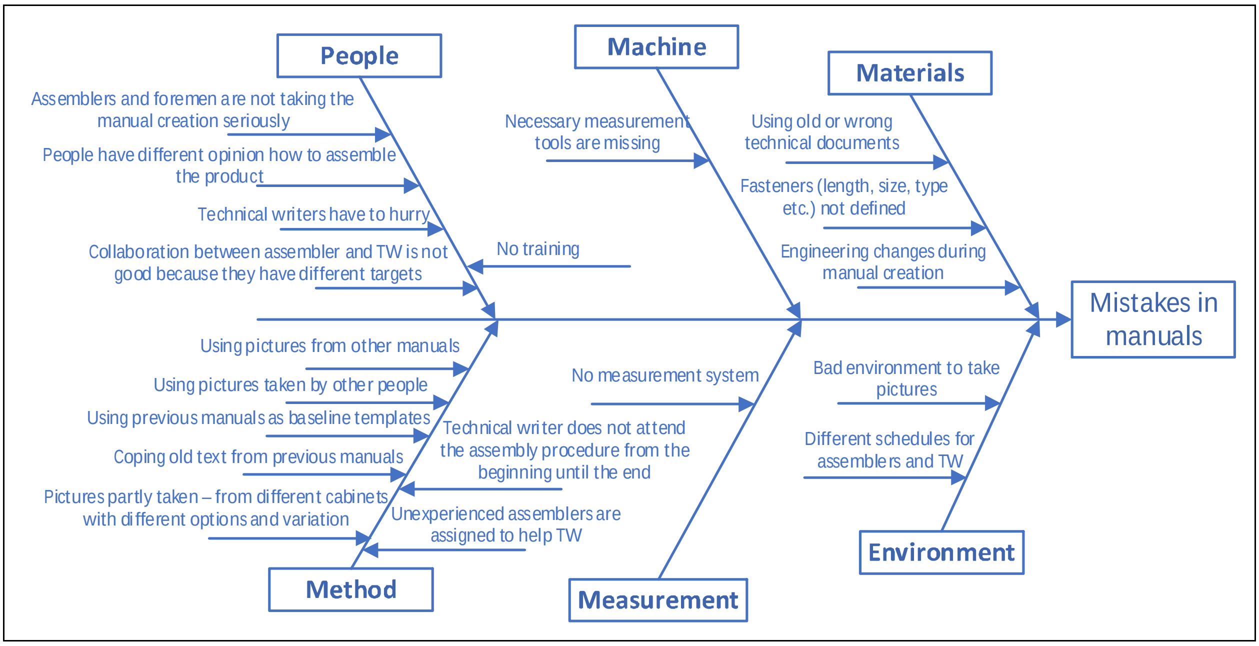


Figure 27. Ishikawa diagram "Mistakes in assembly instructions" - list of potential "x" factors
Source: Author's figure

After Ishikawa diagram, a survey for internal customers was made to identify the Critical to Quality parameters and their relative weight against each other. This is important because the project team needs to understand what is affecting the customer the most. In addition, the idea comes from project management principle that defines three parameters what are usually working against each other. These are time, quality and cost. The idea of this concept is that one parameter affects other parameters, for example, less time is affecting the lower quality and cost of the project. To understand the importance of each parameter, pairwise comparison was used with predefined criteria illustrated in Table 3.

Pairwise comparison is a method were critical to quality parameters are evaluated against each other and their relative weights are calculated based on results.

The table with the assignment of scores and pairwise comparison table, where internal customers had to rank time, correctness and understandability against each other, was sent to 15, from which 13 internal customers replied. The pairwise comparison table and the following relative weights are illustrated in Table 6 and Table 7

	Time	Correctness	Understandable
Time	1		
Correctness		1	
Understandable			1

Table 6. Pairwise comparison table for assembly instructions
Source: (Watson, 2004) with authors modifications

	Raw weight	Relative weight
Time	103,72	0,39
Correctness	56,88	0,21
Understandable	106,74	0,40

Table 7. Pairwise comparison results
Source: Author’s table

Next task was to create a cause and effect matrix to identify how big of an effect on critical to quality parameters different causes defined on Ishikawa diagram have. For this, all problematic aspects were listed on the cause and effect matrix and possible solutions to fix these root causes were defined. After all possible corrective actions were listed, each cause and a possible solution was ranked with predefined evaluation criteria, illustrated in Table 8.

1. Effect on Time - adds how much time	2. Effect on Mistakes - creates how many mistakes per instruction	3. Effect on understandability	2. Frequency	3. Amount of time to fix	4. Necessary investment
1 – 3p: 0 – 3h	**1 – 3p:** 0 – 10	**1p:** no effect	**1p:** 10% of instructions	**10 – 8p:** Less than one day	**10p:** No necessary investment
3 – 6p: 3-6h	**3 – 6p:** 10 – 20	**3p:** low effect	**2p:** 20% of instructions	**7 – 5p:** 1d – 7d	**9 – 7p:** 10 – 1k€
6 – 9p: 6-9h	**6 – 9p:** 20 – 30	**6p:** moderate	…	**4 – 2p:** 1wk – 1mo	**6 – 4p:** 1k€ - 10k€
10p: 10h+	**10p:** 30+ mistakes	**10p:** huge effect	**10p:** 100% of instructions	**1p:** 1mo+	**3 – 1p:** 10k€ - 100k€

Table 8. Evaluation parameters for cause and effect matrix
Source: Author’s table

After evaluation, each result for effect on time, quality and understandability were multiplied with the relative weight defined by internal customers. This method helps to take into consideration also the customers perspective on different critical to quality parameters, the frequency of listed issues and the resources needed to solve challenges.

Each root cause and solution was scored by multiplying the evaluation results, and the cumulative effect was calculated. The results are illustrated in Table 10 and Figure 28. Pareto analysis indicates that from 50 listed causes 16 have a cumulative effect of 80% and can be solved having the biggest impact on customer needs while using the least resources and effort.

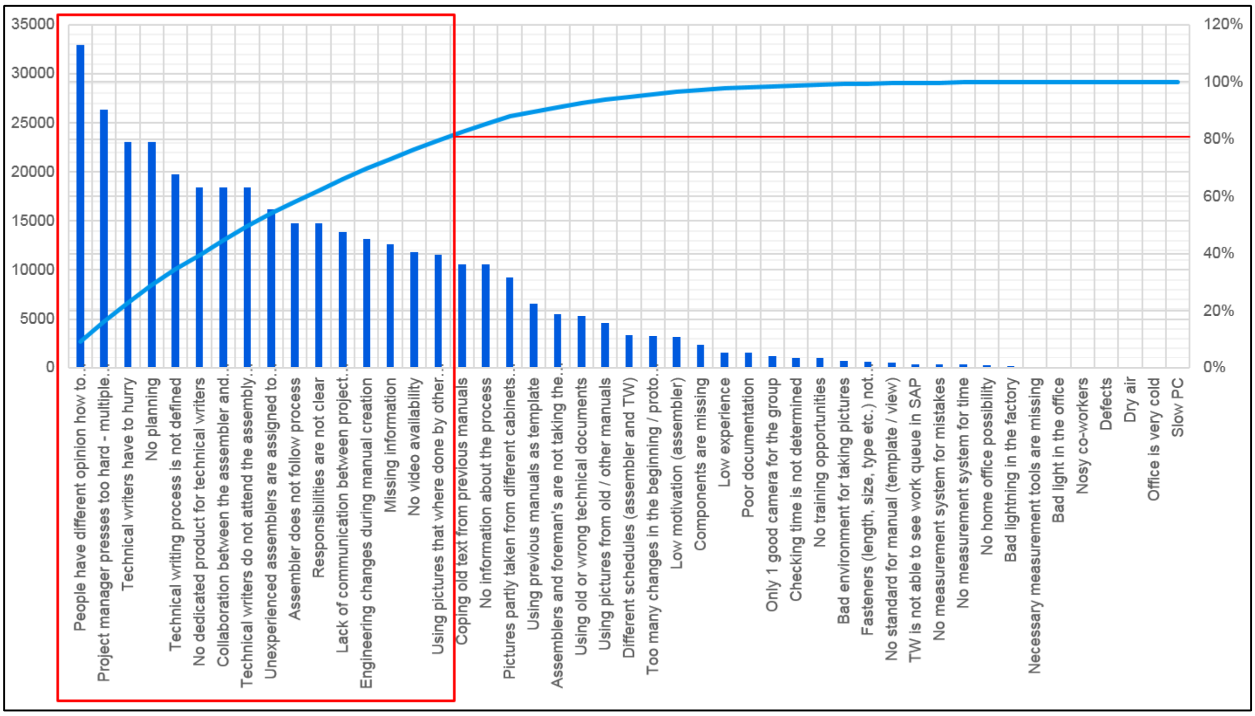


Figure 28. Pareto chart for Cause and Effect analysis
Source: Author’s figure

Using these results an action plan was formed, a new process was defined and agreed within the organisation, standardised work pace was agreed and planning for assembly instruction creation was implemented. Improvements are explained in the solutions section.

3.1.2. Manufacturing and Process Engineers

The Manufacturing and Process Engineering team main challenges were related to communication – the main customer, the production workers, were not able to reach engineers, and when they were reached, there was no information about the status of the issue.

The second main area that needed to be fixed was related to improvement projects. The input from factory manager and production managers was, that while they have seen that everyday problems are solved, there was no significant improvement in the main KPIs.

Root cause analysis was made using the Ishikawa diagram, the results are illustrated in Figure 29 and Figure 30

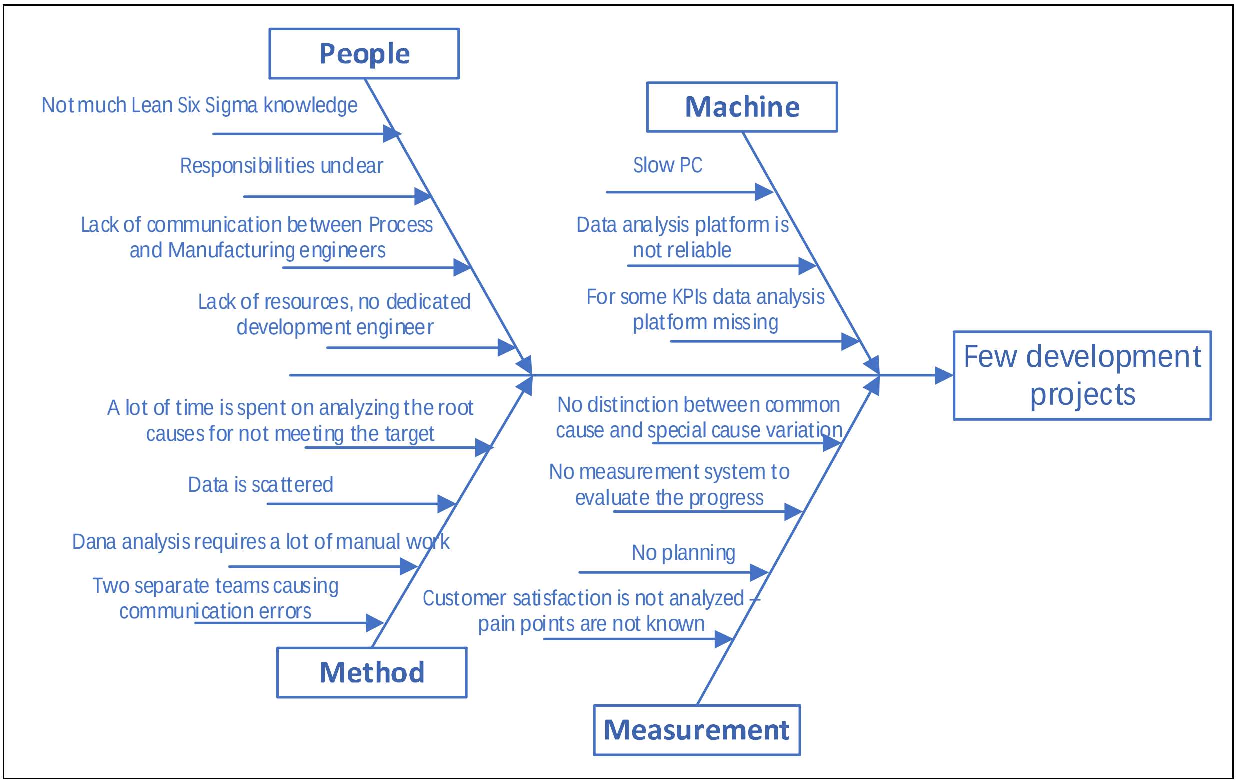


Figure 29. Ishikawa diagram "Few development projects" - list of potential "x" factors
Source: Author’s figure

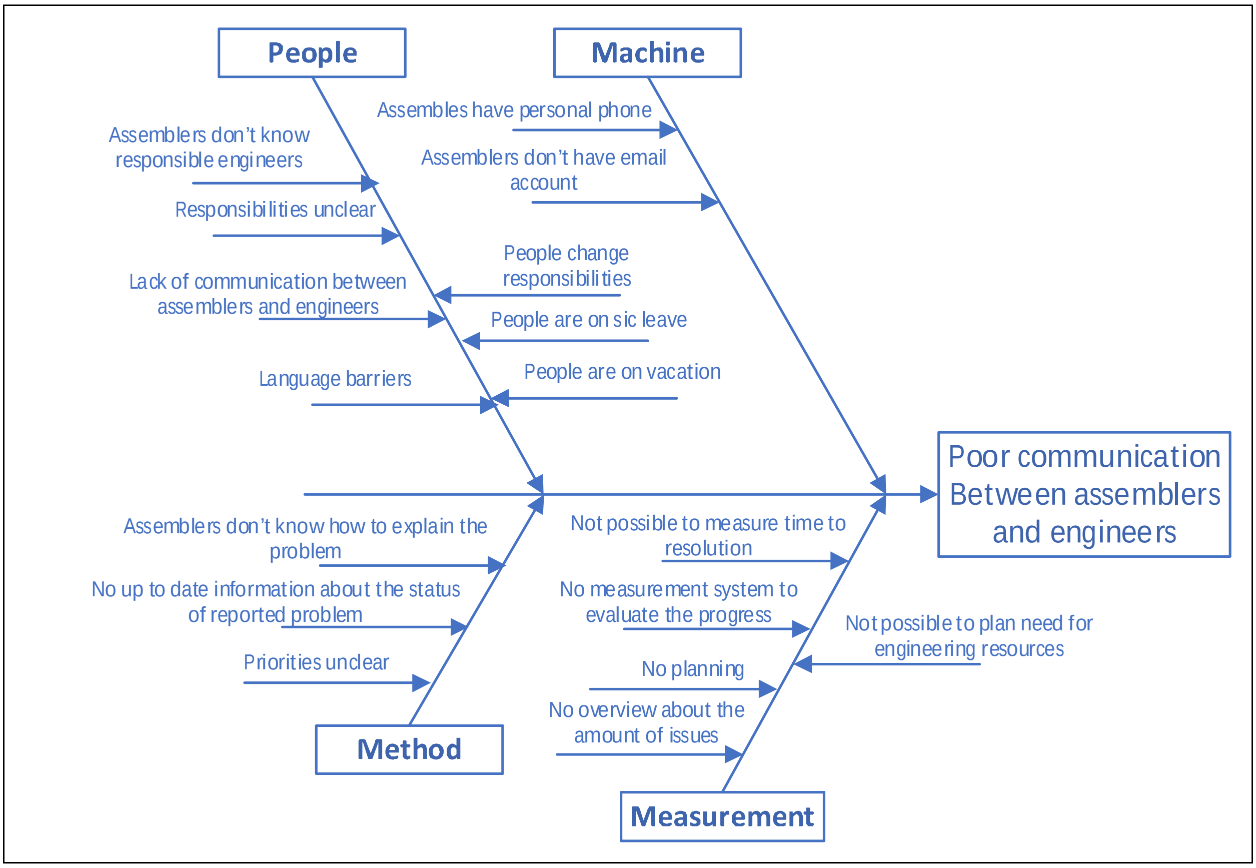


Figure 30. Ishikawa diagram "Poor communication between assemblers and engineers" - list of potential "x" factors
Source: Author's figure

The cause and effect matrix was not created because during the root cause investigation it became clear that most of the root causes are solvable with few solutions that will be explained in the following chapters.

3.2. Solutions

The following chapter will demonstrate what solutions were implemented to improve the current state of performance to increase the efficiency and effectiveness of the departments.

3.2.1. Technical writers

First, a task list was formed with the SMART principle. The SMART principle means that every task needs to be:

1. Specific – clearly defined what needs to be done and by whom
2. Measurable – clearly verifiable that something is agreed upon or achieved
3. Achievable – the target is mutually agreed and possible to implement in the organisation
4. Relevant – the target is mutually agreed that it is relevant to achieve
5. Time-bound – clearly defined when the target needs to be reached

Cause 80%	**Solution**	**Responsible person**	**Target**	**Status**
1. People have a different opinion on how to assemble the product	PcE will set the assembly sequence in place and assemblers must follow - if the process is not defined then PcE has to instruct the worker during the assembly instruction creation phase. Agree the responsibilities and state in the process map.	Process Engineer (PcE); Technical Writer (TW)	W36	DONE
2. Project manager presses too hard - multiple projects at the same time	Resource planning in Assembly Instruction Planner - TW are not set to multiple projects; Database created; Process implemented	Team Lead	W27	DONE
3. Technical writers have to hurry	Agree reasonable pace and make the process systematic; min. 5 pages per day; report to the database. Make a template for assembly instructions and a systematic folder structure.	Team Lead; Technical Writing Team	W32	DONE
4. No planning	Resource planning in Assembly Instruction Planner; create a database for resource planning	Team Lead; Technical Writing Team;	W27	DONE

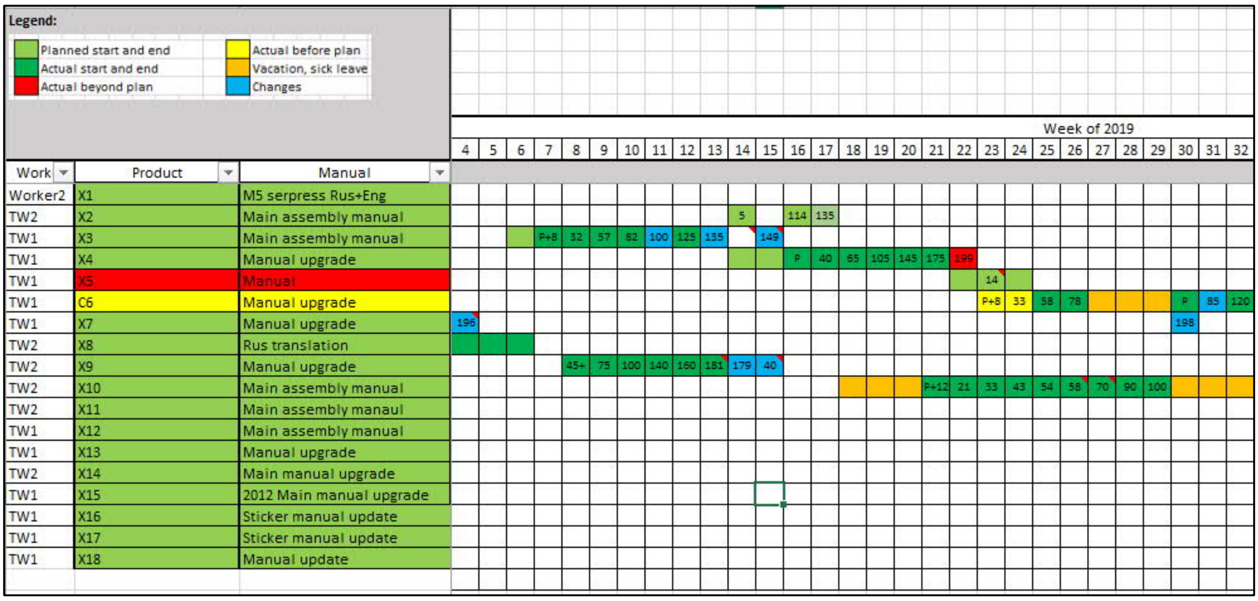
		Manufacturing Engineers		
5. The technical writing process is not defined	Define the assembly instruction writing process that the organization agrees to follow	Team Lead; Technical Writing Team; Manufacturing Engineers; Process Engineers	W31	DONE
6. No dedicated product for technical writers	Change the process so that the cabinet is assembled and then later assigned to a production order. – take more time for cabinet assembly. Agree and define in the process map.	Team Lead	N/A	Cancelled
7. Collaboration between the assembler and TW is not good because they have different targets	Change the process so that the assembler does not have a "time limit" or has extended time for assembly. Agree with foremen new process.	Team Lead; Foremen; Planners; Assemblers; Technical Writers	W32	DONE
8. Technical writers do not attend the assembly process from the beginning until the end	Change the process so that TW can attend the assembly process from beginning till the end; assembly is done in one shift	Team Lead; Foremen; Planners; Assemblers; Technical Writers	W32	DONE
9. Inexperienced assemblers are assigned to help TW	Only highly experienced assemblers will be assigned to help assembly instruction creation; assembler has to have good skills of assembly on the certain working field. Agree and define in the new process map.	Foremen; Assemblers	W32	DONE
10. The assembler does not follow the process	PcE will set the assembly sequence in place and assemblers must follow - TW has to escalate this problem; Agree within the team and define in the process map.	Process Engineers; Technical Writers	W32	DONE
11. Responsibilities are not clear	Define responsibilities; responsibilities are determined in the process map	Team Lead; Technical writing team; Manufacturing Engineers; Process	W31	DONE

		Engineers; Foremen; Planners; Assemblers		
12. Lack of communication between project members	A clear and understandable process that the organization will follow; Communication must be followed according to the updated and implemented process map	Team Lead; Technical writing team; Manufacturing Engineers; Process Engineers; Foremen; Planners; Assemblers	W30	DONE
13. Engineering changes during assembly instruction creation	Shorten the assembly instruction creation cycle. Engineering change notifications (ECN) will be implemented in a new cycle; first revision of assembly instructions must be done ASAP on the first try; other assembly instruction revision can be based on incoming ECNs/changes. Plan incoming changes.	R&D; Manufacturing Engineers; Technical Writers	W31	DONE
14. Missing information	Information will be gathered to the assembly instruction folder- agree with PcE and ME teams.	Process Engineers; Manufacturing Engineers; Team Lead; Technical Writers	W29	DONE
15. No video availability	Organize WiFi cameras to film process and use it for assembly instruction creation	Team Lead	W32	DONE
16. Using pictures that were done by other people	Change the process - TW must partake the full assembly and take pictures. If information is missing from pictures then this information has to be shown using 3D models or TW will take necessary pictures and update the assembly instruction.; TW must follow the updated process map	Technical Writers	W31	DONE

Table 9. SMART task list
Source: Author’s table

Next key outputs were made, to reduce the waste defined by Lean:

1. Responsibilities determined, a new process developed, defined and agreed within the organisation. The To-Be process is illustrated in Figure 43
2. Database created to plan the work in the long term and measure the pace and quality of technical writers. Assembly instruction planning database is illustrated in Figure 31



Legend:

🟩 Planned start and end
🟩 Actual start and end
🟥 Actual beyond plan
🟨 Actual before plan
🟧 Vacation, sick leave
🟦 Changes

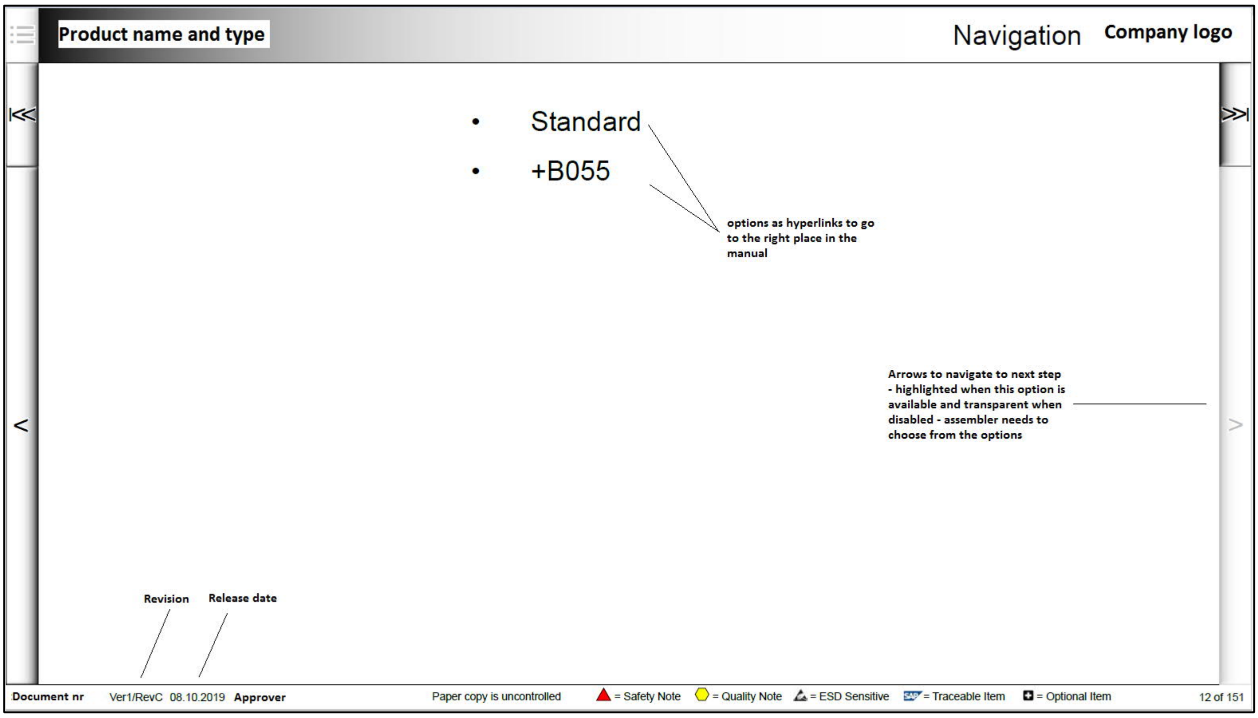
Week of 2019

Work	Product	Manual	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Worker2	X1	M5 serpress Rus+Eng																													
TW2	X2	Main assembly manual											5		114	135															
TW1	X3	Main assembly manual			🟩	P+8	32	57	82	100	125	135		149																	
TW1	X4	Manual upgrade											🟩	🟩	P	40	65	105	145	175	199										
TW1	X5	Manual																			🟩	14	🟩								
TW1	C6	Manual upgrade																				P+8	33	58	78	🟧	🟧	🟧	P	85	120
TW1	X7	Manual upgrade	196																										198		
TW2	X8	Rus translation	🟩	🟩	🟩																										
TW2	X9	Manual upgrade					45+	75	100	140	160	181	179	40																	
TW2	X10	Main assembly manual															🟧	🟧	🟧	P+12	21	33	43	54	58	70	90	100	🟧	🟧	🟧
TW2	X11	Main assembly manaul																													
TW1	X12	Main assembly manual																													
TW1	X13	Manual upgrade																													
TW2	X14	Main manual upgrade																													
TW1	X15	2012 Main manual upgrade																													
TW1	X16	Sticker manual update																													
TW1	X17	Sticker manual update																													
TW1	X18	Manual update																													

Figure 31. Assembly instruction planner to track pace, quality and prioritise work in long term
Source: Author’s figure

3. Assembly instruction writing work pace was agreed
4. Standardised templates, illustrated in Figure 32, and folder structures created to reduce the time for preparation.
5. More time is given to the assemblers who are supporting the assembly instruction creation, reducing the risk of late delivery because of not standard work procedure.
6. Agreed with the line organisation that only highly skilled assemblers will be assigned to help the technical writers.
7. Prioritisation with the team lead was agreed so that the whole organisation is aware of what is the order of assembly instructions being produced.
8. Shorter control cycles to reduce the amount of work and increase the communication cycle.

9. Hyperlinks were introduced to assembly instructions to increase the understandability of the working sequence. Illustrated in Figure 32.



options as hyperlinks to go to the right place in the manual

Arrows to navigate to next step - highlighted when this option is available and transparent when disabled - assembler needs to choose from the options

Figure 32. Standard template for assembly instructions
Source: Author’s figure

10. With the line organisation, it was agreed that the acceptable time for assembly instruction creation for bigger products (cabinets) is around 8 weeks and for smaller ones (modules) 4 weeks.

In the end, it was also decided that products that are used to create assembly instructions will not be assembled without a customers production order. Instead, products will be released to production much sooner so that assemblers have sufficient time buffers for on-time delivery.

3.2.2. Manufacturing and Process Engineers

To overcome the communication errors and language barriers it was clear that it is not feasible to start teaching different languages either to engineers or production workers, instead a simple communication tool needed to be created to bring the problems to correct person and measure the time of resolution. With that tool, it becomes clear to resource owners how many daily issues there are and how fast these are solved.

For production workers, an easy interface was created to report the issues with a few simple clicks. Reporting is done either from computers or from mobile phones. The most common failure types were defined and structured into main and subcategories. The view of the main categories is illustrated in Figure 33.

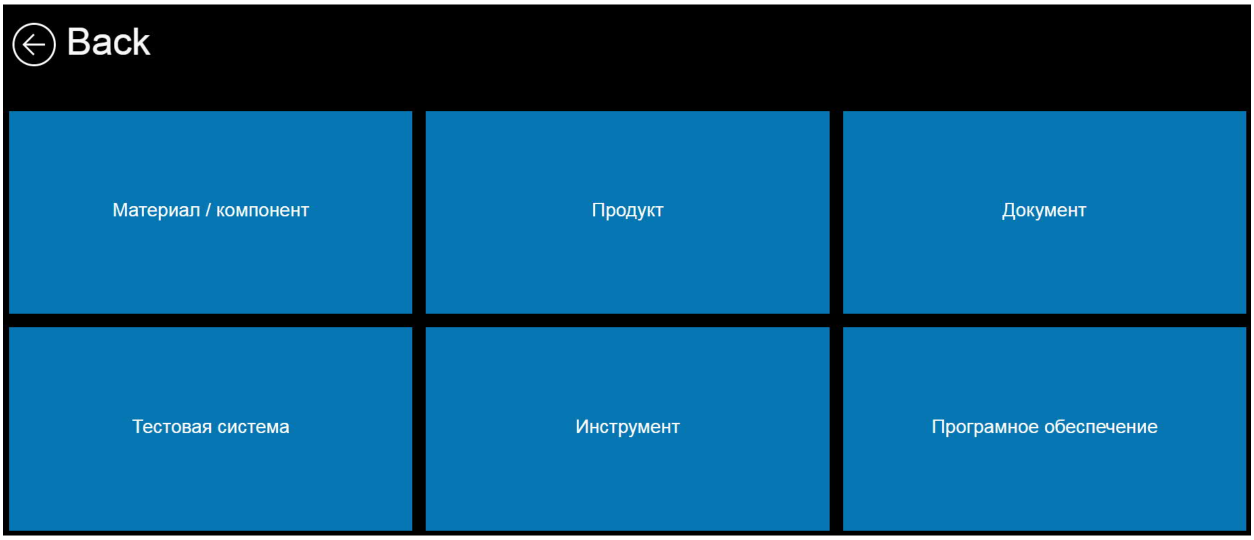


Figure 33. Main categories to report problems to engineers
Source: Author’s figure

It was decided that because most of the production workers are Russian speaking, then the default language for the interface must be Russian, but the engineers' view is in English. After the main and secondary category selection, the workers have a possibility to leave a message by typing or speaking to a microphone. This is not a mandatory step and the problem can be issued with an empty field by pressing on the send button. This option is illustrated in Figure 34

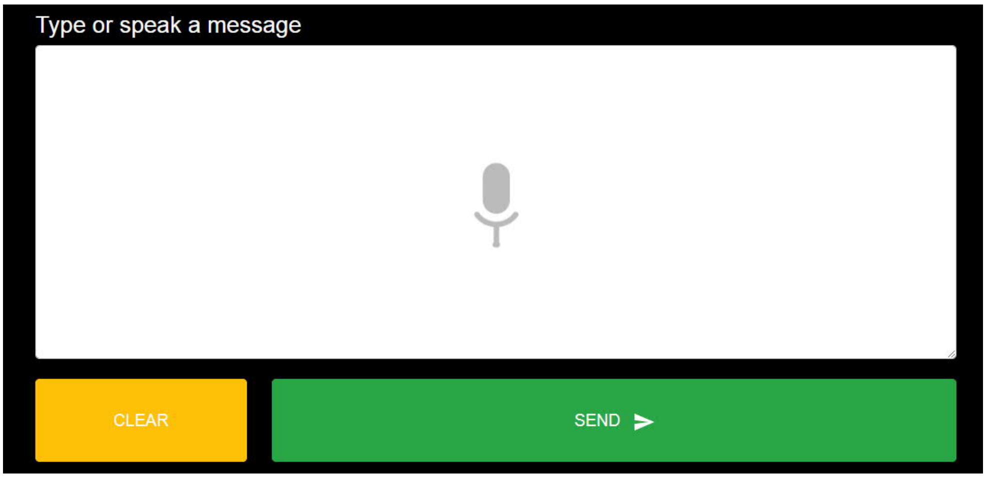


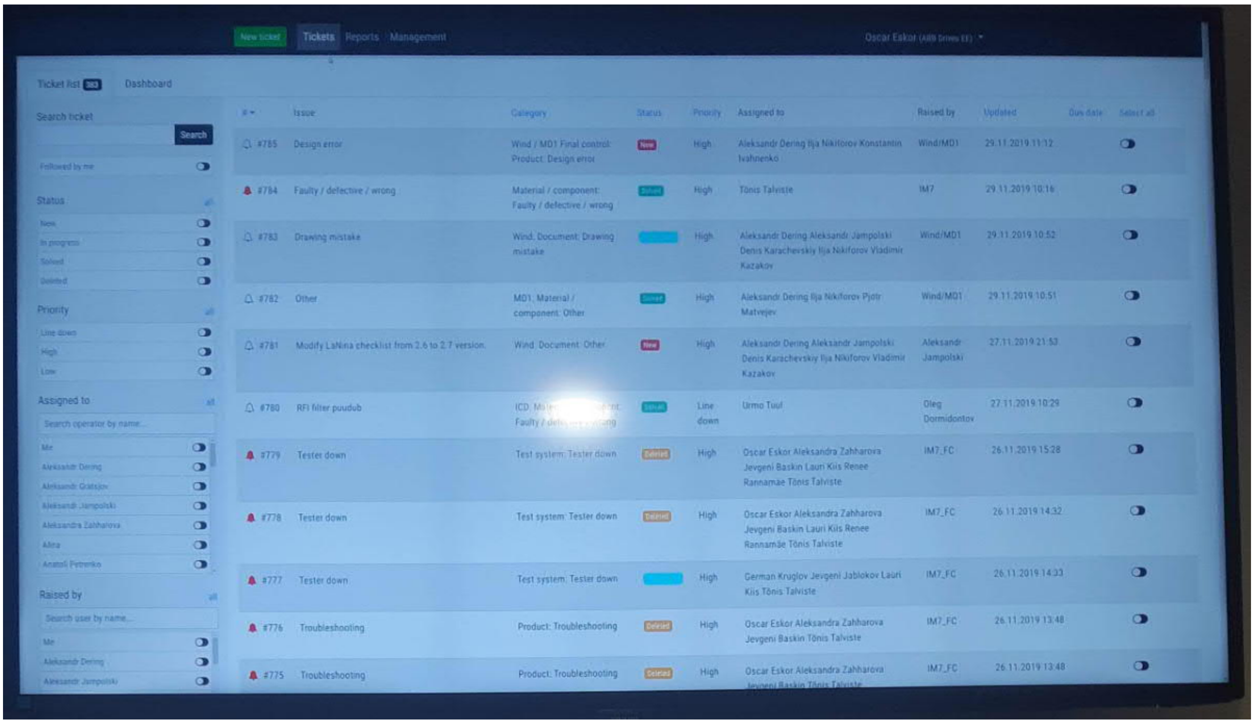
Figure 34. Reporting interface for detailed problem description with recording possibility
Source: Author`s figure

After the issue is posted by the assembler, the responsible engineer receives a notification as an email and the problem appears on the office interface. It is closely monitored by Manufacturing and Process engineers. On the interface, it is possible to see the general description, status, priority, assigned engineer, issue raiser and the date of the last update. The office interface is illustrated in Figure 35.

#	Issue	Category	Status	Priority	Assigned to	Raised by	Updated	Due date	Select all
#785	Design error	Wind / MD1 Final control: Product: Design error	In progress	High	[redacted]	[redacted]	29.11.2019 16:14		
#784	Faulty / defective / wrong	Material / component: Faulty / defective / wrong	Solved	High	[redacted]	[redacted]	29.11.2019 10:16		
#783	Drawing mistake	Wind: Document: Drawing mistake	In progress	High	[redacted]	[redacted]	29.11.2019 10:52		
#782	Other	MD1: Material / component: Other	Solved	High	[redacted]	[redacted]	29.11.2019 10:51		
#781	Modify LaNina checklist from 2.6 to 2.7 version.	Wind: Document: Other	New	High	[redacted]	[redacted]	27.11.2019 21:53		
#780	RFI filter puudub	ICD: Material / component: Faulty / defective / wrong	Solved	Line down	[redacted]	[redacted]	27.11.2019 10:29		
#779	Tester down	Test system: Tester down	Deleted	High	[redacted]	[redacted]	26.11.2019 15:28		

Figure 35. Office interface for tracking the daily issues
Source: Author`s figure

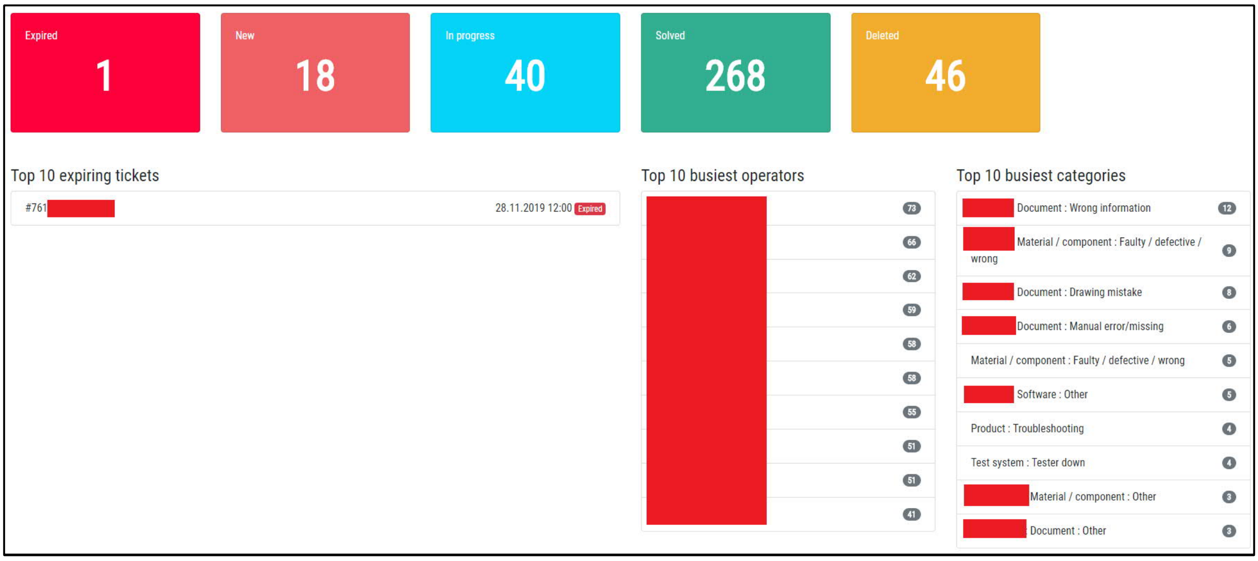
A screen was hanged to the office for everybody to see the status of raised challenges and a routine was set in place to follow up the daily issues. The screen is illustrated in Figure 36



#	Issue	Category	Status	Priority	Assigned to	Raised by	Updated	Due date	Select all
#785	Design error	Wind / MD1 Final control: Product: Design error	New	High	Aleksandr Dering Ilja Nikiforov Konstantin Ivahnenko	Wind/MD1	29.11.2019 11:12		
#784	Faulty / defective / wrong	Material / component: Faulty / defective / wrong	[illegible]	High	Tõnis Talviste	IM7	29.11.2019 10:16		
#783	Drawing mistake	Wind: Document: Drawing mistake	[illegible]	High	Aleksandr Dering Aleksandr Jampolski Denis Karachevskiy Ilja Nikiforov Vladimir Kazakov	Wind/MD1	29.11.2019 10:52		
#782	Other	MD1: Material / component: Other	[illegible]	High	Aleksandr Dering Ilja Nikiforov Pjotr Matvejev	Wind/MD1	29.11.2019 10:51		
#781	Modify LaNina checklist from 2.6 to 2.7 version.	Wind: Document: Other	New	High	Aleksandr Dering Aleksandr Jampolski Denis Karachevskiy Ilja Nikiforov Vladimir Kazakov	Aleksandr Jampolski	27.11.2019 21:53		
#780	RFI filter puudub	ICD: [illegible] Faulty / [illegible]	[illegible]	Line down	Urmo Tuul	Oleg Dormidontov	27.11.2019 10:29		
#779	Tester down	Test system: Tester down	Deleted	High	Oscar Eskor Aleksandra Zahharova Jevgeni Baskin Lauri Kiis Renee Rannamäe Tõnis Talviste	IM7_FC	26.11.2019 15:28		
#778	Tester down	Test system: Tester down	Deleted	High	Oscar Eskor Aleksandra Zahharova Jevgeni Baskin Lauri Kiis Renee Rannamäe Tõnis Talviste	IM7_FC	26.11.2019 14:32		
#777	Tester down	Test system: Tester down	[illegible]	High	German Kruglov Jevgeni Jablokov Lauri Kiis Tõnis Talviste	IM7_FC	26.11.2019 14:33		
#776	Troubleshooting	Product: Troubleshooting	Deleted	High	Oscar Eskor Aleksandra Zahharova Jevgeni Baskin Tõnis Talviste	IM7_FC	26.11.2019 13:48		
#775	Troubleshooting	Product: Troubleshooting	Deleted	High	Oscar Eskor Aleksandra Zahharova Jevgeni Baskin Tõnis Talviste	IM7_FC	26.11.2019 13:48		

Figure 36. The screen on the office wall
Source: Author`s figure

For the team lead a general overview was created to see what the most problematic areas are and whether more resources need to be assigned to solve raised issues. Also, data is gathered to measure the time for resolutions. The general overview is illustrated in Figure 37.



Expired	New	In progress	Solved	Deleted
1	18	40	268	46

Top 10 expiring tickets

#761[redacted] 28.11.2019 12:00 Expired

Top 10 busiest operators

[redacted]	73
[redacted]	66
[redacted]	62
[redacted]	59
[redacted]	58
[redacted]	58
[redacted]	55
[redacted]	51
[redacted]	51
[redacted]	41

Top 10 busiest categories

[redacted] Document : Wrong information	12
[redacted] Material / component : Faulty / defective / wrong	9
[redacted] Document : Drawing mistake	8
[redacted] Document : Manual error/missing	6
Material / component : Faulty / defective / wrong	5
[redacted] Software : Other	5
Product : Troubleshooting	4
Test system : Tester down	4
[redacted] Material / component : Other	3
[redacted] Document : Other	3

Figure 37. General overview of raised issues
Source: Author`s figure

This solution helps the department and production to solve issues in a fast manner, have short communication pathways, see the status of problems and measure the time and resources needed to solve raised issues.

Next general problematic area was that the department was not able to push through enough improvement projects and show the improvement of responsible KPIs. A lot of time was put on analysing the root causes of not meeting the weekly targets and less time was put to do the actual improvements. To reduce the time of analysis and increase time for effective improvements, first general understanding in the organisation needed to be changed. The objectives of the department were aligned with Lean Six Sigma principles. Instead of certain targets for quality, reaching zero defects was set as the ultimate goal and statistical process control was introduced and taken into use. The new objective of the department was to keep the processes stable and do a fast root cause analysis only for special causes. Otherwise, data from the whole year needs to be consolidated and the problems fixed using the Pareto principle.

Before the change, engineers had to make weekly root cause analysis when the target was not met. Figure 38 illustrates the first pass yield of one of the products. First pass yield (FPY) is a quality metric showing the yield of products that pass the automatic testers and visual inspection the first time. FPY takes into account mistakes related to components, supplier, assembly errors, tester limits.

In 2019 from week 1 to 48 the FPY result was 37 times below the target line and a root cause analysis was required, in other words, a lot of working hours were necessary to fulfil the requirement.

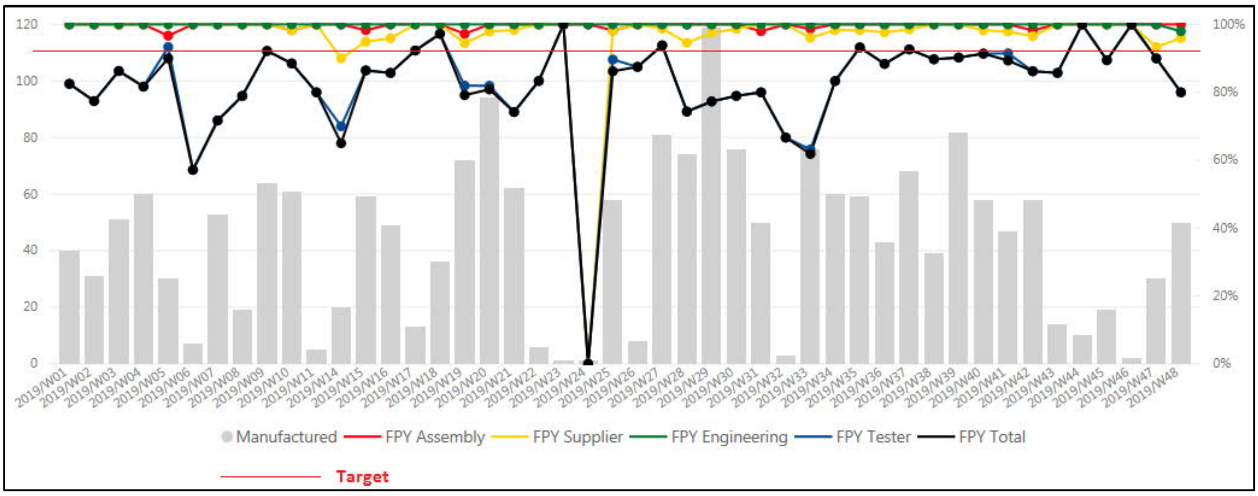


Figure 38. 2019 KPI for one of the products – measuring the old way
Source: Author`s figure

From Lean Six Sigma perspective this is waste because there is no identification of special cause and common cause variation. People are spending time on a weekly basis analysing the common cause issues and trying to make small and insignificant improvements. Instead, the special cause variation needs to be identified and removed, while the common cause variation needs to be studied using the Pareto principle, and “off-line” improvement projects launched. This new method maximises the effect of projects and shows long term improvements. For that purpose, the data structure was also changed from defective products to defects throughout the production process. A product may have many defects and because of that, it gives a much better overview of the current state of the production line. Lean Six Sigma defines that defects are much stronger attributive data type than defectives. Figure 39 illustrates the 2019 results using the new method.

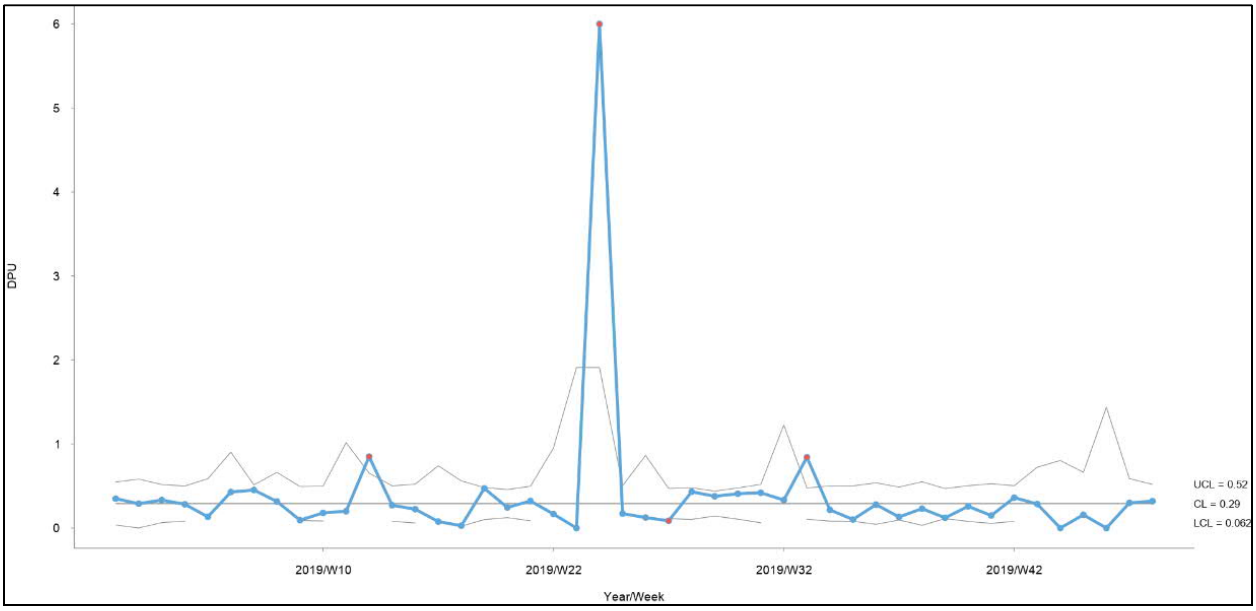


Figure 39. 2019 KPI for one of the products – measuring the new way
Source: Author’s figure

Comparing these two methods it can be clearly seen that there are much less root cause analyses, 4 instead of 37, required for the year and people can spend more time on improvement projects with a bigger effect on the bottom-line results.

To root the new methods into the everyday work another screen was set up at the office showing the dashboard of line-specific KPIs and quick 15-minute meetings were set in place to track the status of production lines to give an overview about the improvement projects. All special causes and improvements were required to be saved to the continuous improvement log book. Figure 40 illustrates the dashboard hanging in the office.

Finally, a continuous improvement logbook was taken into use, where all projects and changes related to specific production lines are described. This was necessary because the input from factory and production managers was, that it is not clear what projects have been undertaken to improve the baseline results. Now there is a clear and understandable log of these changes, and the results are more visible and understandable.

CONCLUSION

The aim of the paper was to analyse a support function in a global company providing electrification, robotics and motion, industrial automation and power grids products and services and use Lean Six Sigma principles and tools to improve the performance of the department.

First, feedback from internal customers was gathered and analysed. Based on these interviews a baseline understanding of the teams' performance and daily challenges was formed. It became clear that different internal customers from the core process are not happy and improvements were needed. Most problematic areas from the customers perspective where the communication, lack of improvement projects and the overall quality of the assembly instructions.

After the customer feedback was gathered the support function processes were studied, mapped and root cause analyses for brought out problems made. It became clear that there are several flaws in the current ways of working and management.

Based on internal customer feedback (interviews) following study questions where compiled and answered:

What are the challenges of technical writers to providing services to internal customers?

During root cause analysis for technical writing function, 50 different challenges and actions were listed. Cause and effect matrix needed to be created and a quantified Pareto method used to prioritise and reduce the number of actions. When customers needs were quantified with the pairwise comparison and the causes and effects graded additionally with the occurrence and necessary time and cost to undertake actions, the number of solutions where reduced from 50 to 16. Most of these root causes were related to not having a standardised working process, planning and cooperation between different departments.

What can be the best solutions to improve the technical writers team's performance?

The solution for technical writing function was to define a new and better process where responsibilities were determined and agreed throughout the organisation. Because there was no long term planning or key performance indicators to measure the performance of the functions, an assembly instruction planner was created and targets agreed and measured. Standardised assembly instruction templates and folder structures were agreed and created to reduce the time for preparation. More time for projects/products that were to be used to create assembly instructions was agreed and only highly skilled assembly workers assigned. Shorter communication cycles between the engineers who control the assembly instructions were set in place and prioritisation of the requests for instructions with the production managers agreed. The overall structure of the assembly instructions was changed to increase the understandability for assembly workers.

What are the challenges of manufacturing and process engineering function to providing services to internal customers?

The root cause analyses for manufacturing and process engineering function for communication and overall performance issues listed many root causes, but it became clear that most of these are solvable with relatively few solutions and there is no need to create cause and effect matrix to prioritise the tasks.

The main communication issues were related to language barriers, assembly workers not having work phones or emails, not knowing when somebody is on sick leave or vacation. The performance issues arise from ineffective resource management and overloading department with root cause analyses that had a low effect on baseline results.

What can be the best solutions to improve the manufacturing and process engineering team`s performance?

The solution was to implement a communication platform that is easy to use for the assembly workers and removes the language barrier between two departments. For managers, it became possible to understand what are their resources working with and how much time it takes to resolve challenges in the production.

To increase the overall performance of improvement projects, a new management principle needed to be introduced. Instead of analysing on a weekly basis why the line-specific target was not reached, common cause and special cause variation needed to be distinguished. According to the new management principle root cause analysis was made only when special cause variation existed in the process. Otherwise, data were to be analysed using the Pareto principle and most effective projects selected and launched. A quantitative study of 2019 results for one strategic production line showed that instead of 37 root cause analyses and action plans only 4 where necessary. Implementation of this new management principle allowed resources responsible for line-specific key performance indicators focus more on meaningful work and projects with high effect on baseline results.

How can Lean Six Sigma be used to analyse and improve technical support function?

This case study showed that when Lean Six Sigma methods and tools are used, it is possible to understand the challenges of provided services. The goal of understanding the root causes and finding the solutions for improvement of efficiency and effectiveness of teams output using a systematic approach was met, also defined solutions where implemented. Usage of Lean Six Sigma philosophy and tools helped to reduce waste created both by management principles and ineffective working methods.

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APPENDICES

Appendix 1. Line specific dashboards

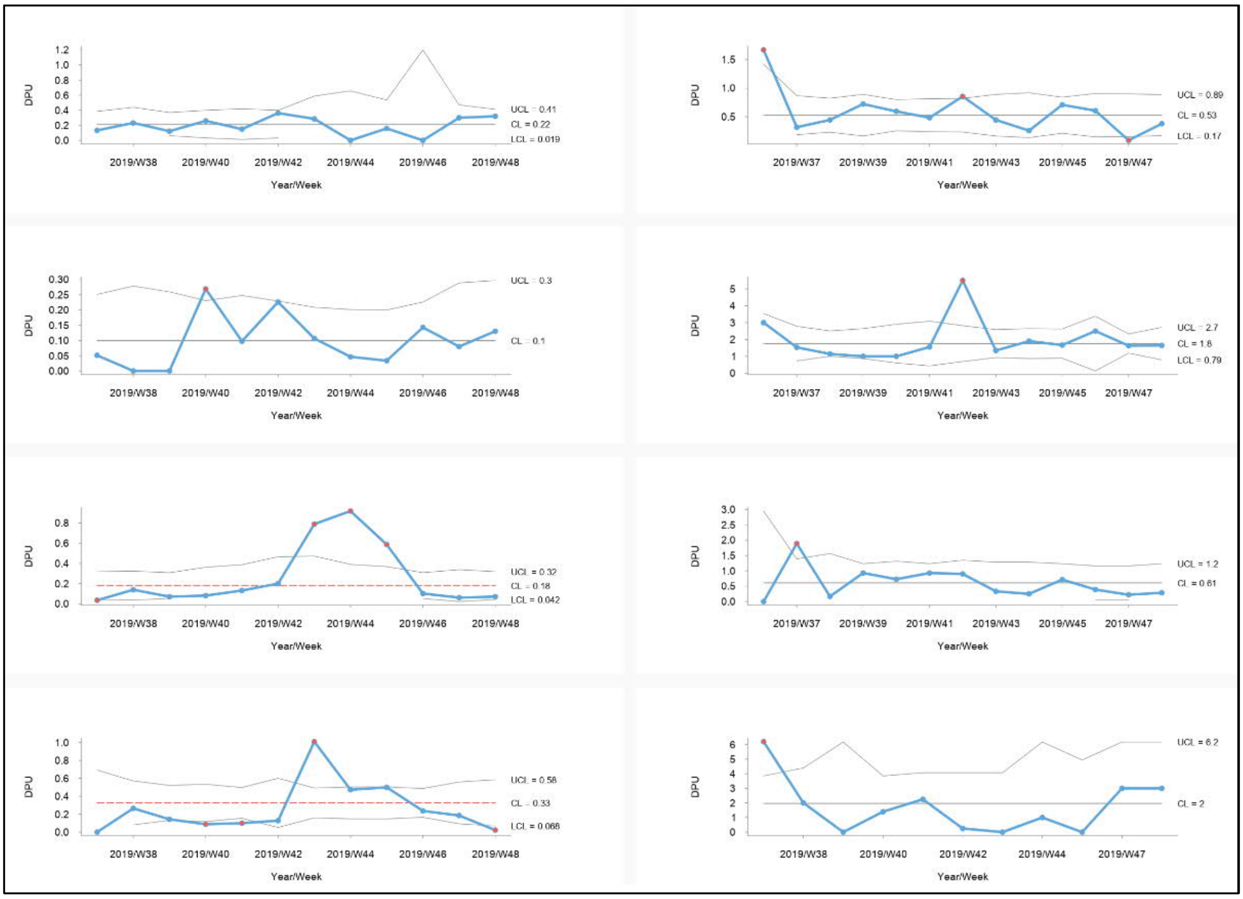

Figure 40. Dashboard for line-specific KPIs
Source: Author`s figure

Figure 41. Office screen for routine KPI meetings
Source: Author`s figure

Appendix 2. As-Is process for assembly instruction creation

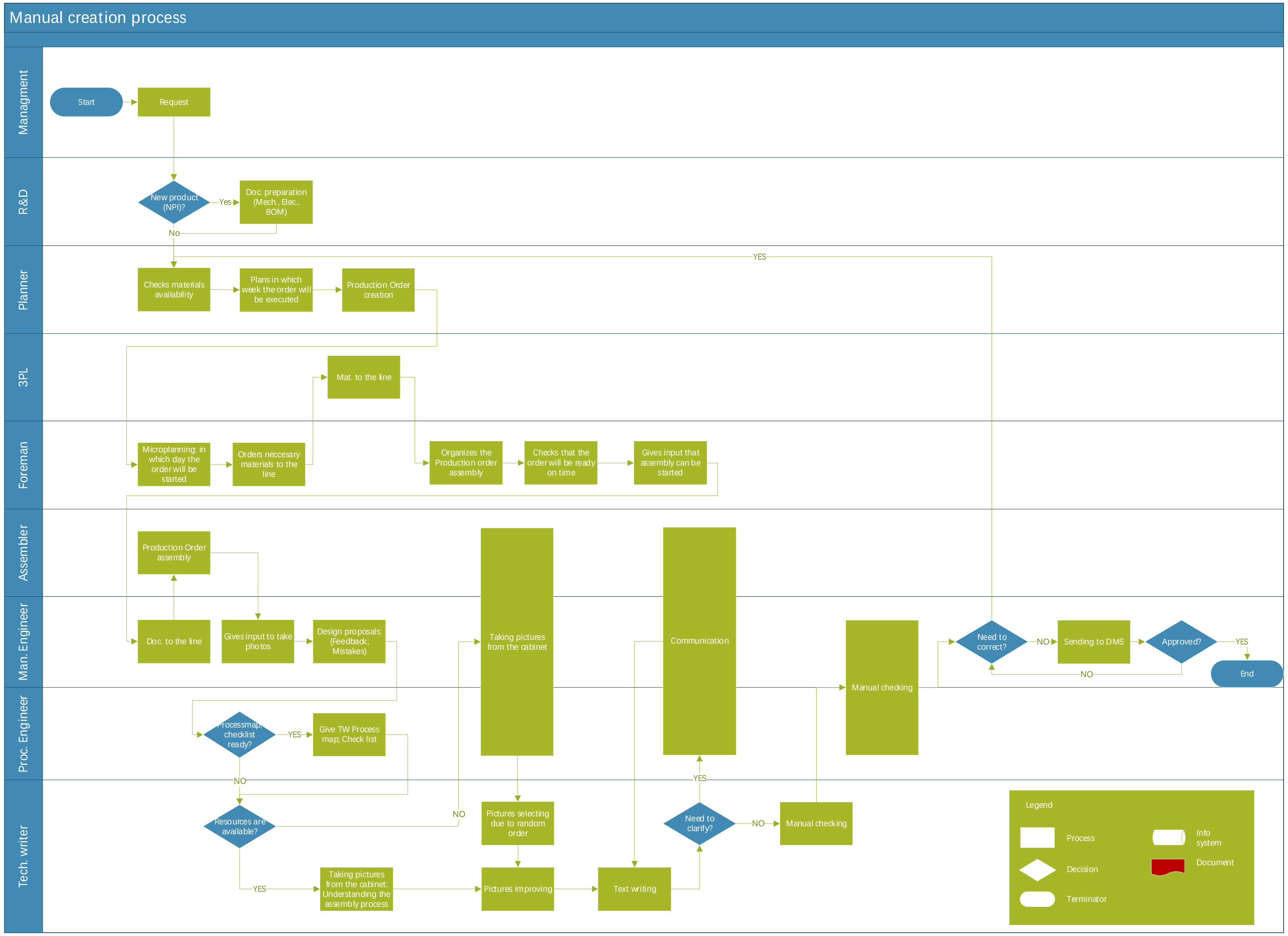

Figure 42. As-Is process for assembly instruction creation
Source: Author’s figure

Appendix 3. To-Be process for assembly instruction creation

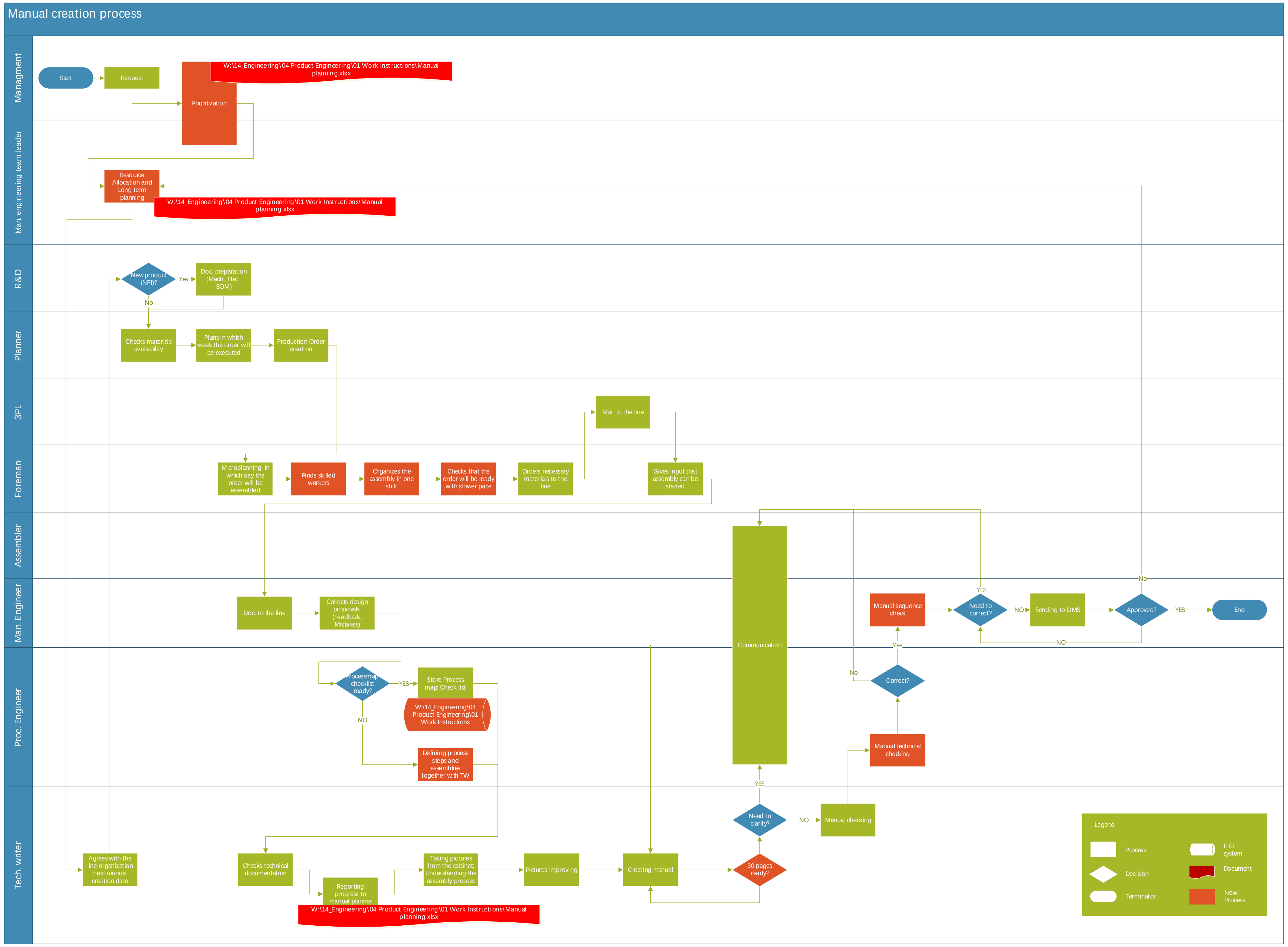

Figure 43. To-Be process for assembly instruction creation
Source: Author`s figure

Appendix 4. Cause and effect matrix

		Outputs important for customers			Other important parameters					
Causes / inputs	Solution	Effect on Time	Effect on Correct	Effect on Underst	Freq	Amount of time to fix	Necessary Investment	Score	Running	Cum
People have a different opinion on how to assemble the product	PcE will set the assembly sequence in place and assemblers must follow - if the process is not defined then PcE has to instruct the worker during assembly instruction creation phase	3,88	2,13	3,99	10	10	10	32956,607	9%	9%
Project manager presses too hard - multiple projects at the same time	Resource planning in Assembly Instruction Planner - TW are not set to multiple projects	3,88	2,13	3,99	8	10	10	26365,286	7%	16%
Technical writers have to hurry	Agree reasonable pace and make the process systematic	3,88	2,13	3,99	7	10	10	23069,625	6%	23%
No planning	Resource planning in Assembly Instruction Planner	3,88	2,13	3,99	10	7	10	23069,625	6%	29%
Technical writing process is not defined	Define the assembly instruction writing process that the organization agrees to follow	3,88	2,13	3,99	10	6	10	19773,964	5%	34%
No dedicated product for technical writers	Change the process so that the cabinet is assembled and then later assigned to an order	3,88	2,13	3,99	8	7	10	18455,7	5%	40%
Collaboration between the assembler and TW is not good because they have different targets	Change the process so that the assembler does not have "time limit"	3,88	2,13	3,99	8	7	10	18455,7	5%	45%
Technical writers do not attend the assembly process from the beginning until the end	Change the process so that TW can attend the assembly process from beginning till the end	3,88	2,13	3,99	8	7	10	18455,7	5%	50%
Unexperienced assemblers are assigned to help TW	Only highly experienced assemblers will be assigned to help assembly instruction creation	3,88	2,13	3,99	7	7	10	16148,737	4%	54%
Assembler does not follow process	PcE will set the assembly sequence in place and assemblers must follow - TW have to escalate this problem	3,10	1,70	3,99	10	7	10	14764,56	4%	58%
Responsibilities are not clear	Define responsibilities	3,88	1,70	3,19	10	7	10	14764,56	4%	62%
Lack of communication between project members	Clear and understandable process that the organization will follow	3,88	2,13	3,99	6	7	10	13841,775	4%	66%
Engineering changes during assembly instruction creation	Shorten the assembly instruction creation cycle and ECN will be implemented in a new cycle	3,10	2,13	3,99	5	10	10	13182,643	4%	70%
Missing information	Information will be gathered to assembly instruction folder- agree with PcE and ME teams	3,88	1,70	2,40	8	10	10	12655,337	3%	73%
No video availability	Organize Wi-Fi cameras	3,49	2,13	3,99	10	4	10	11864,379	3%	76%
Using pictures that were done by other people	Change the process so that TW can partake the full assembly and take pictures. If information is missing from pictures used in assembly instruction, then this information has to be communicated to TW who will take necessary pictures and update the assembly instruction.	3,88	2,13	3,99	5	7	10	11534,812	3%	80%
Coping old text from previous assembly instructions	Change the process so that TW can partake the full assembly and take pictures	3,88	1,70	3,99	5	8	10	10546,114	3%	82%
No information about the process	PcE has to partake the assembly instructions creation process when it is not in place	3,88	2,13	3,99	8	4	10	10546,114	3%	85%
Pictures partly taken from different cabinets with different options and variations	Dedicated product	3,88	1,70	3,99	5	7	10	9227,85	3%	88%
Using previous assembly instructions as template	Create one assembly instruction template that will be used as a template	3,88	0,85	3,99	5	10	10	6591,3214	2%	90%
Assemblers and foremen are not taking the assembly instruction creation seriously	Agree with the organization that assembly instruction creation is a teamwork effort not "one-man show"	3,88	1,06	2,40	8	7	10	5536,71	2%	91%

Using old or wrong technical documents	Technical documentation has to be checked and gathered by PcE and ME before the process starts	3,10	2,13	3,99	5	4	10	5273,0571	1%	93%
Using pictures from old / other assembly instructions	Not allowed, TW has to partake the whole assembly	3,88	0,85	3,99	5	7	10	4613,925	1%	94%
Different schedules (assembler and TW)	Dedicated team and product for assembly instruction creation	3,88	0,64	2,40	8	7	10	3322,026	1%	95%
Too many changes in the beginning / proto build	Dedicated cabinet and shorter cycle times	3,88	2,13	3,99	10	1	10	3295,6607	1%	96%
Low motivation (assembler)	Change the process so that the product assembly does not have time limit	3,88	1,06	2,40	8	4	10	3163,8343	1%	97%
Components are missing	Dedicated cabinet that will not be finished until all components are attached	3,88	2,13	3,19	9	1	10	2372,8757	1%	97%
Low experience	Trainings for TW	3,88	2,13	3,99	8	1	6	1581,9171	0%	98%
Poor documentation	Technical documentation has to be checked and gathered my PcE and ME before the process starts	3,88	2,13	2,40	4	2	10	1581,9171	0%	98%
Only 1 good camera for the group	Order a second camera	2,72	1,06	3,99	6	3	6	1245,7597	0%	98%
Checking time is not determined	Define the checking time for 30 pages	3,88	0,43	0,80	10	8	10	1054,6114	0%	99%
No training opportunities	Define necessary trainings for TW	3,88	0,64	2,79	8	3	6	996,6078	0%	99%
Bad environment for taking pictures	Order necessary lighting system and white background that can be used in dedicated assembly area	3,88	0,21	3,19	8	4	8	674,95131	0%	99%
Fasteners (length, size, type etc.) not defined or are changing	ME and PcE have to give input to TW when this information is missing. Should be on technical drawings	3,10	1,06	3,19	6	1	10	632,76686	0%	99%
No standard for assembly instruction (template / view)	Create one assembly instruction template that will be used as a template	1,94	0,21	1,60	10	7	10	461,3925	0%	100%
TW is not able to see work queue in SAP	Agree with Lauri Tamberg	2,33	0,43	0,40	10	9	10	355,93136	0%	100%
No measurement system for mistakes	Create a system	0,39	2,13	0,40	10	9	10	296,60946	0%	100%
No measurement system for time	Create a system	3,88	0,21	0,40	10	9	10	296,60946	0%	100%
No home office possibility	When the process is stable, reasonable pace agreed, then agree the possibility of home office	2,33	0,43	0,40	8	7	10	221,4684	0%	100%
Bad lightning in the factory	Order "spot" light for TW team	1,16	0,21	2,40	10	5	6	177,96568	0%	100%
Necessary measurement tools are missing	Order necessary tools for TW	0,78	0,43	0,80	7	6	8	88,58736	0%	100%
Bad light in the office	Order table lamps if necessary	1,55	0,64	1,20	10	1	6	71,186271	0%	100%
Nosy co-workers	Home office possibility?	1,55	0,64	1,20	10	1	5	59,321893	0%	100%
Defects	Dedicated product that does not have "time constraint"	1,94	0,43	2,00	3	1	10	49,434911	0%	100%
Dry air	Order device that is on the table and people can switch it on to make the air more humid	1,55	0,64	1,20	10	1	1	11,864379	0%	100%
Office is very cold	Warmer clothes	1,55	0,64	1,20	5	1	1	5,9321893	0%	100%
Slow PC	Order faster PCs	0,78	0,43	0,80	2	2	5	5,2730571	0%	100%

Table 10. Cause and Effect matrix
Source: Author`s table

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