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Addressing Quality Errors through Total Quality Management Strategies

Case Danfoss Drives Oy

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ABSTRACT:

The people of 21st century world is more aware of quality than ever. Therefore, it's essential for a company to prioritize quality to remain competitive. To achieve this competitiveness companies are required to set well-defined goals, cost efficiency, process improvements and continuously improve supply chains. However, these are not achieved without first-class quality management. This thesis investigated how implementing strategies and tools from popular quality management concept, Total Quality Management, could improve case company quality by reducing quality errors in certain production lines.

This thesis is an action research combining quantitative data analysis of quality errors with qualitative opinions from interviews with factory management and personnel. This approach allows comprehensive understanding of the issues the case company is having and creation of practical solutions that can be implemented "on-the-go". Already existing quality error data provided by the case company allowed us to categorize quality errors in multiple different fault categories, which were then further analyzed using popular TQM tools such as pareto charts and Cause-and-effect diagrams. Initial data analysis revealed the major causes for quality errors which were further analyzed with the help of Statistical Process Control.

After the analysis, recommendations were made for the case company on how to improve these identified pain-points. Main recommendations were to optimize the limits on the smart wrenches to ensure proper fastening of screws, establishing a Total Productive Maintenance program for tester machinery to prevent the need of investing to new machinery and to create clear testing limits for system discharge time and electrical breakdown voltage limits.

The findings highlight the importance of continuous improvement, employee involvement, and leadership commitment in promoting effective quality management. This thesis underlines that while the implementation of TQM strategies can lead to significant quality improvements, the effectiveness of these strategies requires ongoing monitoring and involvement. This thesis also indicates that with proper training and a systematic approach, TQM tactics can be universally applied to anywhere to enhance quality performance.

KEYWORDS: Total Quality Management, Continuous Improvement, Quality control

VAASAN YLIOPISTO**Tekniikan ja innovaatiojohtamisen akateeminen yksikkö**

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2000-luvun ihmiset ovat laatu-tietoisempia kuin koskaan. Siksi yritysten kannalta on välttämätöntä asettaa laatu etusijalle säilyttääkseen kilpailukykynsä. Sen saavuttamiseksi yritysten on asetettava selkeät tavoitteet, parannettava kustannustehokkuutta, tehostaa prosesseja ja kehitettävä toimitusketjujaan jatkuvasti. Näitä ei kuitenkaan pystytä saavuttamaan ilman ensiluokkaista laatujohtamista. Tässä tutkielmassa tutkittiin kuinka suositun laatujohtamiskonseptin, Total Quality Managementin (TQM), strategioita ja työkaluja hyödyntämällä voidaan vähentää laatu-
virheitä tietyillä tuotantolinjoilla ja parantaa case-yrityksen laatua.

Tutkielma toteutettiin toimintatutkimuksena, jossa yhdistettiin laatu-
virheiden määrällinen analyysi ja tehtaan johdon ja henkilöstön laadulliset haastattelut. Tämä tutkimustapa tarjosi kokonaisvaltaisen ymmärryksen kohdeyrityksen ongelmista sekä mahdollisesti käytännön ratkaisuiden luomisen lennosta. Yrityksen tarjoama laatu-
virhedata luokiteltiin erilaisiin vikakategorioihin, joita edelleen analysoitiin suosittujen TQM-työkalujen, kuten Pareto-kaavioiden ja syy-seuraus-
kaavioiden avulla. Alustava analyysi paljasti merkittävimmät laatu-
virheiden syyt, joita tutkittiin tarkemmin tilastollisen prosessinhallinnan (SPC) avulla.

Analyysin pohjalta case-yritykselle annettiin suosituksia tunnistettujen ongelmakohtien parantamiseksi. Keskeiset suositukset olivat älyvääntimien kiristysrajojen optimointi, jotta ruuvien tarpeen mukainen kiinnitys varmistetaan, kokonaisvaltaisen kunnossapito-ohjelman (Total Productive Maintenance) käyttöönotto testauslaitteille uusien laitteiden hankintatarpeen vähentämiseksi sekä selkeiden testausrajojen määrittäminen taajuusmuuttajien sähkön purkautusmisajalle ja läpilyöntijännitteen rajoille.

Tulokset korostavat jatkuvan parantamisen, työntekijöiden osallistamisen ja johdon sitoutumisen merkitystä tehokkaan laatujohtamisen edistämiseksi. Tutkielma osoittaa, että vaikka TQM-strategian toteuttaminen voi johtaa merkittäviin parannuksiin laadussa, niiden tehokkuus edellyttää jatkuvaa seurantaa, sitoutumista, ja osallistamista. Lisäksi tutkielma osoittaa, että oikeanlaisella koulutuksella ja lähestymistavalla TQM-menetelmiä voidaan soveltaa universaalisti laadun parantamiseksi melkein missä tahansa.

AVAINSANAT: Total Quality Management, Continuous Improvement, Quality control

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1 Introduction

In the 21st century, ensuring quality is paramount for organizational survival. Satisfying modern day customers and stakeholders requires effective goal strategies, cost optimization, process improvement, and continuously improving supply chains. Neglecting quality can lead to disastrous outcomes, boosted by people's immediate access to information. In this era, quality isn't just a competitive advantage; it's a strategic imperative for sustainable success. It can be said that quality equals customer satisfaction. (Oakland, Oakland, & Turner, 2020, p. 3-4)

But quality cannot be built overnight, Takeuchi and Quelch (1983) notes out that it takes time and big effort to gain customer's trust, and it can't be done simply by promoting the quality of the product. Customers need to feel the quality by themselves. Otherwise promoting quality when there is none will destroy customers' trust. They propose that the quality needs to be built within their products or services, which means commitment from top-to-bottom to eliminate errors at every step of the process.

But what is even quality? Tervonen (2001) explains that usually the word "quality" is associated to a product and its technical features. He even claims that the word "quality" is overused in marketing up to a point it has lost its meaning. He concludes that usually "quality" is perceived as the synonym for "good" and a product or a service is considered to be good if it fulfills the customer's needs, expectations, and requirements.

Paul Lillrank explains in his book "Laatumaa" (1990, p. 41) that quality can have six different dimensions (production related, product related, value related, competition related, customer related, environmentally related) which are not exclusive to each other which is why quality management is needed to balance these out and find the best possible combination of these perspectives.

One popular approach to quality management is *Total Quality Management*-approach, also called TQM. TQM is founded on six basic concepts.

1. Organizational support from top-to-bottom
2. Strong focus on both internal and external customers
3. The entire workforce is efficiently involved and utilized.
4. Focus on the continuous improvement.
5. Suppliers should be treated as partners.
6. Establishing KPI's for the processes

(Naidu, Babu, & Rajendra, 2006)

One of the concepts within TQM is especially important when trying to compete in the business environments of rapidly developed technology and increased dynamics, and it is continuous improvement. According to the Institute of Quality Assurance, continuous improvement is described as an ongoing process of gradual change aimed at enhancing the effectiveness of an organization in achieving its policies and objectives. Continuous improvement is not limited purely to quality initiatives. Improving business strategies and results, and the relationships between customers, employees and suppliers can be considered to be part of continuous improvement. Even though the idea of continuous improvement might seem simple, only a handful of companies have successfully managed continuous improvement in the long run. Most companies reduce the effort put to continuous improvement initiatives once some initiatives have been successfully implemented even though the idea of this concept is to constantly try to improve processes, even after implementations are in place. (Marutschke, 2012)

1.1 Case company and background of the study

Danfoss Drives specializes in a key product called frequency converter, often referred to as an AC drive or simply as a drive. Its primary role is to control the frequency of electricity, commonly used for controlling the speed of electric motors. Proper motor speed control not only improves process management but also reduces energy consumption and can even efficiently generate electricity. In addition, it can extend the lifespan of motors by reducing mechanical strain and optimize processes for electric motor-dependent applications. Given that over half of the world's electrical energy is consumed by

electric motors, it's likely that you'll encounter a drive-supported electrical application daily. A significant portion, around 75%, of drives are employed in pumps, fans, and compressors, with common applications including HVAC systems and elevators. Danfoss suggests that employing drives in suitable applications worldwide could lead to a 10% reduction in global energy consumption. (Danfoss, 2023)

In 2018, the global market for AC drives was valued at \$10.39 billion, with ABB leading the market share. Other notable players include Schneider Electric, Siemens, Fuji Electric, and Rockwell Automation. Factors such as environmental consciousness, population growth, and urbanization, particularly benefit the AC drive market due to its pivotal role in the industrial sector, providing flexible and energy-efficient solutions that greatly benefit manufacturing and processing industries. Predictions estimated that the AC drive market will reach \$15 billion by 2026 (Fortune Business Insights, 2019), but it surpassed \$16 billion already in 2022 and is expected to continue growing at a yearly rate of 4.7% from 2023 to 2032. (Global Market Insights, 2023) This growth trend is already evident at Danfoss Drives' Vaasa Factory, which aimed for record-breaking results in 2023. (Ilkka-Pohjalainen, 2023)

As the market for AC drives rapidly expands, manufacturers must scale up their operations and enhance productivity. Ensuring the implementation and maintenance of robust quality management systems within these companies is vital to support this growth effectively.

1.2 Research questions, Purpose, Objectives and limitations

This thesis aims to improve case company Danfoss Drives Vaasa Factory's quality by reducing the amount of quality errors occurred in the production by using TQM approach. The proposed research question is *"How can Total Quality Management (TQM) tactics be effectively utilized to address and mitigate quality errors in quality control processes?"* Research question is supported by three sub research questions.

- “What are the factors driving quality errors in frequency converter production, and how are they related to the manufacturing process?”
- How can Total Quality Management (TQM) framework/tactics be improved and implemented to mitigate quality errors in frequency converter production, considering the complexities of the manufacturing process?
- How effective are the implemented Total Quality Management (TQM) strategies in decreasing quality errors in frequency converter manufacturing?

By achieving the goal of the thesis, the case company can achieve better process flow and reduce operational costs, leading to improved customer satisfaction. The goal is achieved by achieving following objectives:

1. Identifying key factors contributing to quality errors in the production of frequency converters through comprehensive analysis.
2. Developing and implementing TQM strategies tailored to the specific needs of the production process to reduce the occurrence of quality errors.
3. Evaluating the effectiveness of the implemented TQM tactics in decreasing the amount of quality errors in the production of frequency converters and assessing improvements in quality control processes and overall product quality.

This thesis is limited to covering only the case company’s Vaasa factory and its products and more specifically high power drives.

1.3 Structure of the study

This thesis is consisted of four main chapters in addition to the introduction, which are literature review, methodology, results and conclusions and discussions. These chapters are then divided into subchapters. Literature review will include three subchapters that are *What is quality?*, *Total Quality Management* and *Quality Standards*.

The first chapter of literature review, *What is quality?* Is further divided into three subchapters, *History of Quality*, *Quality in Japan* and *Quality in the 21st century*. As one of the objectives of this thesis is to reduce the amount of quality errors, it is important to

first understand what quality is and what it is not as well as how the quality has evolved since its inception all the way to the present day.

The chapter about Total Quality Management is divided into five subchapters, *History of TQM, Continuous Improvement, TQM Tools and Techniques, Evaluating the effectiveness of TQM Strategies* and *Criticism and Challenges of TQM Implementation*. The concept of TQM was chosen to this thesis because the case company's quality management is influenced by this concept and the aim is to achieve this study's objectives by using tools and techniques that TQM concept includes.

The final chapter of literature review *Quality Standards* will handle international quality standards and is important for the study as the case company's processes are recognized by multiple different standards.

Following literature review, the methodology of this thesis is presented. This chapter will discuss the selected research method, quantitative method, thoroughly and the case study is presented in detail as well as how the data was collected and analyzed.

The fourth chapter of this thesis will present the results of the study. The chapter will introduce what current quality tools the case company has already implemented within their processes as well as recommendations for the production process based on this study. In the final chapter, *Conclusion and Discussions* findings on the research questions are presented. Lastly, in the discussion part of the chapter, future research ideas and improvement ideas are presented.

2 Literature review

Boell and Cecez-Kecmanovic (2010) explain that the importance of literature review lies within the researcher getting deeper understanding of the research problem the more the literature review will progress. This will enable the researcher to identify the most relevant and pressing questions about the topic of the study. They continue to emphasize the importance of literature review for any research project, and they highlight the support given by the librarians to academics in their literature hunt. They also claim it might be difficult for unexperienced researchers to understand the process of literature review. In other words, as being important part of any research project, it is not easy to conduct a thorough literature review, even for professional academics. Booth et al. (2012) also explains that besides providing deeper understanding of the research topic, literature review will also provide information about previously done research about the same topic.

2.1 What is quality?

Merriam-Webster Dictionary defines “Quality” as an *“inherent feature”, a “degree of excellence”, a “distinguishing attribute”* or as *“being of high quality”* (Merriam-Webster, 2024) These definitions concur to what Lillrank (1990, p. 39) explains, quality is a good word. It gives the perception of value, and it is generally accepted ideal under which is easy to motivate customers and workers. Nobody wants to buy or produce low quality products or services.

But in reality, “Quality” as a concept can be hard to perceive as it is relative and has multiple different dimensions. There also isn’t one clear definition of what quality is, as quality is always subject to comparison. We compare achieved values to values we set as goals, structure to performance and the need to fulfilment. The closer these are to each other, the better the quality is. As quality might be difficult to comprehend, it’s always important to define what quality is when thinking about improving the quality of any product, process, or service. (Lillrank, 1998, p. 19)

Even generally acclaimed “quality gurus” have different definitions for quality. Ghobadian & Speller (1994) summarized how the gurus define quality:

William Edwards Deming defines quality as *“satisfying the customer, not merely to meet his expectations, but to exceed them”*. In other words, Deming focuses on the customer’s needs, over the customer’s demands. Deming has also emphasized staying ahead of the customer to predict the needs and demands.

Joseph M. Juran defines quality as *“fitness for purpose or use”*, which means that the customer is the judge whether the quality is good or bad. He also emphasized that you shouldn’t “over satisfy” your customer, which in his opinion is waste of resources.

Philip B. Crosby defines quality as *“conformance to requirements”* making quality easy to measure. It either fills the given specifications or not. Crosby is also known for his claim that *“quality is free”*, meaning that investments in quality will eventually reduce costs and therefore increase profitability.

Armand V. Feigenbaum defines quality as the *“total composite product and service characteristics of marketing, engineering, manufacture and maintenance through which the product and service in use will meet the expectations of the customer.”* In other words, Feigenbaum recognizes that quality has multiple different dimensions and that trade-offs should be made between the dimensions to achieve the best possible product.

John M. Grocock defines quality as *“the quality of a product is the degree of conformance of all relevant features and characteristics of the product to all of the aspects of a customer’s need, limited by the price and delivery he or she will accept”*, which can be said to include aspects from both Crosbys *“conformance to requirements”* and Juran’s *“fitness for purpose”*. Grocock’s definition is value-led, and he openly acknowledges the trade-off between a product's quality and its price.

Genichi Taguchi defines quality as the *“loss imparted to the society from the time a product is shipped”*. He emphasized that quality should be measured in terms of customer satisfaction and the reduction of variability in products and processes. Taguchi's approach focuses on the idea that improving quality leads to cost reduction and increased customer satisfaction over the product's entire lifecycle, rather than just meeting specifications at the manufacturing stage.

Kaoru Ishikawa defines quality as the *“development, design, production and service of a product that is most economical, most useful, and always satisfactory to the customer.”* He claims that all employees should be trained to use the seven basic tools of quality: process flow charting, check sheets, histograms, pareto analysis, cause-and-effect diagram, scatter diagram, control charts.

As said in the introduction and what is perceived from the definitions of quality by the gurus, quality as a concept is multidimensional. Lillrank (1990, p. 41-51) categorizes quality in six different dimensions:

1. **Production related:** Emphasizing the flawlessness of production. Products are made according to given standard and the standard dictates whether product is nonconforming or not. Nonconforming products are tried to be identified already in the production process. Measured by nonconforming units per batch of products.
2. **Product related:** Emphasizing that it is the product's features that support the intended use that dictate the quality of the product. For example, the lifespan of a light bulb. Generally, it is thought that the longer the lifespan, the higher quality the light bulb is. But what if a customer values the tone of the light over the lifespan? So, it's not always easy to know which features to focus on.

3. **Value related:** Emphasizes the relationship of so-called quality and the price of the product. A product is considered to be high quality if it provides the best price-quality ratio, ideally the product is at the same time the best, and the cheapest. It's important to estimate the added value of the product in relation to purchasing power of the customer. Therefore, it's important to identify different price categories and a comparison between products should be made within these categories.
4. **Competition related:** Emphasizing that the product should be precisely as good as the competitor's product is. Adding more would be considered as waste of resources also known as "overquality". This involves a risk of diminishing product development.
5. **Customer related:** Emphasizing the ability to fulfill customers' needs. As previously mentioned, according to quality guru Joseph Juran "*Quality is fitness for use*". The key is to identify what actually is the customers' needs, which can be difficult. Sometimes a high-end expensive product does not fulfill the general population's needs and therefore is not considered as a quality product. Customer related quality has become the most important dimension of quality as a result of free markets and the increase of living standards.
6. **Environmentally related:** Emphasizing product's overall impact on society and nature and the need of uniting the needs of customer, society, and nature. The customer is not necessarily thinking about societies and nature's needs when trying to fulfill its own needs and therefore in the modern days, there are certain environmental standards and measures that are monitored.

The many different dimensions of quality leads to organizations' need to find the best possible mix of these dimensions to provide the company with the competitive

advantage. It's important to organize companywide quality trainings to make sure that all people from marketing to engineers will have the same perception of quality and to understand each other's quality needs. (Lillrank, 1990, p. 41-51)

What definition and dimension of "Quality" is used in this thesis? As the quality errors in Danfoss Drives that are scope of this thesis are always identified during testing, it could be suggested that Crosby's definition "*conformance to requirements*" would be the most suitable definition for quality for this thesis. The testing is straightforward, either the drive passes, or it doesn't, and it doesn't take any other factors into account. Also, Crosby's statement "*quality is free*" could be also applied as the investment made to reduce quality errors within production lines should eventually pay the investment back by reducing the amount of labor hours used and rework needed for drives that failed the test. As for the dimension of quality, this thesis clearly handles quality from a production related dimension.

2.1.1 History of Quality

Although quality thinking has gained popularity only from the 20th century quality the concept is not new. Quality has always been around. Humans as a race exist only because the quality of our environment has been good enough. The air we breathed needed to be just right, the temperature we lived on needed to be between quite narrow limits and the nutrients in our food needed to be good enough for humans as a race to develop to where we are now. (Juran, 1998, p. 35.1) Gitlow et al. (1995) refers to the Code of Hammurabi, Item 229, which states: "*If a builder has built a house and his work is not strong, and the house falls in and kills the householder, that builder shall be slain*", which indicates that quality thinking has been around as far as from 2000 BC. The basic concept of quality has still remained the same.

Garvin (1998, p. 3) explains that modern quality thinking has not evolved overnight, but rather gradually over a century's time period. He continues to explain that discoveries

regarding quality in United States can be divided into four separate “quality eras” : *inspection, statistical quality control, quality assurance and strategic quality management*.

The inspection era goes back to the 18th and 19th century where mass production did not exist yet, and almost all manufacturing was done by hand by skilled craftsmen and artisans in small volumes. Quality inspection was only done informally, and good quality products were usually what could be expected from skilled artisans and craftsmen. Only when the need of firearms by a large number of quantity arose, started the manufacturing industry focus on starting mass production with the help of specially designed machinery that were able to produce interchangeable parts with breakthrough happening in early 1800s when rational jigs and fixtures were developed. With the help of these tools, manufacturing products with equal quality became easier. In addition to helping the manufacturing process, inspection became easier as well, when different kinds of gauging systems were developed and started to be used at the final inspection of the product. Quality control did not evolve further for several years. (Garvin, 1998, p. 3-5.)

According to Garvin (1998, p. 6-12) the era of statistical quality control began on 1931 when W.A. Shewhart published his publication *Economic Control of Quality of Manufactured Product* which gave first scientific foundations on quality control. Many quality control we use even today, are linked to Shewhart’s publication. Garvin explains that Shewhart was first to recognize that variability would be always present in the manufacturing process and the idea of removing variability needed to be changed to how to control the variability and that this could be done with basic principles of probability and statistics. Based on this realization, Shewhart concluded that a phenomenon is under control if it’s possible to predict within limits, how the phenomenon will vary in the future. Shewhart continued to develop simple statistical tools to determine these limits which resulted to a basic process control chart that is still one of the most powerful tools used by quality professionals.

Garvin (1998, p. 6-12) continues to explain that although the statistical tools Shewhart developed were proven to be highly effective in the company he worked for, Bell Telephone Laboratory, the tools did not gain popularity outside of Bell. Only when the World War II erupted, statistical quality control became a necessity to produce high volumes of munition and equipment.

After the World War II, quality control was well known among industries, but still mainly focused on the production processes. Development of quality management stalled over a decade, until late 1950s and early 1960s when several important publications on the matter were published, which started the next quality era, quality assurance. The era of quality assurance meant that quality was not only thought on the factory floor anymore, but also in the management as multiple different quality tools outside of statistics were developed, the costs of quality, total quality control, reliability engineering and zero defects (Garvin 1998, p. 12)

Garvin (1998, p.12-13) explains, that until the 1950s there were no established way to estimate the cost of quality, and it was only considered that defects were expensive. This made it hard for management to decide whether it would be wise to invest in improving the quality. Garvin continues to explain that Joseph Juran took a stand on this in his first edition of Quality Control Handbook in 1951. Juran noted that the costs associated with reaching a certain quality level can be categorized into avoidable and unavoidable costs. Avoidable costs included expenses from defects and product failures, wasted materials, labor hours for rework and repair, complaint handling, and financial losses from dissatisfied customers. Juran considered failure costs as "gold in the mine," as by investing in quality improvement, those could be heavily reduced. Now, managers were able to decide how much should be invested in quality improvement.

Garvin (1998, p. 13-15) explains that in 1956 Arman Feigenbaum proposed "total quality control" principle on how to think about quality. Feigenbaum stated that high-quality products cannot be produced if quality is only thought about in the factory floor. Instead, it needed to be thought throughout the supply chain, from the product design to the

moment the product is delivered to the customer. This meant that basically all departments within the company needed to be involved in the quality in some way, which all together formed a closed quality system. Because of this, Garvin explains that together with Juran, Feigenbaum proposed that a quality professional needed more competence than just statistical knowledge to succeed in this new quality system as it now involved departments all around the company such as new product development, supplier management and customer service. Feigenbaum and Juran proposed that to manage this new quality system a new function called quality control engineering needed to be formed. This new function would oversee the quality planning and activities within different departments as well as establish standards and measurements for quality.

Garvin (1998, p. 16-20) concluded that the last major development of quality assurance era was *zero defects* which saw its light in Martin Company, an aircraft and aerospace manufacturing company from who the US Army had ordered to manufacture Pershing missiles. The problem for these missiles was that to achieve high-quality outcome, extensive inspection was needed. Eventually with the help of these extensive inspections and testing and also setting inducements for the workers if they reach certain defect rate, a missile with zero defects was delivered for the US Army in 1961. This proved that making a missile with zero defects was possible and therefore Martin Company's general manager agreed to deliver another Pershing missile for the US Army a month quicker than scheduled. In addition, it usually took 90 days to get the missile operational, from the day of the delivery, but Martin Company's general promised to have the missile fully operational already in ten days after the delivery. This was a huge task for Martin Company, which required everybody's contribution to minimize errors as there wasn't any time for the usual inspection and repairs. But still, Martin Company was able to deliver operational missile in two months. Martin Company learned from this challenge that usually companies are focusing on acquiring knowledge and investing in proper facilities, but they oversee the lack of attention. Motivating workers is the last step achieving perfection. With this realization, zero defect program was created which emphasized motivation and awareness and which only accepted zero defects as the quality standard.

Garvin (1998, p.21) continues to explain that although it was a common belief that quality as a concept was at its peak when quality assurance was developed but when CEO's and presidents started to notice that high quality could be linked directly to profitability and therefore could be used as an aggressive weapon of competitiveness, it can be seen that the era of *strategic quality management* had started. Juran and Gryna (1993, p. 115) explained Strategic Quality Management or SQM as a "*process of establishing long range quality goals and defining the approach to meeting these goals. SQM is developed, implemented, and led by upper management.*" Garvin (1998, p. 22) explained that the upper management's interest in quality did not evolve overnight, but over a longer period of time, due to the rising global competition and governments interest to reduce safety hazards. The latter caused many companies to issue expensive recalls for their faulty products and rising amount of lawsuits for product liability, which rose at an annual rate of 28% between 1974 and 1981. Top management quickly learned that high quality had become a necessity to compete.

Juran and Gryna (1993, p.116) explained that an approach to strategic quality management should focus on four basic elements. Focusing on the customer's needs identifies organization's strengths, weaknesses, opportunities and threats. Based on the SWOT-analysis specific goals can be identified. Secondly, upper management needs to be invested to develop quality goals and strategies. Thirdly, transforming multi-year strategies to annual business plans. And finally, having the whole organization implement these plans and not just the quality departments.

Table 1 illustrates how quality evolved from inspection to SQM.

Identifying Characteristics	Inspection	Statistical Quality Control	Quality Assurance	Strategic Quality Management
Primary concern	Detection	Control	Coordination	Strategic impact
View of quality	A problem to be solved	A problem to be solved	A problem to be solved, but one that is attacked proactively	A competitive opportunity
Emphasis	Product uniformity	Product uniformity with reduced inspection	The entire production chain, from design to market, and the contribution of all functional groups, especially designers, to preventing quality failures	The market and consumer needs
Methods	Gauging and measurement	Statistical tools and techniques	Programs and systems	Strategic planning, goal setting, and mobilizing the organization
Role of quality professionals	Inspection, sorting, counting, and grading	Troubleshooting and the application of statistical methods	Quality measurement, quality planning, and program design	Goal setting, education and training, consultative work with other departments, and program design
Who has responsibility for quality	The inspection department	The manufacturing and engineering departments	All departments, although top management is only peripherally involved in designing, planning, and executing quality policies	Everyone in the organization, with top management exercising strong leadership
Orientation and approach	"Inspects in" quality	"Controls in" quality	"Builds in" quality	"Manages in" quality

Table 1. Stage of the Quality Movement (Garvin, 1998, p. 19)

2.1.2 Quality in Japan

History of quality cannot be explained without introducing how the quality management evolved in Japan. (Fisher, 2009) But it was not until the 1980's when the high quality of Japanese products was discovered, which shocked the American managers. Garvin (1998, p.23) explained how Hewlett-Packard's management were shocked how high quality RAM chips Japanese were able to produce. After inspecting 300 000 RAM chips, the quality difference was clear. Three Japanese manufacturers were able to achieve zero defects during the incoming inspections whereas three American manufacturer's defect rate varied from 0.11 to 0.19 percent. And even after 1000 hours of use Japanese chips only had a failure rate of between 0.010 and 0.019 whereas American's chips failure rate was between 0.059 and 0.276 percent. The high quality of Japanese chips aimed their way to achieve large market shares in chip markets, only in a few years. Japanese companies were doing something right, what the Americans were not doing yet.

Ishikawa (1985, p. 15) dates the first steps of Japanese quality control back to May 1946 where Japan was crippled due to the loss of the second World War. All major industries were destroyed and there was a lack of food, clothing and housing. When the US occupational forces noticed that the Japanese telephone system was not reliable enough to be used as a tool of communication, they introduced Japanese telecommunication to the modern quality control and began to educate the industry with Shewhart's statistical quality control, which was already a standard practice in the USA at the time. Lessons were learned within the telecommunication industry and statistical quality control soon spread to other industries.

According to Deming (1994, p. 2-3) the actual "quality awakening" in Japan happened in soon after this in 1948 and 1949 when some proactive Japanese engineers observed that improving quality leads to improved productivity as Shewhart already stated in his book "*Economic Control of Quality of Manufactured Product*" in 1931.

At the same time Edward Deming, a recognized scholar in the field of quality sampling, was frustrated as his thoughts on correctly identifying and elimination the most important sources of variation would be the best way to improve quality was not appreciated in the USA even though his advices on sampling and statistical control greatly benefited the US weapons industry and the American Bureau of Census during the second World War. So, he then decided to educate those, who would appreciate his thoughts, the Japanese. He did two trips to Japan in 1946 and 1948 before holding an 8-day seminar about statistical quality control. (Logothetis, 1994, p. 27-28) (Ishikawa, 1985, p. 17) Ishikawa continues to explain that the seminar had three main topics.

1. How to use so-called “Deming cycle, more familiarly called Plan, Do, Check, Action-cycle (PDCA-cycle, Figure 1).
2. The importance of understanding variance in statistics
3. Process control using control charts and how to use them

Seminar was well liked and benefited all the participants.

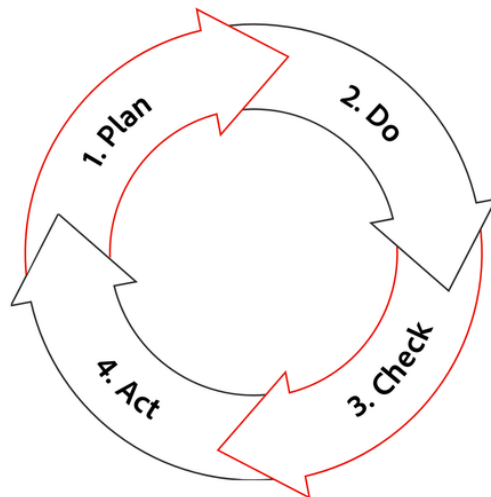


Figure 1. PDCA-cycle

After Deming's visit to Japan in 1950, a simple flow chart, also called "Deming's value chain" (Figure 1) which was, according to Deming (1994, p.3), presented in every top management meeting from July 1950 onwards. Management in Japanese companies were quick to adopt this flow chart which led to one single goal within the companies, quality.

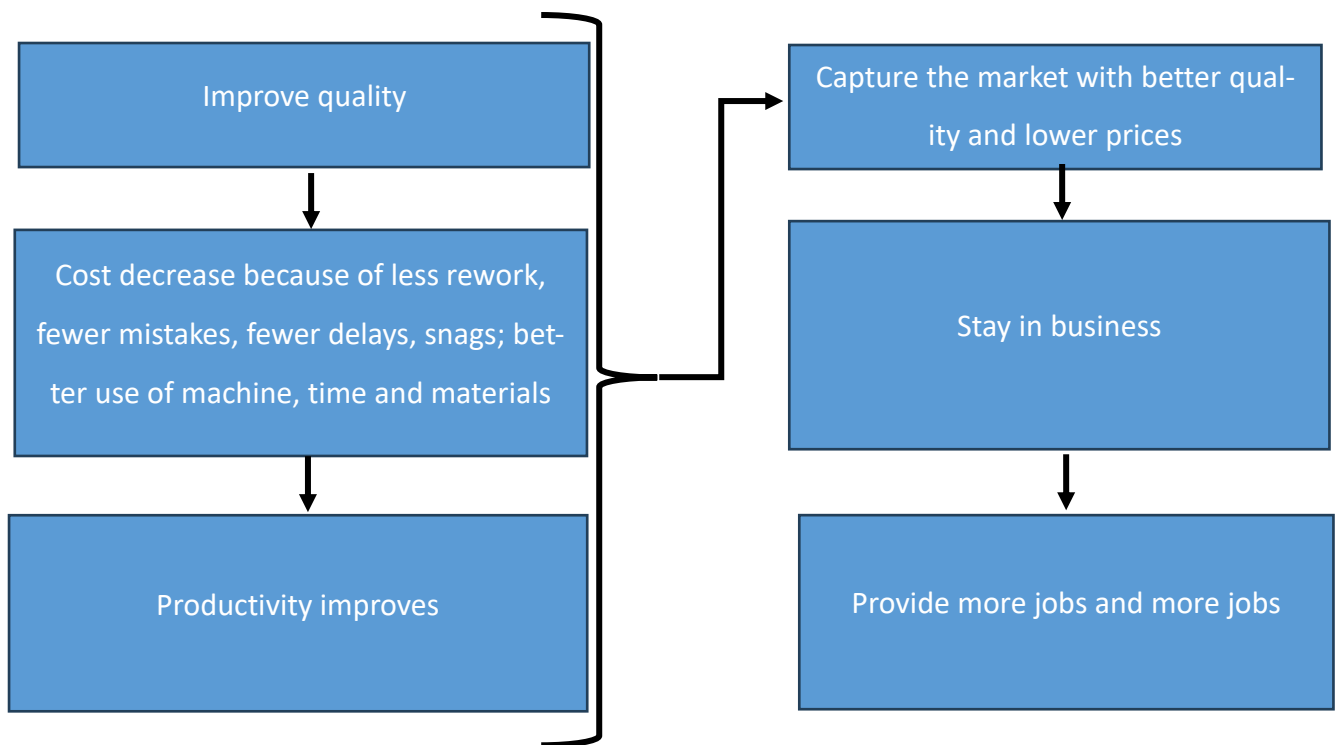


Figure 2. "Deming's value chain" (Deming, 1994, p. 3)

It's an understatement to say that Deming had a big impact on the evolvement of quality in Japan. Logothesis (1994, p. 13) even claims that Deming is *the* reason for Japan's industrial success after 1950. Deming also gave the name for the highest industrial award in Japan, The Deming Prize, which given every year to the company or person who has done the most to improve statistical techniques and their better use in design, research and development, manufacturing, or service.

Implementing modern quality tools within Japanese industries was not painless though. Ishikawa (1985, p. 18) points out multiple different “pain-points” industries struggled with. Japanese workers were experienced on their fields and there was traditional resistance to change as the experienced workers would rather trust on their experience than statistical methods. Japanese companies also lacked set standards and struggled to set them due to again, resistance to change. Management was confident that they could run the factory without standards as they had until that moment. Companies were also lacking data to be used with statistical methods and when data was tried to be collected, it was not collected properly resulting in data that could not be used and finally the devices used to collect the data were destroyed by the workers as they believed devices were installed purely to monitor the worker’s performances. Ishikawa (1985, p. 18-19) continues to explain that these challenges were also educational. It was learned that even though statistical methods were effective, those were still overly emphasized. Sophisticated statistical methods were used in processes where simpler methods would have been enough. Secondly, standardization had problems. Standards were set but were not used as for many standards felt as a way to bind people. Lastly, quality control and statistical methods were still only used and known by the engineers and workers within the factories and middle to top management didn’t show much interest in quality movement. Popular misconception was that establishing quality control would cost money.

Ishikawa (1985, p. 19-20) explains that to tackle these challenges another “quality guru” Joseph M. Juran came to Japan in 1954 to give seminars to middle to top management about their roles in quality control. Juran was able to educate the management that for statistical methods to be as effective as possible, management needed to be involved as well. Juran eventually succeeded and his visit marked a shift in Japan's quality control from focusing mainly on factory technology to a broader concern for overall management. The shift was needed as statistical quality control has its limits if it only involves engineers.

Ishikawa (1985, p. 37) explains that by the of 1960's Japanese quality control had already surpassed its western counterparts and had six distinct characteristics:

1. Whole organization participated in quality control
2. Quality control trainings and awarenesses
3. Quality control circle activities
4. Quality control audits
5. Use of statistical methods
6. Quality control was promoted nationwide

The successful implementation of quality control and management was also reflected in the economic growth of Japan. Japan's trade deficit in 1980 was 10 billion dollars, but already next year deficit was changed to surplus of 8 billion dollars, and it increased by tenfold by the year 1987 when it was 77 billion dollars. (Lillrank, 1990, p. 12) This affected also common people as Japan's standard of living in the mid 1980's was already ranked at the same level with other developed countries. (Britannica, 2024) Lillrank (1990, p. 15) explains that Japan's mains export drivers in the end of 1980's were Toyota, Mazda, Nissan and Honda.

2.1.2.1 Toyota and Lean

Toyota being number one exporter of Japan in the end of 1980's didn't come easy. Taiichi (1982) explained that after the Japan's defeat in the Second World War Japan's productivity was only one eight of what USA was able to produce. The day that the war ended, 15th of August 1945, the President of Toyota, Kiichiro Toyoda stated to his workers that *"Catch up with America in three years. Otherwise, the Japanese auto industry will never stand on its own"*. Fujimoto (2012) reveals that the goal was unrealistic, and it took almost 15 years before Toyota were as productive as for example Ford Company. Ohno (1982) explained Toyoda did realize that USA did not have ten times more physical power than Japan, but that gap was caused by too much waste in the Japanese processes. Eliminating waste in the processes could improve productivity by ten-fold. And this elimination of wasteful practices is the basic concept of "Toyota Production System". There are

also two fundamental principles which support this concept, “Right on time” and “Automation”. Sugimori et al. (1977) explained “Right on time” or “Just-in-time” as a methodology of having as little components as possible in stock for the production to function and only produce as many products as it is needed. Ohno (1982) stated that if this methodology is followed, stock value could almost be reduced to zero which would be a financial benefit. Sugimori et al. (1977) explained that Toyota named this kind of production system the Kanban System.

Ohno (1982) emphasized that the second fundamental principle within Toyota Production System, “automation” at Toyota, didn’t mean traditional automated production processes. He elaborates that in Toyota “automation” means “to work of itself” or “self-working” meaning there were already some level of intelligence within the machines. Sugimori et al. (1977) explained that the machines were able to stop their processes if there would any abnormal activity or defective condition within the process. They further explained that this functionality was called “Jidoka” (automatization with human manufacturing). The machine was able to stop working, before it produced a defective product. Ohno (1982) continued to explain that with this kind of automation production of defective parts could be reduced to almost zero and the machine only needed a human intervention when the machine stopped. So, a single worker could monitor multiple machines at the same time leading to low need of personnel and high improvement of productivity.

Toyota Production System laid the foundation to “Lean Manufacturing” which was first introduced in 1991 when James P. Womack, Daniel T. Jones and Daniel Roos published their book “The Machine That Changed the World” which compared American and Japanese companies. The book identified Toyota Production System to be the most efficient production system and the first production system which worked according to Lean principles. Lean is also considered to be the successor of the Toyota Production System (Dekier, 2012) Čiarnienė and Vienažindienė (2012) explains Lean manufacturing as a widely recognized manufacturing philosophy centered on improving processes to meet

the customer needs. Its key principle is to deliver greater value to customers while minimizing resource consumption and cycle times through the elimination of waste. They further specify that Lean is a way of manufacturing that uses different ideas, tools, and techniques to improve business processes. The goal is to save time, use most of the workers and equipment available, and make production more efficient, while also making the products and services better for the customers. Using lean manufacturing is very important for companies to be more competitive in the global market. Lean manufacturing is a practice that sees anything that doesn't add value to the final customer as waste. It includes several management methods like just-in-time, quality control, work teams, and supplier management, all working together in one system.

2.1.3 Quality in the 21st century

Industry 4.0, also known as the Fourth Industrial Revolution (4IR), represents the next stage in the digital transformation of the manufacturing industry. It is driven by disruptive trends such as the growing importance of data and connectivity, advanced analytics, human-machine interaction, and advancements in robotics. The Industry 4.0 follows the inventions from the Third Industrial Revolution, which happened between the 1950s and the early 2000s. This period, also called the digital revolution, gave us computers, electronics, the Internet, and many other technologies. Industry 4.0 takes these inventions even further, using four main types of new technologies across the value chain. These include:

1. **Connectivity, data, and computing power:** such as cloud technology, the Internet, blockchain technology, and sensors.
2. **Analytics and intelligence:** including advanced analytics, machine learning, and artificial intelligence.
3. **Human-machine interaction:** like virtual reality (VR), augmented reality (AR), robotics, automation, and autonomous guided vehicles.
4. **Advanced engineering:** including additive manufacturing (for example 3D printing), renewable energy, and nanoparticles.

(McKinsey & Company, 2022)

Albers et al. (2016) explain that companies that have implemented Industry 4.0 technologies have seen productivity increases of up to 50% and that 80% of companies have seen efficiency increases. In addition, 45% of the companies' state that their customer satisfaction rates have been increasing as well.

Sader et al. (2019) proposes that Industry 4.0 will bring many new opportunities for improving quality management practices. With advancements in technology, there are now new methods to ensure product quality, better inspection tools, early failure detection techniques, and self-adaptation capabilities. These technologies allow production facilities to redesign their production lines to meet customer needs, handle changes in demand, and prevent machine failures or downtime. Other benefits of Industry 4.0 in the context of quality include interconnectivity and sensors where the entire production system is interconnected and every part of it can be monitored. This will also provide real-time information flow from the production system to factory management which will increase the effectiveness of decision-making process. The data gathered from the sensors can be analyzed in real time which helps the production system avoid and prevent defects, system failures and downtimes. Sader et al. (2019) even proposes that *"Quality management has never been as smart as when utilizing Industry 4.0"*

Decheng et al. (2022) also explained that scholars and researchers have also noticed Industry 4.0 emerging, and they propose that Industry 4.0, together with Internet of Things (IoT) and Big Data have become new research focus with increasing interest. However, they conclude that these advancements have not yet had a significant enough impact on quality management to suggest that it has fully evolved beyond Total Quality Management, which remains the most recent development in the field, and which will be discussed in the next chapter. They propose that the next development of quality management, at the moment called Quality X.0, will include numerous changes to current quality management processes. For example, quality management department may be removed completely as smart machines and smart factories will start emerging, making

operators not necessary anymore. Smart machines and smart factories will produce fewer errors leading quality management to focus more on improving the value stream. The focus on quality control will reduce as well, which will shift the focus more to design quality.

2.2 Total Quality Management

As it was explained in the previous chapter, quality movement developed from quality inspection, control and assurance to quality management. Companies noted that instead of focusing on the inspection, you could also affect quality by correct management. Weckenmann et al. (2015) state that *Total Quality Management* is the latest development of quality movement. (Figure 3) They say that the quality is no longer just about market pressure but about the overall importance of delivering high-quality results.

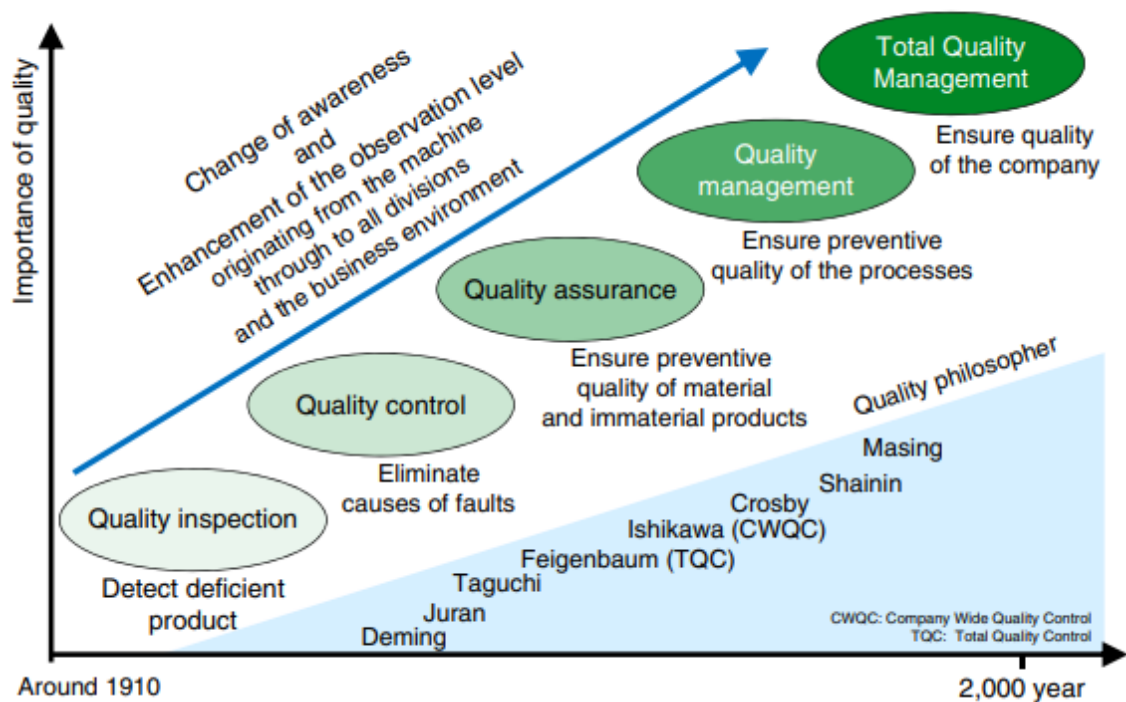


Figure 3. Overview of concepts in quality management (Weckenmann, Akkasoglu, & Werner, 2015, p. 283)

But there are many definitions on what Total Quality, also known as TQM, is. Godfrey (1998, p. 14.2-14.3) explains TQM is often linked to similar concepts such as *Total Quality Control (TQC)*, *Company Wide Quality Management* or *Continuous Quality Improvement*. He continues to explain that TQM is commonly used in USA, where TQC was more common in Japan. But to simplify this chapter and this thesis, TQM will be used to cover all these concepts, methods and philosophies that are used for quality management. Godfrey (1998, p. 14.3) also points out that JUSE (Union of Japanese Scientists and Engineers) has been using TQM instead of TQC from the year 1997 as TQM was more globally used term for quality management. JUSE also defined TQM as a management approach with following characteristics:

1. Clear mid and long-term visions and strategies should be established under strong top-management leadership
2. The concepts, values, and scientific methods of TQM should be properly utilized.
3. Human resources and information should be regarded as vital organizational infrastructures.
4. Under an appropriate management system, a quality assurance system and other cross-functional management systems, such as cost, delivery, environment, and safety, should be effectively operated
5. Supported by fundamental organizational strengths, such as core technology, speed, and vitality, sound relationships with customers, employees, society, suppliers, and stockholders should be ensured.
6. Corporate objectives should be continuously realized through achieving the organization's mission, building a respected presence, and consistently securing profits.

(Godfrey, 1998, p. 14.3)

Even though there are many different definitions for TQM, there are few elements which are highlighted in most of the definitions which are *customer satisfaction*, *system oriented approach* and *participation of the whole organization*. (Tervonen, 2001, p. 46)

Lillrank (1990, p. 34) also points out that as there are many definitions for TQM, it's easy for different organizations to implement TQM to their operations in a way they see fit. Logothesis (1992, p. 5) summarizes that TQM is a culture where there is an inherent total commitment to quality, with everyone involved in the continuous improvement of products and services. This commitment is expressed through the use of innovative scientific methods.

2.2.1 History of TQM

According to Lillrank (1990, p. 34) Feigenbaum was the first to introduce the term TQC in his book Total Quality Control in 1951. In his book Feigenbaum stated that *"Total quality control is an effective system for integrating the quality development, quality-maintenance, and quality-improvement efforts of the various groups in an organization so as to enable marketing, engineering, production, and service at the most economical levels which allow for full customer satisfaction"*. Feigenbaum also claimed that control should begin with the design of the product and should only end when the product is in the hands of a satisfied customer. Martinez-Lorente et al. (1998) however explain that even though Feigenbaum did think that all departments in a company should be responsible for quality, his TQC definition still missed many elements of the TQM concept we know today, such as importance of supplier relationships and empowering the personnel.

According to Lillrank (1990, p.34) Japanese made their own version of TQC after Joseph Juran introduced them to it in the 1950's. Japanese version of TQC was called Company Wide Quality Control or CWQC. Martinez-Lorente et al. (1998) explains that Japanese modified TQC to be better suitable for Japanese culture and business environment. They merit Kaoru Ishikawa for this. Ishikawa states in his book *"What is Total Quality Control? The Japanese Way"* (1985, p. 91) that contrast to Feigenbaum's idea that it's enough to have a quality control specialists in each division, he thinks that *"everyone in every division in the company must study, practice, and participate in quality control"*. He explains

this with cultural differences as Japan having strong hierarchy, the single QC specialists wouldn't be heard by the management. Martinez-Lorente et al. (1998) however state that TQC and CWQC are essentially the concept as TQM.

Martinez-Lorente et al. (1998) conclude that even though most of the elements of TQM was developed between 1950 and 1970, it didn't gain much popularity until the end of 1980's, which according to Dahlgaard-Park (2011) was due to western companies' high pressure to answer on competitiveness of Japanese companies. She proposes the time between the early 1980's and the early 1990's as the phase one of the "*renaissance of the quality movement in Western societies*". She explains that during that time Western companies lost market shares and jobs for Japanese companies, which woke Western managers to realize that quality should be improved by systematically applying quality management principles. During this time, Western interest in Japanese management approaches shifted towards the main areas of quality management. Practitioners and theorists began to focus their efforts on understanding and developing new knowledge in the field of quality management. Joiner (1996) explains that this made a big impact for US companies which were able to stop the steep decline they experienced in the 1970's and 1980's. For example, the quality of the American made cars improved drastically.

Dahlgaard-Park (2011) proposes that the second phase of the western quality movement happened between the early 1990's and 2000. In this era, the number of companies which implemented TQM practices increased as well as the general knowledge about quality management. In this era, Six Sigma and Lean practices boomed.

The third phase of western quality movement occurred between early and 2011. Dahlgaard-Park (2011) explained that many critics of TQM acclaimed that "TQM" is dead and the management approaches affected by TQM should be updated. Joiner (1996) explained that many believed TQM to be "dead" already in 1996. But he thinks that it was because even though TQM principles and methods were used, TQM as a concept wasn't said to be used. Dahlgaard-Park (2011) stated that even though the critics and other

people thought TQM would be dead, many examples surfaced where TQM was still relevant and worth implementing. However, many companies shifted their focus from TQM to simpler, more reductionist approaches, like the Balanced Scorecard.

2.2.2 Continuous Improvement

Godfrey claims in *"Juran's Quality Handbook"* (1998, p. 14.6-14.7) that continuous improvement is one of the fundamental concepts of quality management. He explains that for centuries societies and governments have been against any changes, everything needed to be done as was instructed or had been always done. It was not until the second World War, when Japanese had to quickly invent ways to improve their industrial production as they were so far behind the western societies. Out of necessity Japanese perfected the continuous improvement methods, which were also later adapted by western companies as in turn, they were starting to leave behind.

Bessant et al. (1994) describes that continuous improvement, or CI, is as its simplest form *"a company-wide process of focused and continuous incremental innovation."*

Bhuiyan and Baghel (2005-2006) defines CI more precisely as *"a culture of sustained improvement targeting the elimination of waste in all systems and processes of an organization."*

Oakland et al. (2021, p. 275-276) have created a framework, called DRIVER for continuous improvement, which helps organizations to approach problems the correct way. DRIVER stands for Define, Review, Investigate, Verify, Execute, Reinforce.

- **DEFINE:** The scope and objectives of the improvement process should focus on meeting customer requirements and the processes that fulfill them.
- **REVIEW:** Understand the existing processes and evaluate their current performance to identify the value-added activities and recognize areas of waste.
- **INVESTIGATE:** Examine the gap between current and desired performance, prioritize issues, and determine the root causes.

- **VERIFY:** Develop improvement solutions, including new processes, to address the problems and prevent them from recurring.
- **EXECUTE:** Implement the improved processes in a way that ensures the gained improvements are sustained.
- **REINFORCE:** Leverage the improvement by "learning the lessons" and creating a reassessment process to ensure continuous improvement.

Figure 4 shows DRIVER framework with recommended tools and techniques.

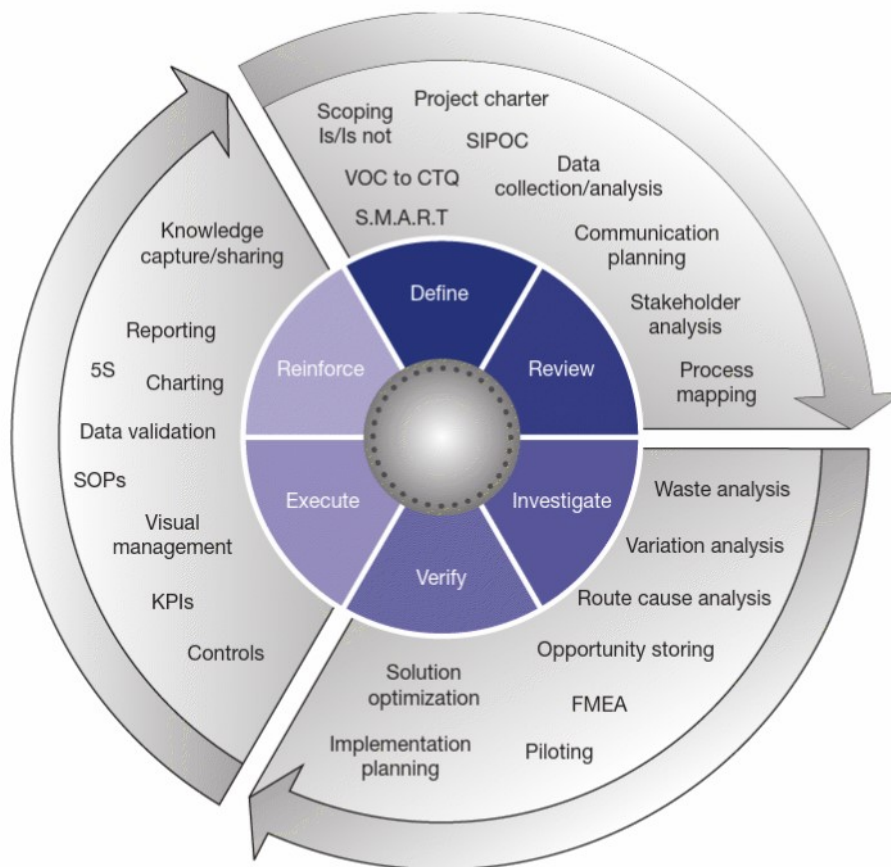


Figure 4. DRIVER (Oakland et al. 2021, p.276)

Another similar and more widely known approach to CI is Six Sigma methodology. Dedhia (2005) explains that Six Sigma methodology aims to reduce variation in the process with the help of statistical methods. Six Sigma approach is used in project forms and

each project will go through the same steps, which are DMAIC – Define, Measure, Analyze, Improve, Control

- **DEFINE:** The problem needs to be defined clearly and explicitly. This is a key step in selecting and prioritizing a project. A well-defined problem sets clear guidelines for the improvement process.
- **MEASURE:** Measurement points, sources, tools, equipment, and their precision and accuracy are vital to the project. Control is impossible without measurement, as accurate measurements are essential for data collection.
- **ANALYZE:** Using the right analytical tools or methods will help in finding a well-defined solution. Data is analyzed to generate information, which builds a knowledge base and supports decision-making for actions.
- **IMPROVE:** Choosing the best alternative solution and implementing it to address the root cause of a problem will yield the desired result. Improvements may include more efficient equipment, new processes, better employee training, or new materials. These improvements involve both corrective and preventive actions.
- **CONTROL:** After implementing improvement activities, monitoring is crucial to controlling the processes.

Lucas (2002) tells that the origins of Six Sigma are at the Motorola company in the early 1980's, but Snee (2004) claims the true origins of Six Sigma are already in the beginning of 20th century when statistical tools such as Analysis of Variance and control charts were developed which are the main tools in Six Sigma methodology. Snee (2004) continues to explain that Motorola were able then to further develop these statistical tools to Six Sigma methodology and were able to save millions of dollars with the help of it. Snee (2004) also claims it to be the best tool for process improvement

Harry (1998) explains that "Sigma" from Greek alphabet is used as a measurement of variance in the statistics. And in Six Sigma methodology sigma levels are used to determine the distance between the actual process performance to its desired process

performance. Most of the companies' processes are valued at Sigma level 4 and the best possible Sigma level is 6, where just a few companies are able to reach. Sigma level 6 indicates 3.4 defective parts per million produced (ppm). It can be seen from Table 2, how the Sigma levels are affecting Cost of Poor Quality, or COPQ. It can be determined how a good Sigma level may give a company a competitive advantage.

Sigma level	Parts per million	Cost of Poor Quality	
6 Sigma	3.4 defects per million	<10% of sales	World class
5 Sigma	233 defects per million	10-15% of sales	
4 Sigma	6210 defects per million	15-20% of sales	Industry average
3 Sigma	66 807 defects per million	20-30% of sales	
2 Sigma	308 537 defects per million	30-40% of sales	Noncompetitive
1 Sigma	690 000 defects per million		

Table 2. Practical Impact of Process Capability (Harry, 1998, p. 61)

Dedhia (2005) presents multiple examples of how Six Sigma methodology was successfully implemented. For example, General Motors were able to increase the usage of communication satellites from 63% to 93% resulting in yearly savings of \$1.3 million. In another example a government in Fort Wayne, Indiana, after successfully running a Six Sigma project, was able to fill 98% of potholes within 24 hours. The average financial impact of successful Six Sigma project varies from \$100 000 to \$200 000.

2.2.3 TQM Tools and Techniques

Quality guru Dr. Kaoru Ishikawa proposed in his book "Gemba no QC Shuho" in 1968 that there are seven basic tools for problem solving and process improvements, 2. Check

sheets, 2. Flowchart 3. Histograms, 4. Pareto charts, 5. Cause-and-effect diagrams, 6. Scatter diagrams, 7. Control charts. He also claims that 95% of process problems can be solved using these tools. (Neyestani, 2017) Sokovic et al. (2009) proposes that these tools are widely used as “graphical problem-solving methods” and that the tools can be used as a management tool in all processes from design to delivery.

Check sheets' main purpose is to collect and analyze data carefully correctly and is often used to record the frequency of specific problems or defects. Data should be presented in a way that is easy to use and analyze it. (Besterfield, 1990, p. 387)

Telephone Interruptions

Reason	Day					Total
	Mon	Tues	Wed	Thurs	Fri	
Wrong number	+++			+++	+++	20
Info request						10
Boss	+++		+++			19
Total	12	6	10	8	13	49

Table 3. Check sheet example. (ASQ, 2024)

Flowchart is a good way to illustrate each step of the process of a product or service from the beginning of the process to the end when the product or service is delivered to the customer. Flowcharts help to visualize the complete process and to identify potential pain points of the process. (Besterfield, 1990, p. 398)

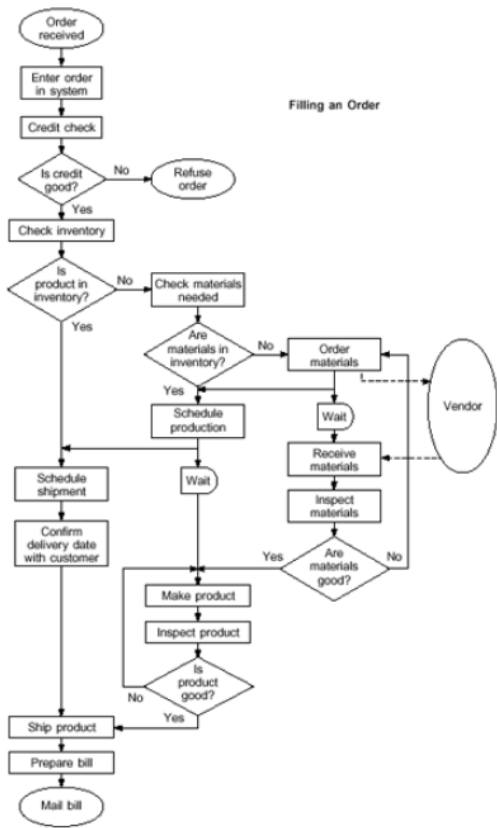


Figure 5. Flowchart example. (ASQ, 2024)

Histograms visualize the variation in the process in form of a bar chart. Its simple construction and easy interpretation make it an effective tool for basic data analysis. (Juran & Gryna, 1993, p. 182-183) The histogram displays the process capability and its connection to the specifications and nominal value. Additionally, it proposes the shape of the population and highlights any gaps in the data. (Besterfield, 1990, p. 387)

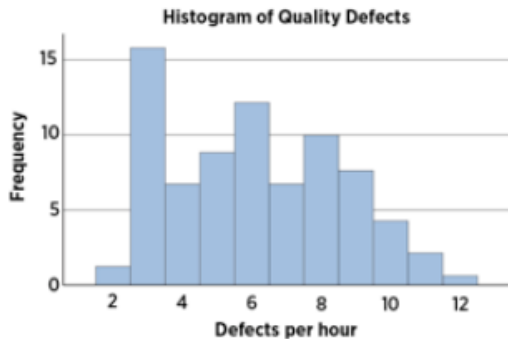


Figure 6. Histogram example. (ASQ, 2024)

Pareto charts are based on Pareto principle which claims that in any population contributing to a common outcome, a small number of contributors, known as "the vital few," are responsible for the majority of the effect. (Juran 1998, p. 5.20-5.21) In other words, identifying the major contributors for product defects and eliminating them can result to major quality improvements. (Logothetis, 1992, p. 206.) Besterfield (1990, p. 378) elaborates that it is usually agreed that 80% of all defects results from 20% of causes. As it can be seen from Figure 7's example, around 80% of all document complaints are caused by three complaint category, "Quality certificate error", "Quality certificate missing" or "Invoice error". By eliminating these three problems in the process, document complaints are reduced drastically.



Figure 7. Pareto chart example. (ASQ, 2024)

Cause-and-effect diagrams or fishbone diagrams are used to identify the most likely causes that lead to a problem. In the diagram all the possible causes or inputs that are connected to the problem are laid out on the diagram. (Logothetis, 1992, p.194) These causes usually are for example people, machine, work methods, materials, measurement and environment which are then divided to subcategories. After the diagram has been formed, brainstorming sessions should be held to determine which are the most likely causes for the problem. (Besterfield, 1990, p. 384-385)

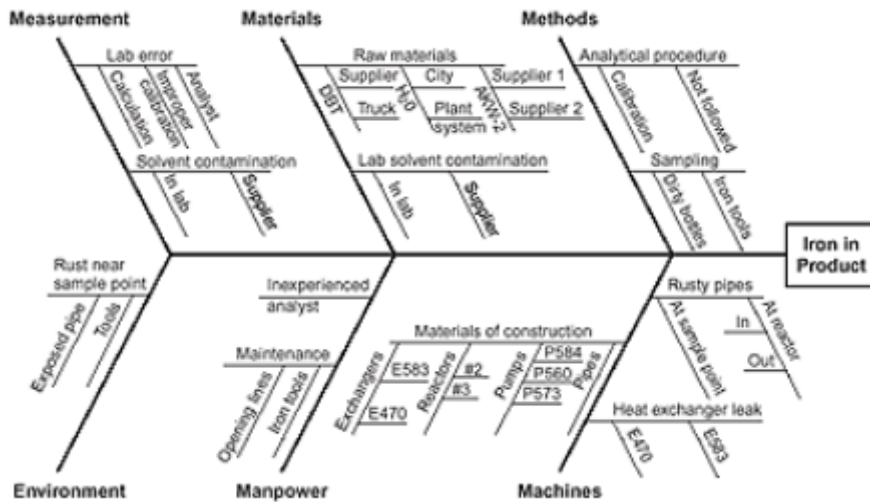


Figure 8. Cause-and-effect diagram example. (ASQ, 2024)

Scatter diagrams are used to identify possible relationships between two variables and to determine if there are correlations between the variables which could indicate a cause-and-effect relationship. (Juran, 1998, p. AV. 11) Logothesis (1992, p.395) proposes that scatter diagrams are the easiest way to determine if cause-and-effect relationship exists. Figure 9 shows a positive correlation between the number of car accidents and speed – the more speed, the more accidents happen.

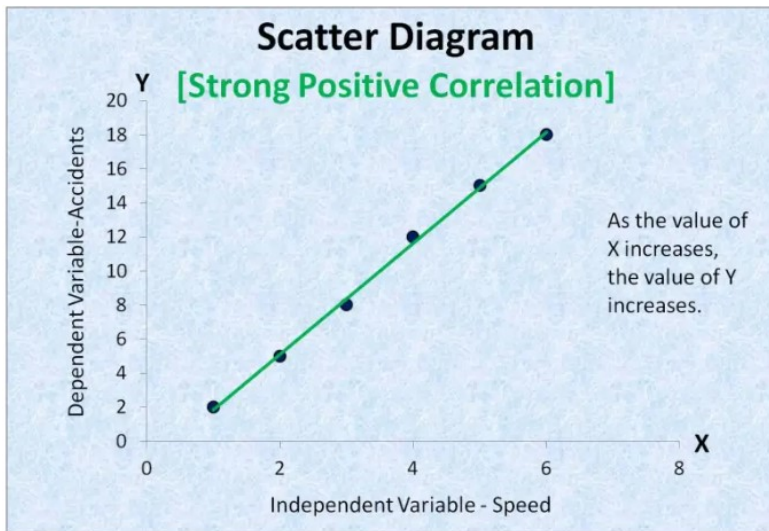


Figure 9. Scatter diagram example. (TQP, 2020)

Control chart was first developed by Walter Shewhart in 1920 as a tool to reduce variation in the performance of the telephones at Bell Laboratories where he worked. However, W.E Deming soon realized that control charts could be used also in the non-manufacturing environment. (Logothesis, 1992, p. 17) Control chart's objective is to visualize the variation in the process, and it shows if the process is in a stable state or not. Control chart first establishes the mean and the standard deviation of the data, and the upper and lower control limits which are ± 3 standard deviations, or $\pm 3\sigma$, away from the mean. (Besterfield, 1990, p. 68) This is also called "3-sigma value" or "rule". It means that 68,27 % of data points are within one standard deviation away from the mean, 95,45 % within two standard deviations from the mean and 99,73 % within three standard deviations away from the mean. (Juran & Gryna, 1993, p. 364-365) If data points are outside of these control limits, and can't be explained with special occasions, the process is out of control. If all data points are within the limits, the process is in control. (Besterfield, 1990, p. 68)

Having process in control means it is predictable, but it does not necessarily mean that the process is capable of producing an output which achieves the wanted results. The process can steadily produce invalid items. The method of assessing if the process is capable of producing items that meets the predetermined requirements is called *capability index*, C_p , which is calculated by dividing the predetermined tolerance, or specification limits with 6 standard deviations (σ) or as:

$$C_p = \frac{USL - LSL}{6\sigma}$$

USL=Upper Specification Limit

LSL=Lower Specification Limit

(Logothesis, 1992, p. 244)

A process which is in the middle of the specification limits has C_p of 1. Gryna (1998, 22.16) proposes that C_p should be at least 1.33 for process to be considered as capable

as there is always variation in the process. He further explains how C_p measures if the process variation can fit within the specification limits.

Another popular way to assess process capability is called *performance index*, C_{pk} , which indicates how close the current process mean is to either the upper specification limit (USL) or the lower specification limit (LSL).

$$C_{pk} = \min \left(\frac{\bar{X} - LSL}{3\sigma}, \frac{USL - \bar{X}}{3\sigma} \right)$$

\bar{X} =Process mean

(Gryna, 1998, p. 22.20)

Besterfield (1990, p. 68) explains that C_{pk} of 1 mean the process is capable of producing an output which meets the specifications and that C_{pk} is always equal or less than C_p .

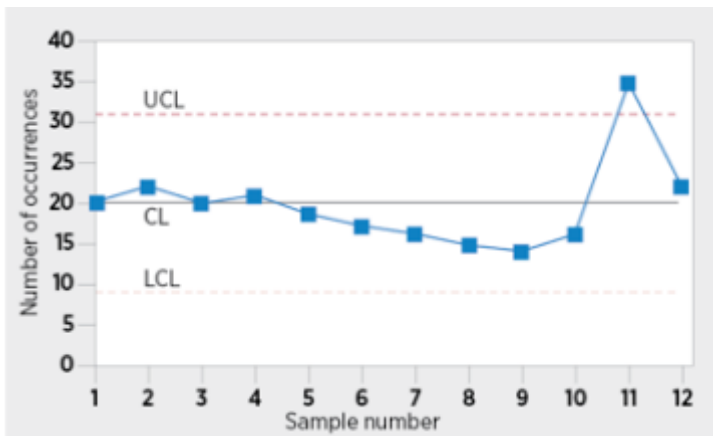


Figure 10. Control chart example. (ASQ, 2024)

Even though Ishikawa stated that 95% of quality related problems could be solved by using these seven tools, a recent study (Antony, McDermott, & Sony, 2023) showed that only 25% of quality professionals agrees with Ishikawa's statement. Total of 456 participants from five different continents participated in the study. The study showed that the

most used tools were Pareto charts, check sheet and control charts and least used was scatter diagram. However, the study showed that these tools are still valid tools to be used for quality improvement.

In addition, there are other popular Total Quality Management tools outside of Ishikawa's seven basic tools such as *Poka-Yoke* and *Benchmarking*.

Pötters et al. (2018) explains that Poka-Yoke is used to prevent faults from ever happening. The goal is to establish a process that produces zero defects. Poka-Yoke is Japanese and "Poka" means "unfortunate mistake" and "Yoke" means "to prevent". To successfully implement Poka-Yoke system, all possible faults and ways how to prevent needs to be identified. Uhanovita et al. (2023) explains that the benefits of Poka-Yoke come from detecting faults already in the production process which decreases the number of reworks needed. Poka-Yoke is also called "mistake-proofing". A functional Poka-Yoke system will usually either eliminate, prevent, or detect the problem. Common everyday Poka-Yokes are for example modern phone chargers or car seatbelt alarms. Modern phone chargers cannot be inserted the wrong way, eliminating the possibility to break the charger by forcefully inserting the charger the wrong way. Car seatbelt alarm on the other hand will detect if seatbelt is not fastened and sound irritating alarm to persuade fastening the seatbelt.

Elmuti and Kathalawa (1997) explain that the goal of Benchmarking is to identify the best standards for products, services, or processes and then improve internal processes to meet those standards, which are often known as finding the "best practices". They continue to explain that the roots of benchmarking are in the late 1970's when Xerox Corporation was losing its market share and was falling behind its competitors. Xerox Corporation decided to compare their processes to their competitors' processes and identified quality standards which were suitable for comparison. After this, benchmarking started to gain popularity. Fuller (2000) explains that it's not enough just to compare business processes, but it is essential to understand how to achieve the benchmarked

results. He proposes that the most major benefit of benchmarking is not necessarily achieving the level of competitors, which might solve problems in short-term, but changing the business culture in long term. He also emphasizes that to make benchmarking work, it should not be used on its own, but together with other tools and management models.

Fuller (2002) that there are four different approaches to utilize benchmarking, which are internal benchmarking, competitive benchmarking, functional or industry benchmarking and process or generic benchmarking.

Internal benchmarking is the most basic approach. In this approach, organization compares business processes against set performance standards within their organization which should help to identify the best internal processes and then adapt them to other functions of the organization as well. (Elmuti & Kathawala, 1997)

Competitive benchmarking is used when organization is comparing its processes to their direct competitors. The goal of competitive benchmarking is to compare companies with similar product within the same market. With this approach organization can get valuable information on how they are performing against their peers. The downside is that it can be really difficult to obtain important information from the competitors. (Elmuti & Kathawala, 1997)

Functional or industry benchmarking is used to compare organization's processes to industry leaders. These industry leaders should be on the same field of business and should share the similar technological and market characteristics for comparison to be valid. In this approach, the benchmarked organization might be more willing to share information as the organizations might not be direct competitors. (Elmuti & Kathawala, 1997)

Process or generic benchmarking is used to compare business processes which are titled as best processes. In this approach, the benchmarked company does not need to be in the same field of business but should still share similar processes and functions. This approach is considered to be extremely effective if done correctly, which is said to be difficult. This approach requires comprehensive understanding of benchmarked company processes. (Elmuti & Kathawala, 1997)

Elmuti and Kathawala (1997) emphasize that each organization should know its goals before deciding which approach to use.

Lillrank (1990, p. 114) explains that it's not enough that quality is promoted through slogans and speeches if nothing concrete is happening within the organization to improve the quality and if the personnel are unable to use for example the tools described earlier in this chapter. And for concrete improvements, employee participation is critical, which JUSE also noted to be one of the main characteristics of TQM. (Godfrey, 1998, p. 14.3) Juran and Gryna (1993, p. 147) explain that *Quality Circles* are one method to participate workers to improve quality. Quality Circles are founded of factory level workers, usually from the same department who voluntarily meets, for example once a week to address recent quality problems. The members of Quality Circle are then educated to use different problem-solving techniques and tools. Lillrank (1990, p. 124) explains that first Quality Circles were founded in 1962 and in 1970 a "bible of Quality Circles", "*QC saakuru Koryo*" was published. In this book the main characteristics of Quality Circles were summarized.

1. Quality Circles' meaning is to promote all around improvement within the company. Every worker is able to improve his/hers own and surrounding activities, and everyone's participation is necessary and welcome.
2. Quality Circle emphasizes the respect of humanity, and its goal is to develop a vivid and warm environment where working is pleasant.
3. The intention of Quality Circles is to harness every worker's hidden resources.

Juran and Gryna (1993, p. 147) explain that if done properly, Quality Circles are very effective way to improve quality. They however note that possibly the most important benefit of Quality Circles is its ability to change workers' attitudes and behavior towards quality.

2.2.4 Evaluating the effectiveness of TQM Strategies

As TQM being successfully implemented affects the whole organization, it can be difficult to evaluate if implementing TQM has improved company's processes. Mehralian et al. (2015) proposes that Balanced Scorecard is a good tool examine company's performance as it reviews both financial and non-financial sides or company's performance.

Pandey (2005) explains that Balanced Scorecard, BSC, was first introduced in 1992 by Robert Kaplan and David Norton. They designed it as a tool of diagnostic and control with both financial and non-financial indicators. Kaplan and Norton (1992) themselves claimed that BSC is a "*set of measures that gives top managers a fast but comprehensive view of the business*". They continue to explain that BSC tells the results of already taken actions in financial measures and operational measures will provide insights into future financial performance. Operational measures include customer satisfaction, internal processes and organizational innovation and improvement activities. They continue to elaborate that BSC should provide managers insights to their business through four different perspectives by asking themselves four basic questions.

1. How do our customers see us? (Customer perspective)
2. What do we need to be great at? (Internal perspective)
3. Is it possible for us to keep improving and generating value? (Learning and growth perspective)
4. How are we perceived by shareholders? (Financial perspective)

Pandey (2005) explains that understanding *Customer perspective* requires that every organization needs to know how their customers see them and how they can create more

value to the customer. A satisfied customer base leads to more revenue and better financial results. Focusing on customer satisfaction is key for long-term success, as poor customer satisfaction can predict future decline, even though the current financial performance would be good. The main metrics for customer perspective include customer satisfaction and retention, market share, and customer profitability. Companies should also measure processes linked to customer satisfaction like delivery time, defect rates and returns and should conduct customer satisfaction surveys.

Pandey (2005) highlights that *Internal perspective* is crucial for an organization to succeed. It focuses on internal business processes to ensure high-quality products and services. Managers must ensure that internal processes are running smoothly, and that products and services meet customer needs and create value for them. This perspective helps to identify key competencies and processes that must excel to achieve customer satisfaction. Key objectives include process improvement and supplier relations. Key performance indicators are cycle time, quality performance, productivity, and after-sales service.

Pandey (2005) explains that *Learning and growth perspective* focuses on innovation, creativity, and employee development. It asks whether the organization is innovative enough to keep creating value for customers and if their employees can handle continuous change and improvement. He highlights that employees are the most important resource in a knowledge-based organization and as technology changes quickly, continuous learning is essential. He continues to emphasize that the learning and growth perspective focuses on training and building a culture that supports personal and organizational development. Managers should act and be seen as coaches, promoting communication and teamwork. Key performance indicators include employee satisfaction and retention, and productivity.

Pandey (2005) explains that the financial perspective answers the question: How should the organization appear to its shareholders? Financial measures provide a standardized

tools for analyzing and comparing companies. He however explains that financial measures alone are not enough to tell anything about the organization's performance. To get the complete picture, you need to assess non-financial measures as well. Key financial indicators include growth, profit margin, return on investment, economic value added, and shareholder market value. He ends by saying that although financial measures are always history, they still provide a good picture have the process improvements translated into financial success.

Kaplan and Norton (1992) explain that the organizations that have implemented BSC successfully have seen that higher management needed to involve mid management to their decision-making process as well to get the complete picture of their business processes, which encompasses the new trends where organizations have implemented cross-functional integrations and trying to be a team more than an individual. With the help of BSC managers can more easily understand how different business processes codependent on each other.

Another good way to measure the effectiveness of TQM strategies is Cost of Quality (CoQ), or Cost of Poor Quality (CoPQ). Gryna (1998, p. 8.1) proposes that measuring cost of quality is a good way to quantify the quality problem and to track the progress in the quality improvement activities. There are many opinions on what should be included in Cost of Quality, but Juran and Gryna (1993, p. 16) explain that different costs can be divided into four broad categories, *Internal Failure Costs*, *External Failure Costs*, *Appraisal Costs* and *Prevention Costs*.

Internal Failure Costs are defects that are found prior delivering the material to the customer. The cost of these defects is caused from, for example scrapping the material, reworking the material, failure analysis and reinspection. (Juran & Gryna, 1993, p. 16)

External Failure Costs are defects that are found only after the material is delivered to the customer. These costs include costs accumulated from warranty charges, complaint adjustment, returned material and allowances. (Juran & Gryna, 1993, p. 17)

Appraisal Costs are formed from the process of inspections that the material meets the quality requirements. These costs accumulate from incoming goods inspection, in-process inspection and testing, final inspection and testing, product quality audits, maintenance of testing equipment and evaluation of stocks. (Juran & Gryna, 1993, p. 17)

Prevention Costs are formed from the cost of trying to keep failure costs and appraisal costs as low as possible. These activities include quality planning and audits, new-product reviews, process control, supplier quality evaluation and training. (Juran & Gryna, 1993, p. 18)

Juran and Gryna (1993, p. 22) also explain that not all costs related to the quality can be easily seen or measured and these costs are called "*hidden*" costs. These costs include for example the loss of potential sales caused by poor quality, redesign costs due to poor quality and the cost of extra manufacturing.

Juran and Gryna (1993, p. 24) propose that generally, manufacturing companies will see the annual cost of poor quality to be 5%-35% of turnover depending on how complex the product is. For service industries cost of poor quality varies from 25% to 40% depending on service complexity.

2.2.5 Criticism and Challenges of TQM Implementation

On the first look, it seems that implementation of TQM principles will solve any company's any problem with ease and would drive profits to a climb, but that is not the case.

Dahlgaard-Park (2011) explains how TQM has been criticized for its reliability as a successful managerial tool due to challenges organizations have faced during the implementation of TQM and not delivering wanted results. She also explains how TQM has been criticized by its lack of standardized terminology and definitions. Rokke and Yadav (2012) highlights reasons why companies might have had challenges implementing TQM principles.

1. **Lack of leadership and top management commitment** – Leadership commitment is critical for successful TQM implementation and top management's lack of commitment was identified to be the main barrier of TQM. Linking management's compensation to quality goals is seen as essential, but on the other hand top-level commitment should be genuine and organization-wide for TQM to work. It was noted that when leaders strongly advocate for quality in their speeches, but their actions contradict it, it undermines their credibility.
2. **Strategic planning** - Many companies prioritize short-term goals over long-term quality and unclear priorities often hinder TQM efforts. Many companies may speak of long-term planning but focus on immediate operational concerns.
3. **Human Resource Inclusion** - Human resources are key to TQM success. Management must share information and engage employees in quality improvement. and simple suggestions are not always enough; employees should be involved in problem-solving teams. Training should focus on quality, not just functional skills, and performance reviews should emphasize continuous improvement.
4. **Dynamic Customer Focus** - Although customer focus is a key TQM principle, many companies struggle with it. TQM requires consistent alignment with customer needs, moving away from a "business as usual" mentality. Quality should be integrated into all operations, not just in product delivery.

Brown (2013) highlights that Government regulations have made organizations focus more on compliance, leading to hiring more compliance specialists and adding compliance tasks to many roles. This focus on just meeting the rules creates a problem for real quality improvement because it values following rules over doing what is actually quality

movement about. Many industries also seek accreditation, often for marketing reasons or to avoid being left behind. He continues to point out that the challenge is to change how quality is seen—from just a burden to something that actually makes jobs, workplaces, and customer interactions better. Compliance should not limit creativity and innovation.

2.3 Quality Standards

As we have learned through previous chapter, quality and quality management have many different definitions and methods. For that reason, the International Organization for Standardization established ISO9000 family in 1987 to unify and standardize these definitions and methods. (White & Mack, 1996)

The ISO 9000 family of standards focused on quality management systems. The family is based on seven core quality management principles, including customer focus, leadership involvement, a process-oriented approach, and continuous improvement. (ISO, 2024) Savolainen (1994, p. 22) explains that ISO-standards are the guidelines to systematic improvement of quality and that ISO9000 focuses on providing universal instructions on how to control and manage quality as well as systematic tools to plan and implement organization's internal continuous improvement projects. The foundational concepts and vocabulary of quality management are outlined in the ISO9000 standard, which serves as the basis for other standards in the series such as ISO9001. (ISO, 2024)

ISO 9001 is an internationally recognized standard for quality management systems (QMS) that helps organizations consistently meet customer and regulatory requirements by improving processes and ensuring quality (ASQ, 2024). It applies to organizations of all sizes and sectors, helping them improve performance and meet customer expectations (ISO, 2024). ISO9001 is a part of The ISO 9000 family of standards focused on quality management systems.

The initial publication of ISO9001 happened in 1987 by the International Organization for Standardization (ISO) and was last updated in September 2015 (ASQ, 2024). The 2015 revision introduced new terminology, emphasized risk-based thinking, increased the requirements for leadership and made the standard more applicable to service industries (ASQ, 2024).

ISO9001 certification has been issued for organizations in 189 countries, making it the most popular quality management standard in the world. It is also the only certifiable standard in the ISO 9000 family, although certification is not mandatory (ISO, 2024)

Implementing ISO 9001 provides various business benefits, including increased customer confidence through powerful quality control and more efficient complaint resolution processes. The standard also drives process improvements by identifying inefficiencies, reducing waste, and promoting cost savings (ISO, 2024).

ISO 9001 follows a Plan-Do-Check-Act (Figure 1) methodology and covers areas such as management responsibilities, resource management, and continuous improvement through internal audits and corrective actions (ASQ, 2024). Regular audits and reviews help organizations refine their quality management systems and achieve long-term success (ISO, 2024). Organizations find that the standard helps them organize processes and continually improve their operations (ASQ, 2024).

3 Methodology

Stringer and Aragon (2021, p. 44) propose that most research is done using *quantitative* or *qualitative* research methods. Hirsjärvi et al. (2013, p. 136) explain that even though the differences of these methods, they complement each other. They also explain that the boundaries of these methods can be hard to describe, even though scholars have tried to do so for decades. Although there are clear differences, Queirós et al. (2017) explains that qualitative research focuses on comprehensive understanding of the given problem, instead of numbers. The goal of qualitative research is to provide detailed and descriptive information to better understand the different aspects of the problem being studied. It deals with parts of reality that cannot be measured, aiming to explain and understand the dynamics of social relationships. Qualitative research deals with a pool of meanings, motivations, aspirations, beliefs, values, and attitudes, which involves a deeper look at relationships, processes, and phenomena that can't be explained by just using numbers. Quantitative research, on the other hand, focuses on objectivity and measurable outcomes. The findings are typically used to represent the entire population under research. To ensure reliable results, researchers often use large sample sizes and standardized methods for data collection and analysis. The data is then analyzed using statistical techniques to draw conclusions.

Stringer and Aragon (2021, p. 45-49) explain that both of these research methods have their flaws. As quantitative research focuses on measurable data, it doesn't take human interaction into account, which in some studies can play a big role. Qualitative research on the other hand lacks the ability to generalize the research results. They continue to explain that to battle these flaws, *mixed methods research* can be a viable option for some studies. It combines both qualitative and quantitative and involves philosophical ideas that guide how the data is collected, analyzed, and interpreted. Mixed method researcher uses both qualitative and quantitative methods to collect and analyze data, and to understand the results. Using both methods together gives a better understanding of the research problem than using just one method alone. For example, mixed methods research can begin with a quantitative study that investigates the relationships

between variables. After that, additional qualitative research can be done to gain a deeper understanding of how and why those variables behave in a certain way.

3.1 Research Method

Similar to mixed methods research is *action research*, which is chosen to be the research method this thesis will follow. Stringer and Aragon (2021, p. 52) explain that these action research and mixed method research methods have several common features with one distinctive difference. Whereas mixed methods research aims to find an answer to research questions, action research aims to find comprehensive *solutions* to practical problems.

Stringer and Aragon (2021, p. 49) explain that action researchers not only try to understand the problem, but also try to work with research participants to find the solution to the problem. They continue to state that action research can use quantitative techniques, for example statistics to investigate relationships between variables and then qualitative techniques to provide better understanding on why and how things happen as they do.

Baskerville (1999) explains that action research method suits best for an environment where the researcher is actively involved in the research, and it is expected that both researcher and organization will benefit from the research. Another suitable environment he proposes was where the researcher can immediately apply the obtained knowledge to use. And finally, he proposes that the research should be cyclical where theory and practice can be linked. Susman and Gerald (1978) explain that the cyclical nature of action research comes from five steps action research should take (Figure 11).

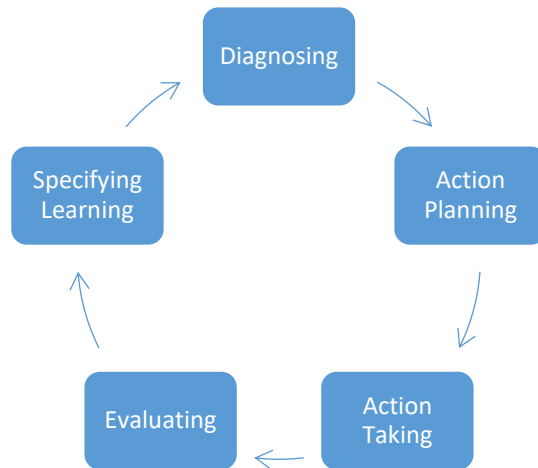


Figure 11. The cyclical process of action research (Susman & Evered, 1978, p. 588)

Baskerville's (1999) explanations to each step:

1. **Diagnosing** – Identifying the main problems that are causing the organization to want to change. This step involves understanding the complex issues in the organization, not by simplifying them, but by looking at them as a whole. This step will create some ideas or theories (a working hypothesis) about the organization and the problems it's facing.
2. **Action Planning** – In this step researchers and practitioners work together. This step identifies specific actions the organization should take to solve or improve the main problems. The plan is based on a theoretical framework that shows the desired goals of the organization, and the changes needed to reach the goals.
3. **Action Taking** – In this step planned actions are put into practice. Researchers and practitioners work together actively to make changes in the organization.
4. **Evaluating** – Results of actions are evaluated. This evaluation involves checking if the expected effects of the actions were achieved and if these actions helped to solve the problems. If the changes were successful, actions need to be critically assessed if the actions taken were the only reason that the problems were solved.
5. **Specifying Learning** – The knowledge gained from the action research should be distributed to the whole organization to see if the same changes could be implemented elsewhere in the organization.

Action research was chosen as the research method of this thesis as it has many similarities with continuous improvement principles. For example, Reason and Bradbury (2008, p. 11) proposes that action research always starts with a question *“How can we improve this situation?”* Which goes almost hand in hand with the research question of thesis; *“How can Total Quality Management (TQM) tactics be effectively utilized to address and mitigate quality errors in quality control processes?”* In addition, Susman’s and Evered’s illustration of cyclical process of action research (Figure 11) resembles Deming’s PDCA (Plan, Do, Act, Check) -cycle (Figure 1) and Six Sigma’s DMAIC (Define, Measure, Analyze, Improve, Control) approach. Also, as it was explained earlier in this chapter, in action research findings from the research should be put to use immediately.

3.1.1 Research method adopted in this thesis

As explained, action research method was used in this thesis which incorporates aspects from both qualitative and quantitative research methods. The research on this thesis could have not been completed only by using either one of the methods. Quantitative part of this research is the data analysis. The amount of data is so large that it cannot be qualitatively examined, instead using e.g. statistics and charts, we can organize the big amount of data to more easily understandable form. And the results of this quantitative analysis are where qualitative analysis comes forward. Statistics and charts only present figures, but not what is behind the figures. And to get understanding on why the figures are the way they are, simple interviews were held with the production director of the case company. With the help of his knowledge about the production processes analyzing the data will become more efficient as he can immediately describe certain part of the process or why things are done like they currently are done and most importantly, what is and has already been done to improve the production process. In addition, other personnel from the factory were interviewed to get a better understanding of case company’s existing quality processes.

3.2 Data collection and analysis

This thesis will use two kinds of data, from primary data sources, and from secondary data sources, which are then analyzed using different data analysis methods.

Primary data sources will include:

1. Quality Dashboard
2. Interviews
3. Observations

Data collection is mainly limited out of this thesis as there is already a functional process of collecting quality data in the case company and the data is accessible through “*Quality Dashboard*” (Picture 1) The quality data, that is used in this study, will include information of every frequency converter tested in the factory and as every frequency converter *is* tested, it can be said that the data is comprehensive and reliable. Some of the charts and figures have been removed from the dashboard due to them being confidential information. The data will indicate the reason why frequency converter has not passed the test, and the reasons are then subcategorized to assembly, material, process or testing errors which are further subcategorized to numerous different categories as seen from Picture 2.

The frequency converters the case company produces varies by size and complexity and therefore it is not sensible to analyze the quality data covering all products. Therefore, after discussion with the case company it was decided to focus on only a few product line producing similar sized products, more specifically, high power drives. Quality data from these production lines were taken from the last full year, 2023, as there might be some periodical variables within shorter periods of time that might affect the quality data. For example, during the summer months when there are summer trainees in the production, quality flaws tend to increase. Once the scope of the data is determined, baseline performance from the year 2023 is checked. Any improvements can then be compared to the baseline performance.

Rest of the primary data sources, interviews and observations are collected by me by interviews with production director and other personnel.

Secondary data sources on this thesis are

1. Documentation review
2. Industry reports and literature
3. Company records

These data sources will be able to improve the understanding of how primary data sources can be interpreted and analyzed. It's also important to understand what is done previously at the case company to improve quality and how workers are currently motivated to sustain the wanted quality level.

3.2.1 Data analysis methods adopted in this thesis

The acquired data is then analyzed with help of different data analysis methods. Main methods are *Statistical analysis, Pareto analysis, Control charts and Thematic analysis*

With the help of thematic analysis, quality error data is categorized by the high level failure cause, to either assembly, material, process or testing errors and on which part of the production process error occurred.

Categorized data is then analyzed with Pareto analysis which will provide easy way to see the causes that account for the majority of errors. Once the main causes are identified, root cause is tried to be identified. For that statistical analysis and control charts can be used.

Overall, the analysis will follow Susman's and Gerald's (1978) steps of action research. In Diagnosing step, the initial problem or problems are diagnosed. *Why frequency converters fail tests? What is the root cause?* In Action Planning step we investigate *how we can improve the situation* so that frequency converters would not fail in the final test. *What actions need to be taken?* In Action Taking step, these identified improvements are taken into production. Personnel are informed about the changes and advised to work according to them. In Evaluating step, we will evaluate if the improvements made to the production have actually reduced the number of quality failures. And finally, in Specifying Learning we will summarize what we have done and learned and will investigate if these learnings and improvements can be applied to other production lines as well.

3.3 Reliability and Validity

Hirsjärvi et al. (2013, p. 231) explain that to ensure mistakes made during the research are reduced, research's *reliability* and *validity* should always be assessed.

Reliability stands for repeatability of the research. Can the same research results be repeated if the research was conducted by another researcher? If two independent researchers end up with the same research result, research can be seen as reliable. *Validity* on the other hand measures how good the research measures what it was intended to measure. For example, if survey participants can understand asked interview questions

differently than the researcher, the results of the research might not be valid. (Hirsjärvi et al. 2013, p. 231-232)

According to Waterman (1998) there isn't much literature available about reliability and validity for action research. She presumes this is because there is a tendency to categorize action research under qualitative research. Though she agrees that some tools to measure validity for qualitative research can be applied to action research as well. But she adds that it's not enough just to assess the validity of action research by using validity tools for qualitative research as action research does have distinct features. Turnock and Gibson (2001) propose that judging reliability in action research is limited because each project is unique and promotes that focus point should be on the validity of the research.

One issue is also that as action research is greatly used in social sciences for example to research public healthcare, all the articles about reliability and validity in action research were done for completely different setting than this thesis. For that reason, it was hard to find any literature which would fit the setting this thesis has. It could be also said that there isn't any standardized method to measure reliability and validity in action research. But on the other hand, reliability and validity can still be discussed.

As it was said earlier, reliability measures the repeatability of the research. Can other researcher get similar results? In this thesis, main data source that was used was Danfoss Drive's quality data from the factory. So at least the source data does not variate. But it can be discussed whether the data itself is reliable? Are the faults categorized correctly? Have the operators been instructed which fault will go under which category? In Danfoss, testers are instructed to how to categorize different faults under correct fault group which will indicate that the collected data is reliable enough.

As the source data is considered to be valid, it's hard to believe that another researcher would receive different results on the root causes of quality errors as there isn't any room for interpretation in, for example pareto charts or SPC. But another researcher

might get different ideas on how to improve the situation, which is why I believe it would be the best to brainstorm the improvement ideas with different stakeholders to improve the reliability. The improvement ideas of this research were brainstormed together with factory's production director which should ensure that this research is reliable.

For the validity of this research, which should measure how well the research measures what it was intended to measure, so how well this measures what it was intended to measure, which was the quality errors and how to reduce them. The objectives (page 9) of this thesis were well aligned with the data that was used in this thesis, which will ensure that correct things, quality errors, were measured. The data used was also collected in a natural setting, as in "real world" and the variables of the data were tried to be minimized by using data from a complete year to take the seasonal variation in production quality into account. Also, as it was said before, this thesis was reviewed by the factory's production director, which will increase the face validity of this thesis.

Taking all this into account, it can be said that this thesis is reliable and valid for the purposes of it. It must be remembered that this research was conducted in a unique setting and the same results could not be replicated in another factory.

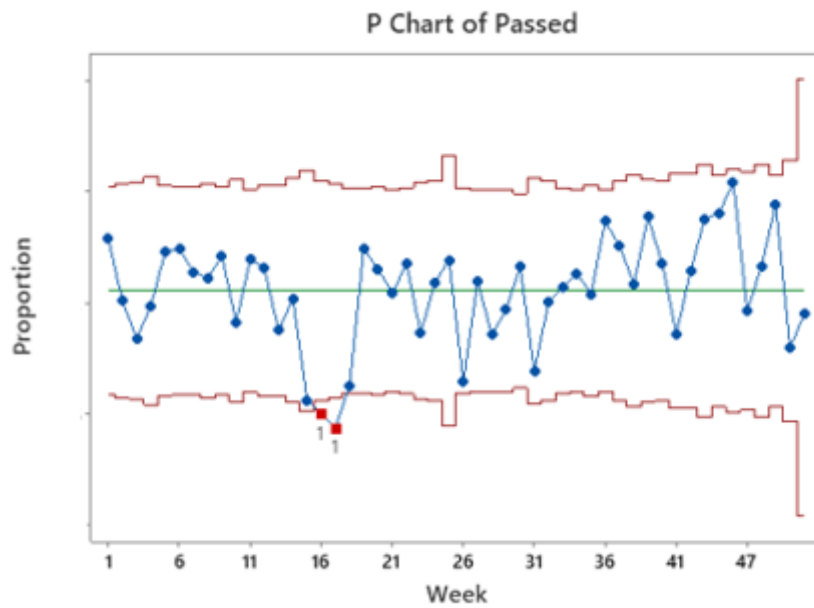
4 Results

In this chapter the results of thesis are presented and questions to research questions are presented. Results are presented in a chronological order, where first the baseline performance is presented which is followed by results of each fault category.

4.1 Baseline performance

As it was stated before, the quality data used in this thesis was from the last complete year, 2023, to take seasonal variation in quality errors into account, such as larger number of temporary workers during summer months etc. Baseline performance is measured from 15 534 tested units from high power drives production lines. Baseline FTY-% is not presented on this thesis as it is not relevant for the results.

From the control chart (Figure 12) we can see that although there are two outliers from weeks 16 and 17 the process itself is stable. Meaning there isn't too much variation on how many drives pass the test, which again means that the production process is stable. As this thesis is limited to high power drives, as in bigger drives, the number of components on the drives it that large, and as each drive is assembled manually by humans, it's only natural that mistakes will happen, and mistakes can't be eliminated completely.



Tests are performed with unequal sample sizes.

Figure 12. Control chart of passed drives

From Figure 13 we can see that majority of quality errors were caused by material errors and the majority of errors happened in a production line “High Power testing”. It was agreed with the case company that quality errors caused by materials are not included in this thesis as those are something the company itself cannot influence. Therefore, focus will be on assembly, testing system and process errors.

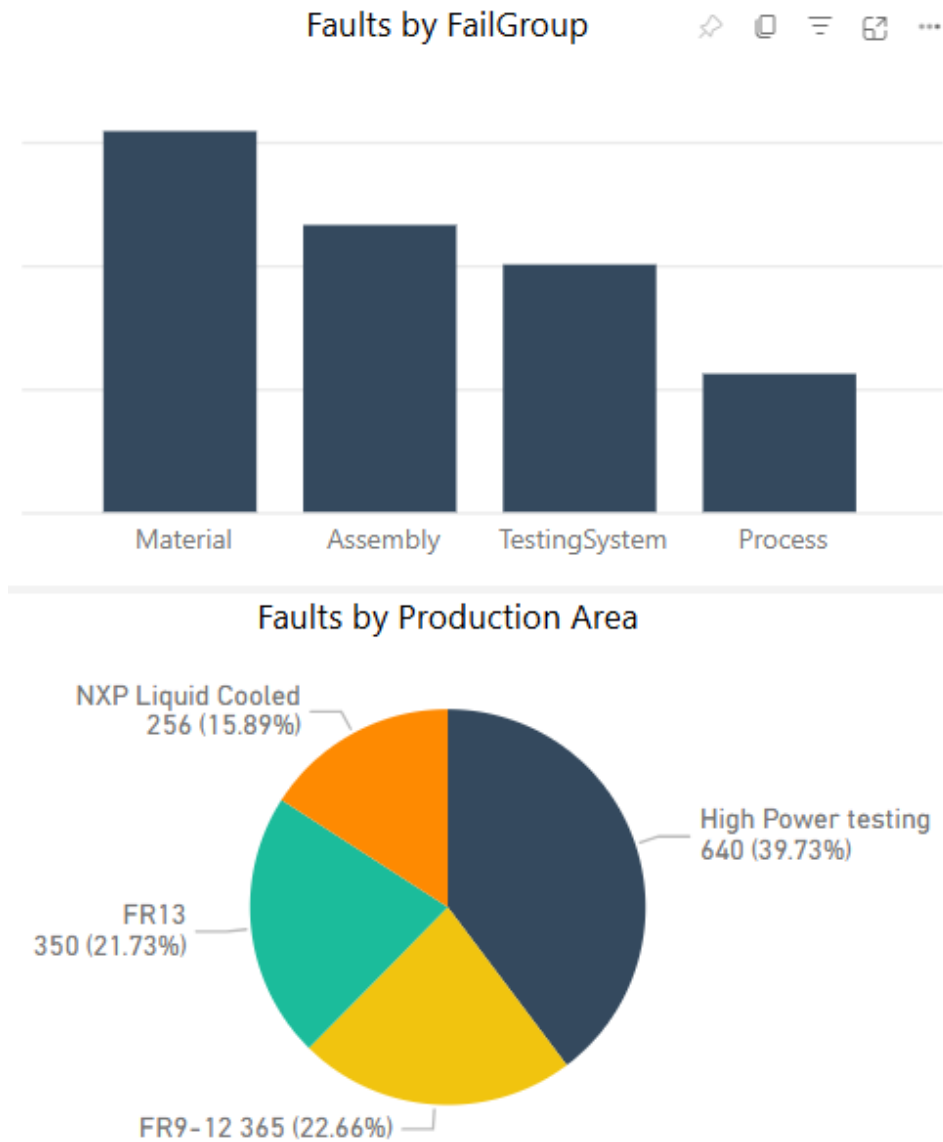


Figure 13. Fault categories

4.2 Analysis

As it was explained previously in this study, **Cause-and-effect diagram**, or **Fishbone diagram**, can be used to identify the most likely causes that lead to a problem, and in this case to a quality error. From the fishbone diagram on Figure 14, all possible causes for quality errors have been listed.

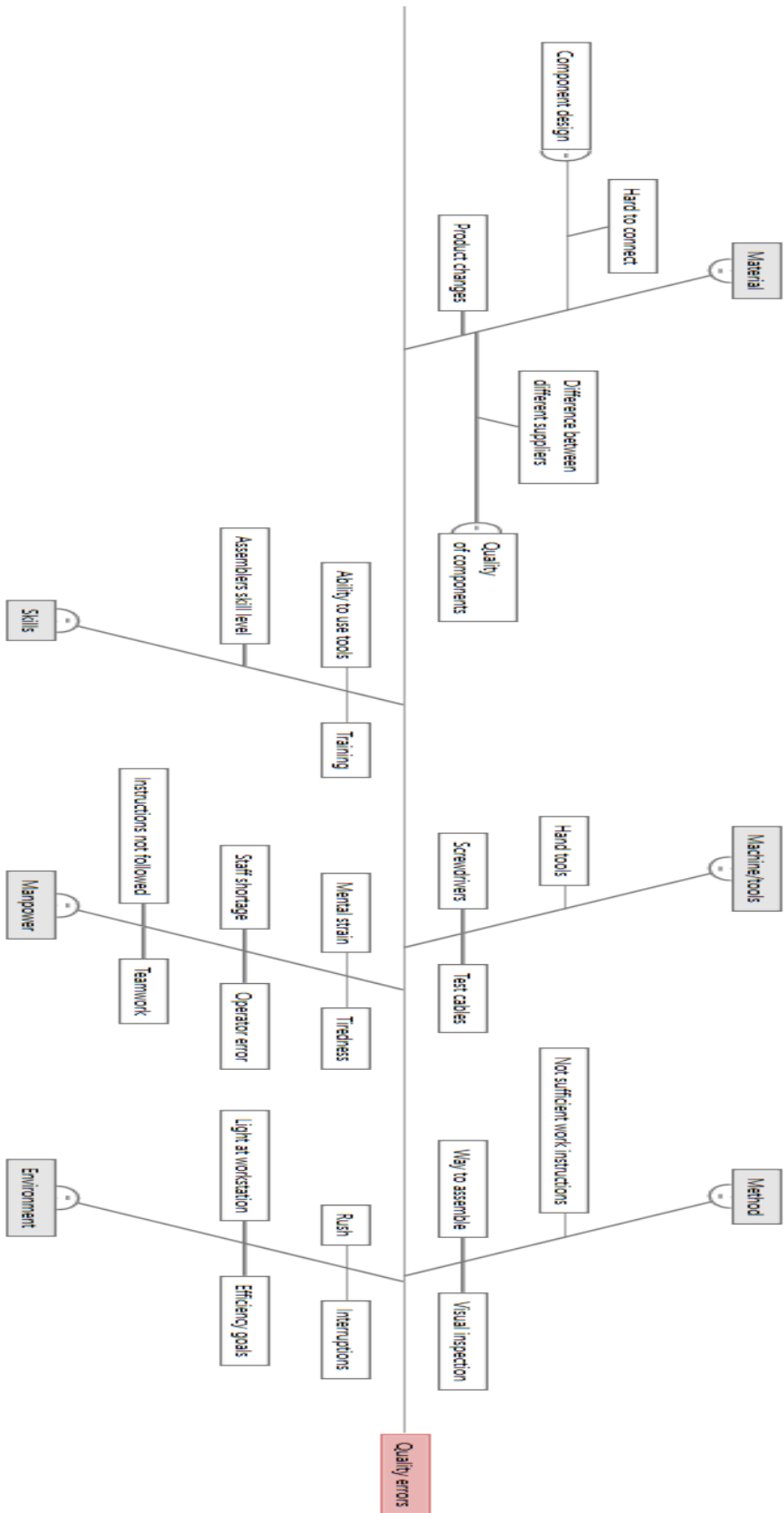


Figure 14. Cause-and-effect diagram

4.2.1 Assembly errors

Pareto chart (Figure 15) made out of Assembly errors supports the findings of the fish-bone diagram.

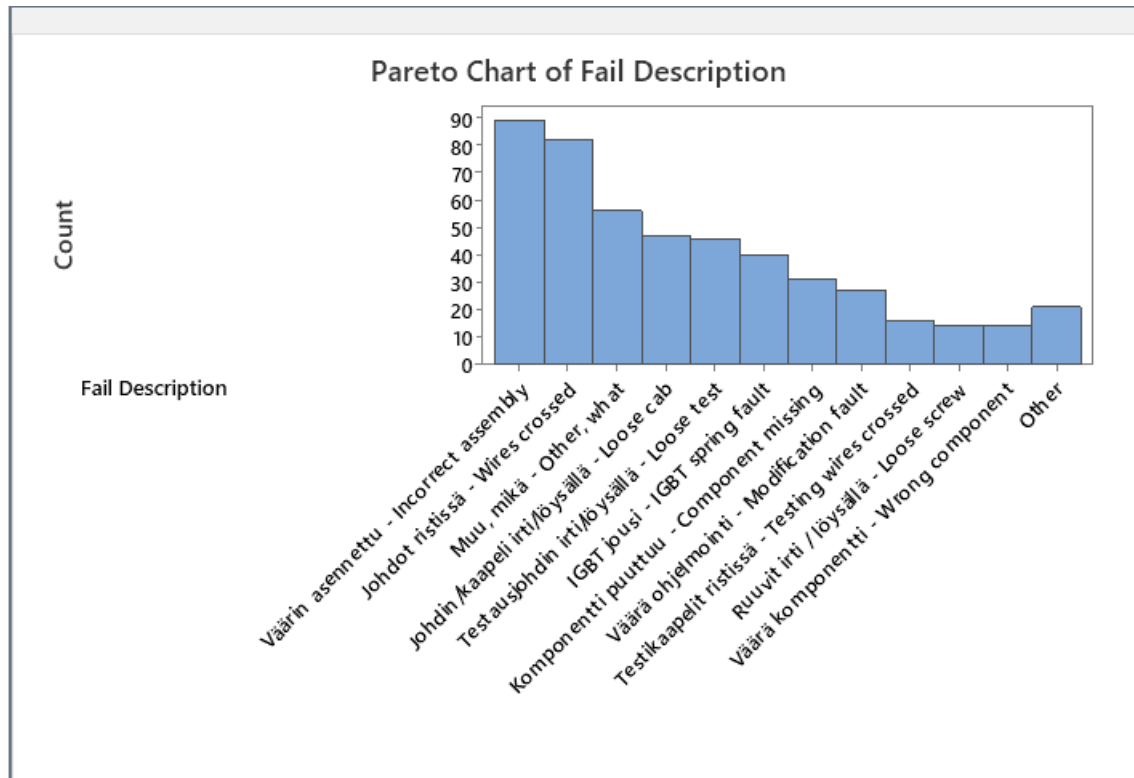


Figure 15. Pareto chart of Assembly errors

From the pareto chart we can see that “Incorrect assembly” and “Wires Crossed” account for majority of the assembly errors. Usually when using pareto chart to improve quality, focus would be on those that account for majority of the errors, but after discussing this pareto chart with the case company, it was decided to instead focus on “Loose Screws”. As it was explained earlier in this chapter, the drives included in this thesis are big in size and include hundreds of components, so it’s only natural that “Incorrect assembly” and “Wires crossed” are prominent on the pareto chart. Those are also something that are hard to improve due to natural variation caused by human errors. Therefore, the focus was decided to be somewhere else. In addition, some of the assembly errors are caused by loose screws or incorrectly fastened screws.

For fastening screws, Danfoss already has a Poka-Yoke implemented with smart wrenches. It automatically fastens the screw to correct torque. But some flaw to it was identified. As the smart wrench mainly measures the torque, it can be that the screw is fastened askew against screw threads. The smart wrench will say the screw is fastened, but in reality, as it is fastened askew, it can loosen easily. Smart wrenches do have possibility to detect if the screw is fastened at incorrect angle, but currently it is not optimized for all production lines. Angle watch works by detecting how many degrees the screw is revolved after the set torque have been reached. The angle should not be too much, but also it cannot be close to zero. Figure 16 includes the final angle data of one screw from the year 2023. From the figure we can see that as the mean is just 24, there are many outliers that have reached over 100 degrees, which according to production tool specialist, will for sure mean the screw is fastened askew or there are other problems on it. But as the angle watch has not been optimized, the operator will not get any indication from this.

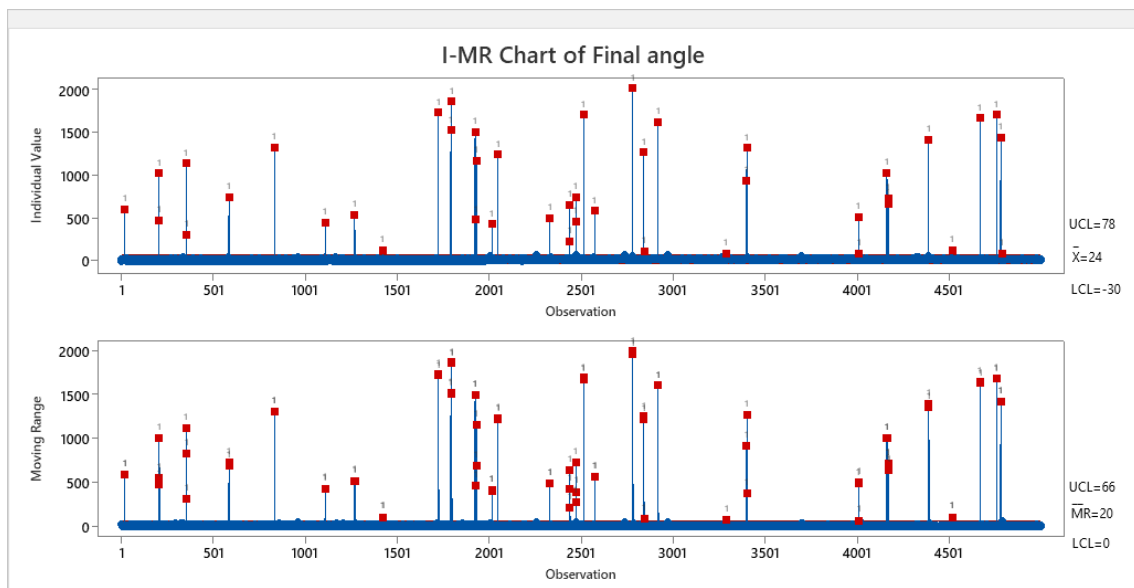


Figure 16. Angle watch control chart

But as above figure includes many outliers so far away from the mean, it makes the chart unreadable and distorts the mean and control limits. Therefore, all readings over 100 are excluded from figure 17.

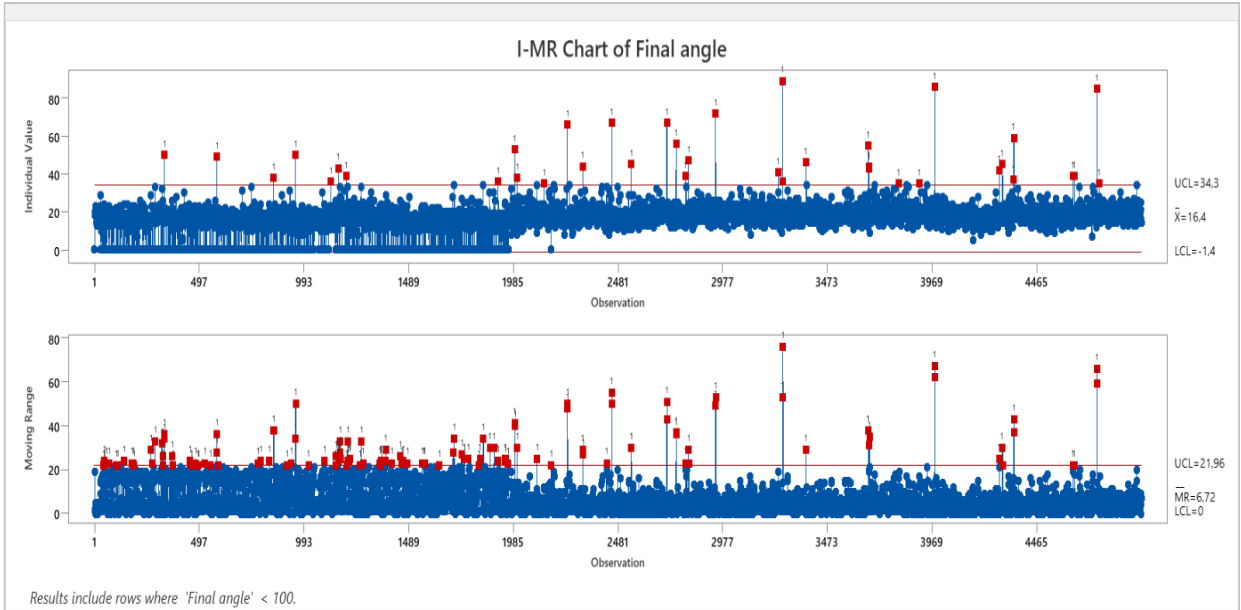


Figure 17. Angle watch control chart (adjusted)

From figure 17 we now get more readable data, but we can also detect that there are lot of “0” readings before observation no. 1985, and nearly none after it, which would indicate a process change. The process change was verified by the production tool specialist. However, these “0” readings still distort the data.

Finally, from figure 18 we have usable control chart. From that figure we can still see some outliers but otherwise the process seems to be stable.

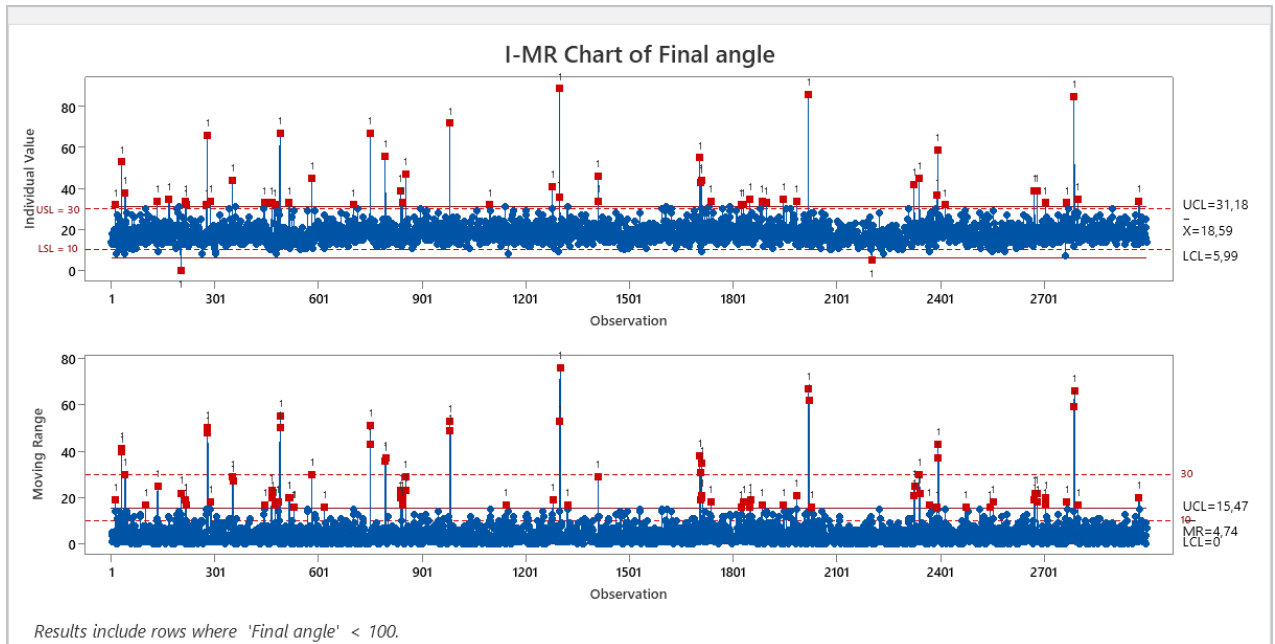


Figure 18. Angle watch control chart (final)

Recommendation: As the angle was not optimized before, I would recommend setting the specification limits of the angle watch to 10 and 50 as it is included on the above figure. All readings above, or below these limits could indicate skewed screw and the screw should be re-fastened with a new screw.

4.2.2 Testing system errors

Looking at the pareto chart made out of testing system errors it is easily seen that “Tester” is the biggest reason for testing system errors.

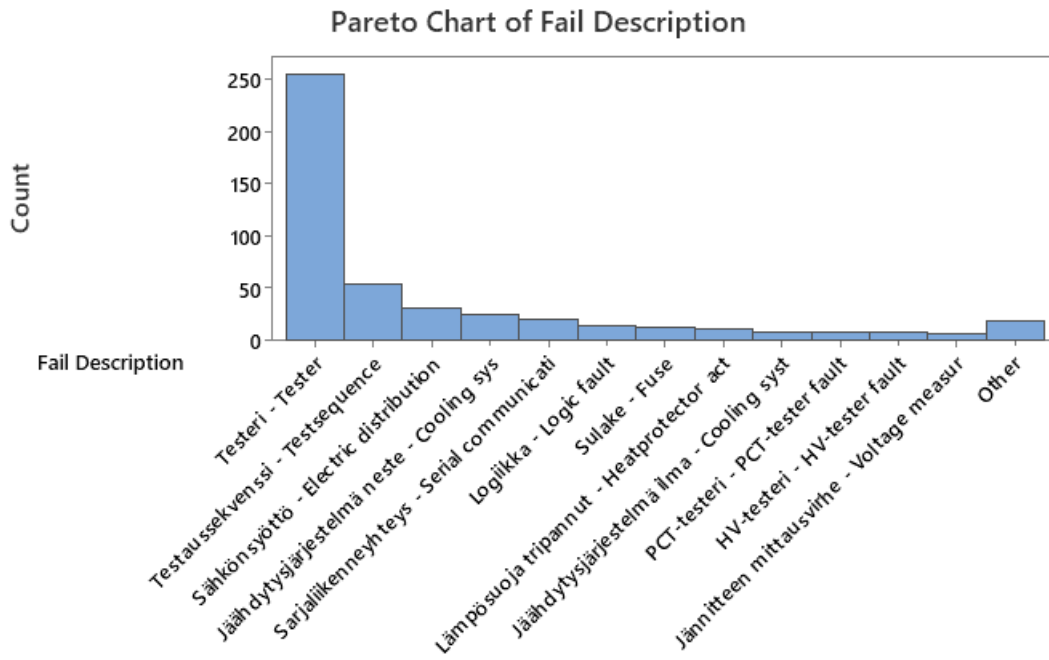


Figure 19. Pareto chart of Testing system errors

Fault descriptions under “Tester” category were categorized which can be seen from figure 19.

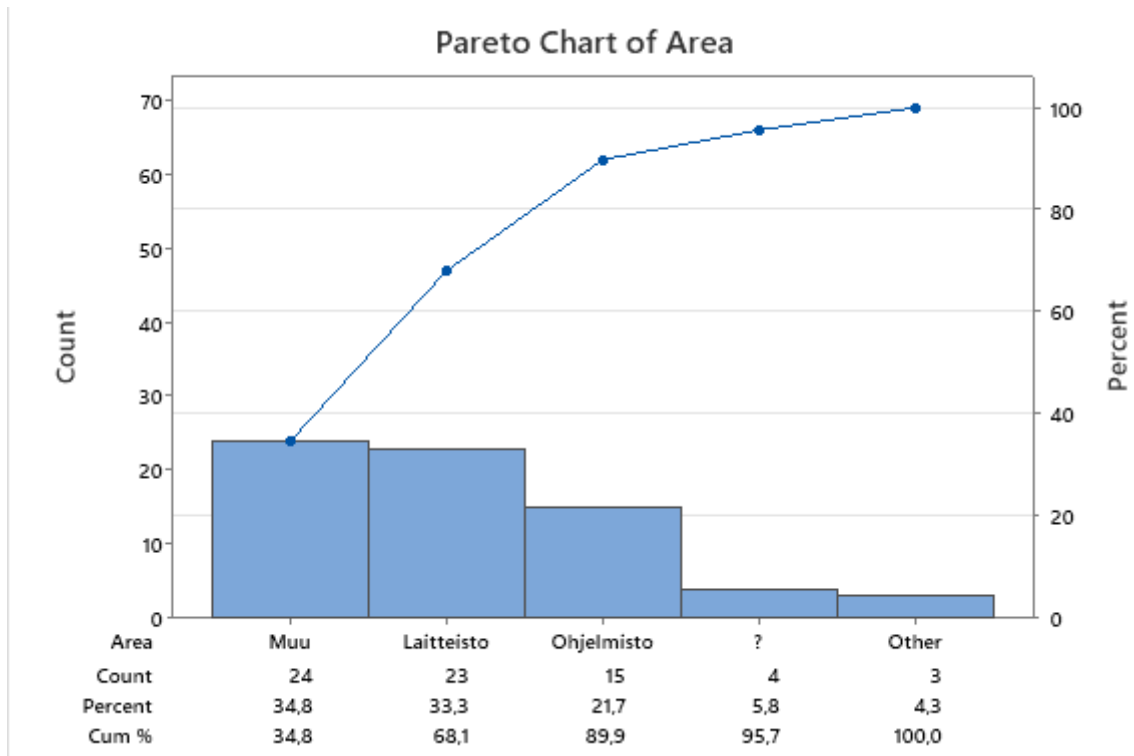


Figure 20. Pareto chart of tester errors.

From the chart we can see that “Muu” as in “Other”, “Laitteisto” as in “Machinery” and “Ohjelmisto” as in “Software” were the biggest causes for “Tester” errors. “Other” errors were mainly user errors or unknown errors which can be hard to solve. Instead, focus was on machinery issues as the tester machines are expensive investments and according to the production director it is somewhat alarming that many of the tester errors are caused by the machinery. This can be caused by poor maintenance and running many different electrical engines without proper optimizations. Also, simply wear and tear will cause issues eventually, if the tester is not properly maintained.

Recommendation: I would recommend the company to establish a “Total Productive Maintenance” or TPM-program for the testers. TPM is a methodology that focuses on improving productivity by keeping all equipment in good condition to prevent breakdowns. It involves everyone in the company, from machine operators to managers, in taking care of the equipment. (ASQ, 2024)

4.2.3 Process errors

From the pareto chart of process errors (Figure 21) we can again see the biggest reason for errors, which in this case is “Vian etsintä” as in “Error identification”. Errors under this category are hard to categorize and therefore focus is on “Limits”

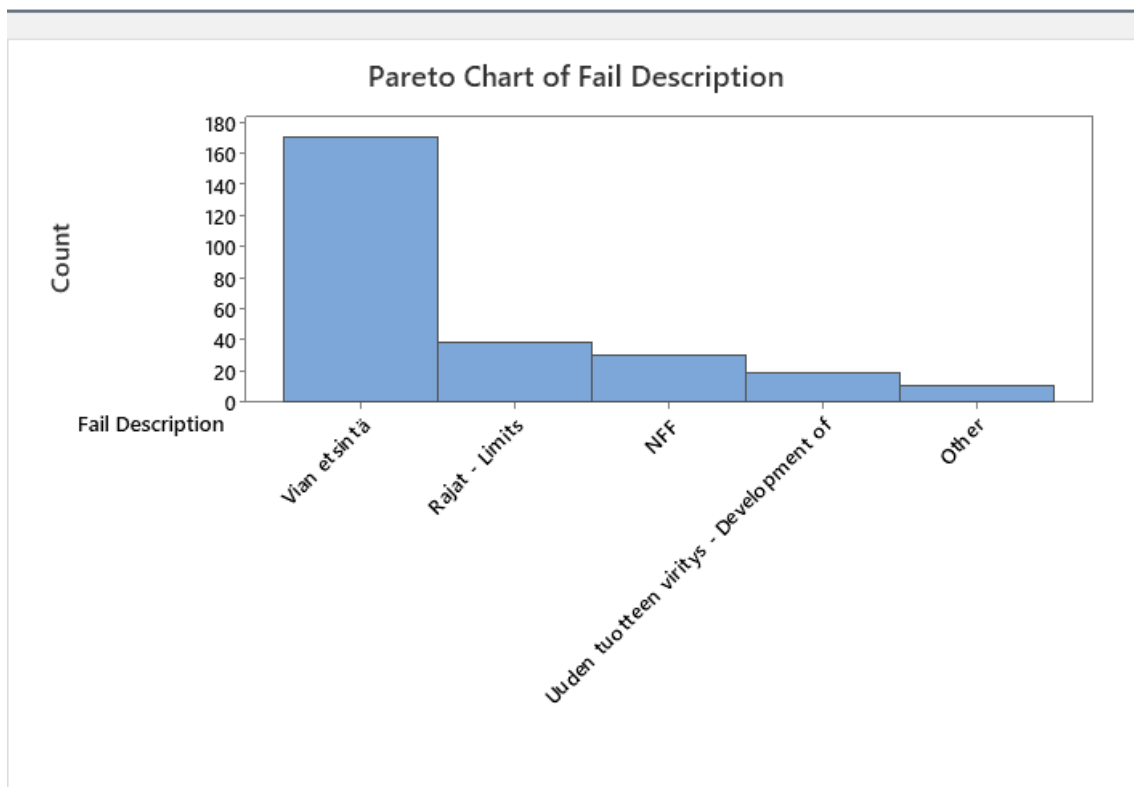


Figure 21. Pareto chart of Process errors

Limits stand for testing limits. Each drive is tested by attaching it to an electrical motor. And certain limits are determined for electrical currency/voltage and discharge time. There are multiple different testing limits, but in this thesis the focus was on limits for electrical breakdown and discharge time. Electrical breakdown limits are important for the safety of the drive. Testing breakdown limits tests that electrical currency runs in a correct places and that there are no shortcuts. With this test it can be made sure that no dangerous drives are delivered to the customer and therefore it functions as a Poka-Yoke

for safety. Looking at the control chart (Figure 22) for breakdown limits we can see that the process is not stable. It means that the drives voltage is always stable, as it should be. On the other hand, the difference between the mean and lower or upper control limit is only ± 2

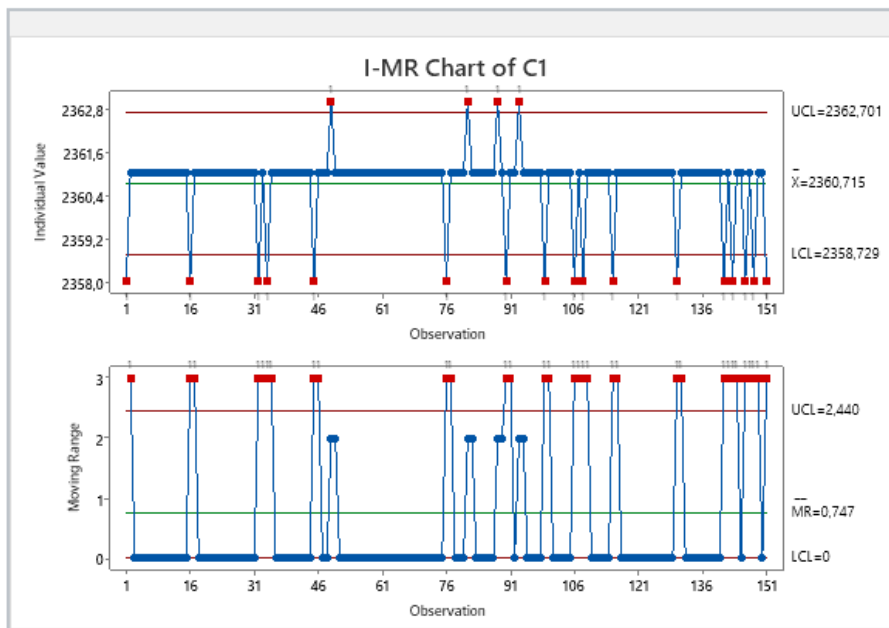


Figure 22. Control chart for breakdown limits

Discharge time is also a matter of safety. It measures time how long does it takes for a drive to discharge its electrical energy. Drives this big have lots of e.g. capacitors which stores electricity, and it takes some time after cutting the power that all those capacitors etc. have discharged their electrical energy. For the data about discharge time, we first analyze that the data is normally distributed and relevant to be analyzed further.

From Figure 23 we can see that data is roughly symmetrical and is slightly skewed to the left, and it's confirmed by the Skewness value $-0,64128$. P-value of the data is $0,015$ which would indicate that the data is not perfectly normally distributed. However, as the data is only slightly skewed ($-0,64128$), it can be determined that the data is not drastically non-normal and therefore can be used for our purposes.

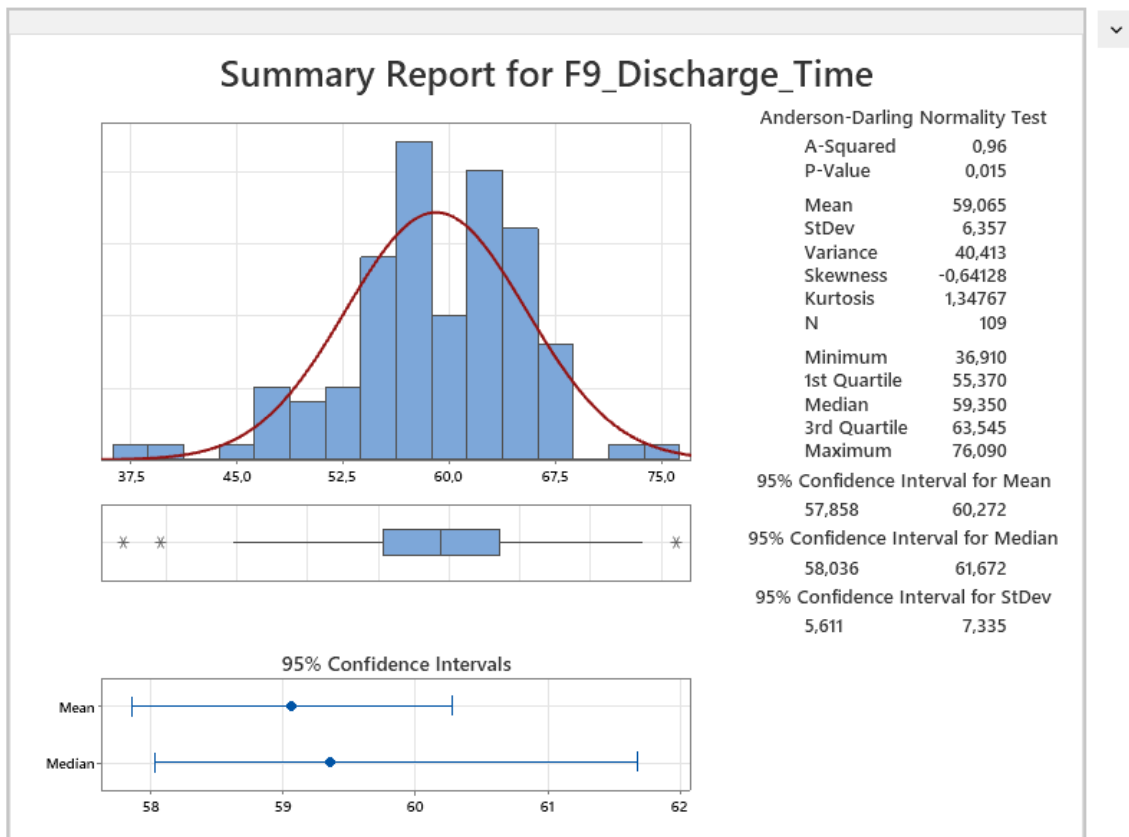


Figure 23. Normal distribution of Discharge time

Control chart (Figure 24) of Discharge time will show that discharge time is somewhat unstable as five datapoints are outside of control limits. But when taking specification limits into account (40, 80), only two datapoints are outside of those. Here it is important to remember that control limits and specification limits measures different things and are not always related. Control limits measures if data points are within ± 3 standard deviations from the mean. Control limits measure the variation. Specification limits are on the other hand usually determined by the process owner and they measure whether the process is capable of producing material that is within e.g. customer's specifications. In this case, specification limits are determined safety in mind. Electrical power should discharge between 40 and 80 seconds or there is something faulty in the drive and can be dangerous for the customer.

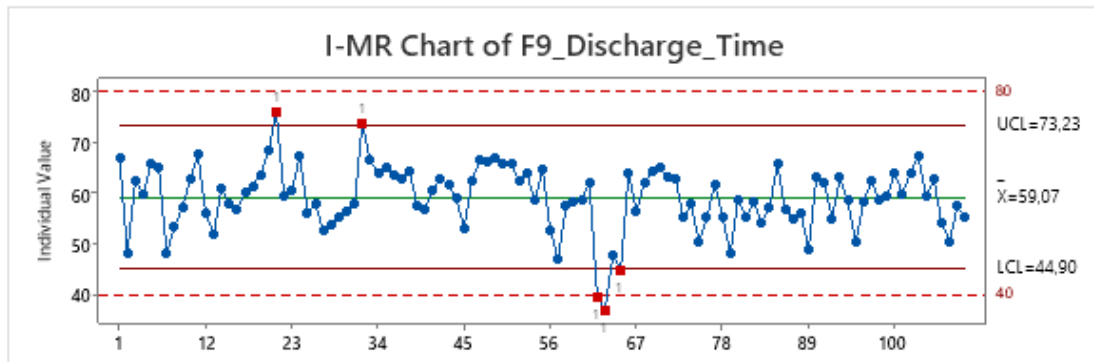


Figure 24. Control chart of Discharge time

Looking at the Process Capability Report (Figure 25) we can see that C_p is 1,41 and C_{pk} is 1,35 which will indicate that the production process of drives is capable of producing drives that falls within these specification limits.

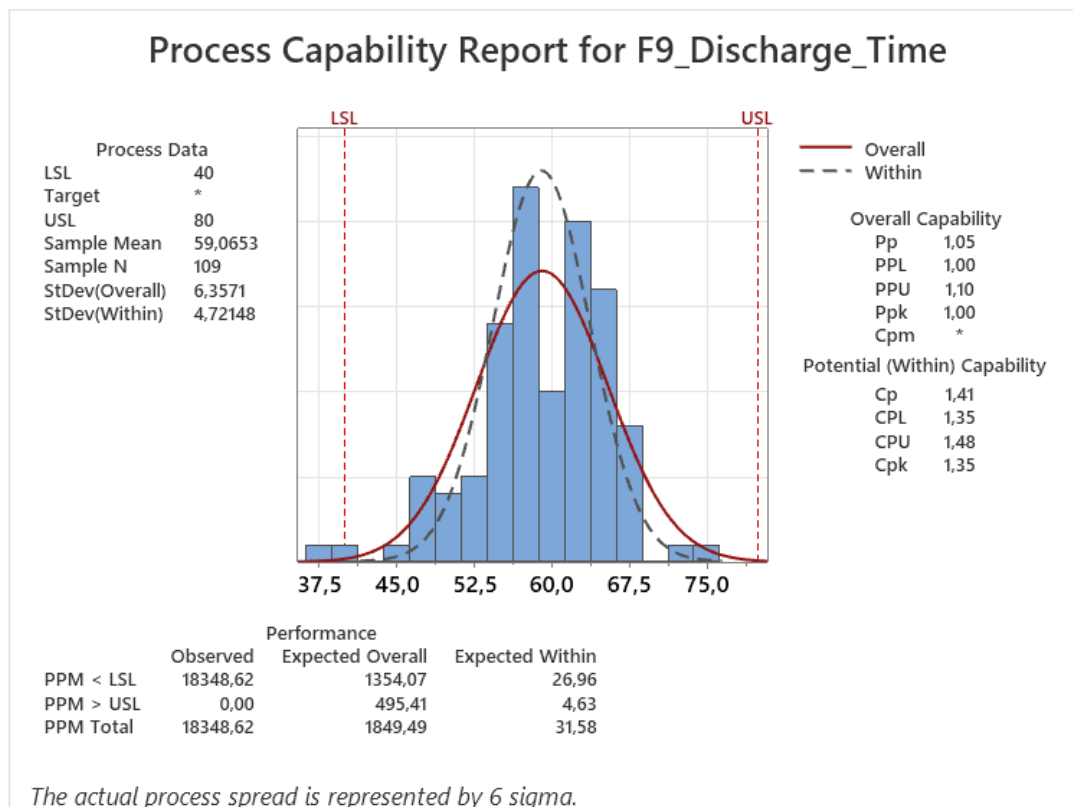


Figure 25. Process capability of Discharge time

Recommendations: Company should set clear testing limits for discharge time and electrical breakdown and if these limits are not met, the drive should be taken to further inspection to ensure safety of it.

4.3 Currently used quality tools and processes in case company

Danfoss, as one of the global leaders in the frequency converter industry, places a strong emphasis on quality management to ensure high quality of Danfoss' products.

Cornerstone of Danfoss's quality management is the ISO9001 certification. This well-known international standard founds the basis for Danfoss's quality management system helping Danfoss to achieve the level of quality that is needed by the customers as well as the regulations. ISO9001 provides Danfoss with a strong basis for continuous improvement operations. In addition to ISO9001 certification, Danfoss follows guidelines of IATF16949-standard which further strengthens their quality management system.

Besides following ISO9001 and IATF16949 which provides the basis for the quality management and continuous improvement processes, Danfoss utilizes multiple different tools to improve their quality and processes.

Six Sigma methodology is commonly used to improve production processes in Danfoss. Danfoss has its own Master Black Belt instructor who holds Six Sigma courses to Danfoss employees. The goal for the course is to instruct the participants to improve real world processes and the course is not passes unless the improvement made has been significant enough. This will motivate the participants to identify good improvement areas. Six Sigma projects are ran also outside of the course and these projects have had significant impact on improving the existing processes.

Supplier quality management is also important part of Danfoss quality system. For example, for circuit boards, Danfoss demands that the boards are tested at the supplier,

but Danfoss still does its own checks for every component at least once a year and more often if more defects have been detected for a single component.

Process charting, which is also a requirement to have ISO9001-certification, is obviously important part of quality management system. Every process in Danfoss has its own process charts, with process owners and facilitators to ensure that there is at least one person who is an expert in that particular process.

Related to process charts, Process Failure Mode and Analysis, or PFMEA is done individually for each production line. PFMEA will map every single step on the product line and each step's risk of failure or error is assessed and determined how severe the potential failure or error might be.

But in the end the most important quality tool Danfoss has is the committed leadership, which is committed to supporting continuous improvement and has established a quality policy for the whole company. Danfoss quality policy states that Danfoss will:

- Support their customers to achieve their business goals through committed leadership and highly skilled, competent staff
- Drive effective and aligned processes, and continually improve them to prevent failures
- Comply with statutory and regulatory requirements and agreed requirements from customer and other interested parties
- Ensure ISO9001 certification and IATF16949 compliance at all manufacturing locations.

5 Conclusions and discussion

The goal of this thesis was to improve Danfoss Drive Vaasa Factory's quality performance with using Total Quality Management tactics. The main research question of this thesis was *"How can Total Quality Management (TQM) tactics be effectively utilized to address and mitigate quality errors in quality control processes?"*

Which was supported by these three sub research questions:

- *What are the factors driving quality errors in frequency converter production, and how are they related to the manufacturing process?"*
- *How can Total Quality Management (TQM) framework/tactics be improved and implemented to mitigate quality errors in frequency converter production, considering the complexities of the manufacturing process?*
- *How effective are the implemented Total Quality Management (TQM) strategies in decreasing quality errors in frequency converter manufacturing?*

Considering these questions, this thesis was able to provide answers to nearly all of them.

- 1. Identifying key factors for quality errors:** This thesis focused on identifying factors which caused quality errors in three different categories, in assembly, withing testing system and within process itself. Main drivers causing quality errors were identified by using pareto charts and Cause-And-Effect diagram. The analysis highlighted that incorrect assembly, and loose screws were significant factors to assembly errors, while tester-related issues were the main cause of testing system errors.
- 2. Implementation of TQM Strategies:** This thesis implemented several different TQM strategies to address the identified quality errors. For assembly errors, the focus was on optimizing the use of smart wrenches to ensure proper fastening of screws, especially optimizing the screw angle watch limits. For

testing system errors, the recommendation was to establish a Total Productive Maintenance (TPM) program to improve the maintenance and reliability of testing equipment and to prolong the lifecycle of testers. Acquiring new testers are huge investments, so by implementing TPM program for testers the company can save significant amount of capital. Process errors were addressed by setting clear testing limits for discharge time and electrical breakdown to ensure safety and quality.

- 3. Effectiveness of TQM Strategies:** Unfortunately, the timeline of making this thesis did only allow us to monitor improvements of optimizing smart wrenches' angle watch limits and only for one screw. By optimizing the limits, we were able to eliminate incorrectly fastened screws. As can be seen from Figure 26. There were two data points outside of specification limits, but these were caused by too little torque. There are datapoints below the lower specification limits as well, but after consulting production tool specialist, he claimed that these are caused by faulty washers. So, by optimizing the angle limits, we were able to eliminate incorrectly fastened screws. But as the limits were only optimized for one screw, this didn't impact the overall quality metrics of that production line. Other recommendations that were made are not quick to implement and would almost require its own thesis and therefore now hard data was available to measure the effectiveness of TQM strategies.

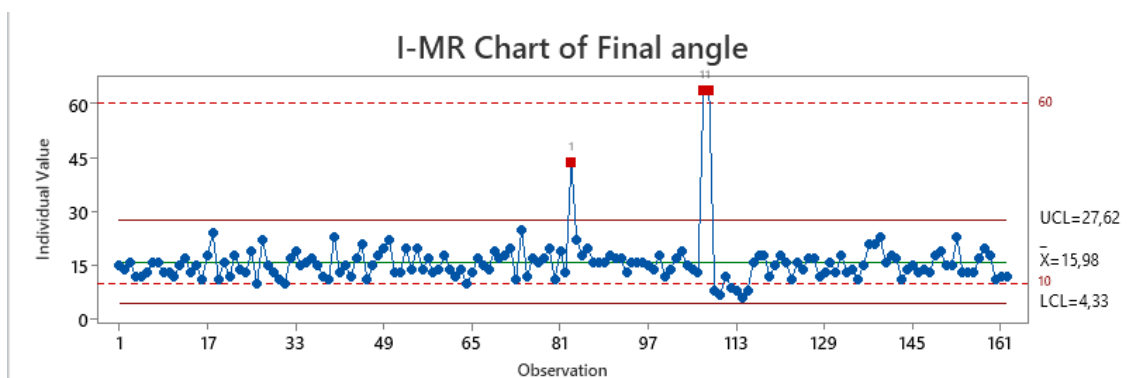


Figure 26. Angle watch control chart (optimized)

But then getting back to the main research question; *“How can Total Quality Management (TQM) tactics be effectively utilized to address and mitigate quality errors in quality control processes?”* This thesis successfully demonstrated how TQM tactics can be utilized to improve company’s quality performance, if only there are people within the company who have been taught to use these tactics. TQM tactics turned out to be that “universal” that I think can be applied to anywhere and to anything. Especially Demings’s PDCA-cycle, Oakland’s DRIVER-framework and Six Sigma DMAIC-framework can be used anywhere. For TQM tools, Statistical Process Control, SPC, turned out to be effective method of analyzing data as it was proven already in the 1930’s by Shewhart.

For the case company Danfoss Drives Vaasa Factory, there already were lot of people who were experts on using TQM tactics to improve quality performance and there already were several TQM tactics implemented. Danfoss also provides several trainings for example root cause problem solving and previously mentioned, their own Six Sigma green and black belt courses. This demonstrates how Danfoss leadership is committed to continuous improvement, which was one the cornerstones of successful TQM implementation. It became clear that successfully implementing TQM tactics are people driven and it requires some imagination and creativity to find out how quality can be improved. It also requires support from the leadership to get the resources and time that is needed to improve the quality performance. But what I did notice was that as the quality performance is already at that good level and TQM tactics widely implemented the company could put an effort to small improvements. Many smaller factors which caused quality errors might have gone unrecognized or were not seen as worthy putting effort into. But addressing many of these smaller issues could make a change in the bigger picture. For example, optimizing the angle watch on smart wrenches was only done for some product lines, and not nearly all of them. Loose screws were not even close to being one the biggest factors causing quality errors but as the saying in Finnish goes, “from small creeks a great river is born”

In conclusion, the implementation of presented TQM strategies at Danfoss Drives Vaasa Factory could lead to significant improvements in quality performance. This thesis demonstrated the effectiveness of using a systematic approach to identify, analyze, and address quality issues. Continuous improvement and employee involvement were identified as key factors in sustaining long-term quality improvements.

5.1 Limitations and Recommendations for future research

As was stated previously on this thesis, quality errors caused by material errors were limited out this thesis as those are mainly caused by faulty materials and there isn't much that can be done for those at the factory floor. But as we can see from figure 13, materials errors were the most prominent cause for quality errors, it would be interested to see what could be done to improve the quality of Danfoss's suppliers. It could be investigated how the suppliers are using TQM tactics, if at all and if some suppliers that have more issues than others can be identified. This kind of research could potentially make a huge improvement on the quality performance.

One of the recommendations made in this thesis was to establish a Total Productive Maintenance Program, TPM for testing machinery. As TPM itself is such a large topic, it was limited out of this thesis and only recommendation of it was given. Implementing TPM for testing machinery would make interesting research topic which could deep-dive into what Total Productive Maintenance actually means and could demonstrate the effectiveness of it by calculating potential savings if successfully implemented TPM could eliminate the need of investing to a new testing machine. Research could also describe how the TPM would be implemented and what is included in it.

And finally, as data collection was also limited out of this study, it could also be an interesting research topic to investigate if the data collected is valid. After all, operators are making the data and operators as humans might have different opinions about which kind of quality error is categorized under which category.

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