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Finding and Eliminating the Root Cause of Defects Identified in Customer Complaints

A case study using the Six Sigma methodology to facilitate root cause analyses

Master's Thesis Project in the Master's Degree Program Quality and Operations Management

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Abstract

Volvo Cars is a global car manufacturer that produces premium brand cars that demand high quality. The quality of a product is often defined by the degree of customer satisfaction. Therefore, Volvo Cars Corporation has internal departments working with customer complaints. This thesis was performed in collaboration with the department Variability Reduction Team who perform root cause analyses initiated by customer complaints on newly produced cars. A case study was performed regarding a customer-initiated problem with loose support bearings at the production plant in Torslanda. People from several different departments possess different knowledge and experience regarding the problem with loose support bearings. Therefore, cross-functional collaboration was essential for the success of this project. In addition to finding the root cause, learnings from the case study were also generalized into recommendations to future projects.

Initially, the existing knowledge about the origin of the problem with loose support bearings was limited, and many short term solutions were used. Some of the implemented short terms solutions lead to additional waste in the form of non-value adding activities. For example, additional controls, replacement of defect support bearings, rework, and administrative work. The root cause is confirmed to be within the production concerning the alignment between the car body and the equipment assembling the support bearing. By making the production process more robust and increasing its reliability, the perceived quality of the car is increased, and high customer satisfaction is maintained.

The case study follows the DMAIC methodology from Six Sigma, which is similar to the problem-solving methodology used internally at Volvo. Therefore, improvement areas were defined based on factors that the authors experienced hindered efficient problem-solving. To solve these challenges and decrease their impact, recommendations were given to Volvo within the four areas: base decisions on facts, standardization, knowledge sharing, and also communication and collaboration. Using these recommendations and thereby making the problem-solving process more efficient could enable a more beneficial resource allocation and better root cause analyses.

Keywords: *Six Sigma, DMAIC, Root Cause Analysis, Robustness, Waste, Customer Satisfaction, Cross-functional Communication*

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Abbreviations

ICA: Interim Containment Action

ME: Manufacturing Engineering

PCA: Permanent Corrective Action

VCBC: Volvo Car Body Components

VCC: Volvo Cars Corporation

VCCH: Volvo Cars Charleston

VCCD: Volvo Cars Chengdu

VCDQ: Volvo Cars Daqing

VCG: Volvo Cars Gent

VCT: Volvo Cars Torslanda

VRT: Variability Reduction Team

WES: Work Element Sheet

R&D: Research and Development

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1. Introduction

To achieve high customer satisfaction and competitiveness in the market, companies need to work with quality in innovating and systematic ways (Bergman & Klefsjö, 2010). High customer satisfaction is considered to be one of the main reasons for future business success (Matzler, Hinterhuber, Bailom & Sauerwein, 1996). Bergman and Klefsjö (2010) state that the measure of quality, which is considered a relative term defined by the competition in the market, is best measured through customer satisfaction. Quality is, therefore, a critical competitive factor for Volvo Cars Corporation that produces premium cars, which entails a high quality. Sower and Fair (2018) argue that continuous improvements are crucial for business success. In this project, the authors got the possibility to perform a case study by executing an improvement project about one quality issue identified by customers.

1.1 Background

This master thesis is performed as a case study at the car manufacturer Volvo Cars Corporation (VCC). VCC is a global manufacturer that produces premium cars in several countries. Further on, the company is referred to as Volvo. In the year 2019, Volvo broke its sales record and sold over 700 000 cars all over the world (Volvo Cars, 2020a). The car production is in Sweden, China, the USA, Malaysia, and Belgium. This project is performed and focused at Volvo's oldest production plant Volvo Cars Torslanda (VCT), in Gothenburg, Sweden. Currently, the plant has a production rate of approximately 60 cars per hour and produces a variety of car models over three working shifts. In VCT, around 300 000 cars are produced yearly. All the car models produced in VCT belong to the Scalable Product Architecture (SPA) platform, and the models produced are V60, V60CC, V90, V90CC, XC60, and XC90.

The goal within production is to produce cars with high quality, but unfortunately, some customers receive cars with smaller defects that might need to be adjusted. For cars no older than three months, all customer complaints from both retailers and repair shops are sent to the department Variability Reduction Team (VRT). This department performs root cause analyses based on quality problems in the production plant as well as customer complaints. The work is performed by working cross-functionally and collaborating with several different functions depending on the type of customer complaints. Before the root cause is found, a temporary solution is implemented to minimize the consequences of the problem. The goal is although to find the root cause and implement actions that prevent the issue from occurring again.

To understand how the work performed at VRT in collaboration with related functions can be improved, a case study was conducted where the authors examine a real problem initiated by customer complaints. This project emerged due to several customers receiving cars from the production plant with loose support bearings, occasionally slipping through the post-production inspection. The sun visors in all Volvo cars are fastened by a hook to a support bearing attached to the headliner and car body (see Figure 1 below). When the support bearing is loose the sun visor's function can be affected, which is shown by the sun visor hanging down that the customer notices. There have been troubles with loose support bearings within the production at VCT for a longer period. Information from the company indicates that there have been variating amounts of problems with loose support bearings since the SPA cars were introduced into VCT 2015. Therefore, there are two permanent controls, where the operators should check that the support bearing is fully attached. These controls could, therefore, be described as the Interim Containment Action (ICA), which should hinder the symptom of loose support bearings reaching the customer. Nevertheless, several cars with loose support bearings have passed these and being delivered to customers. Therefore, this problem has gained a new focus since these types of failure should not reach the field.

Figure 1. Picture of the sun visor and placement of the support bearing (Volvo Cars, 2020b).

The support bearing is delivered by an external supplier and is thereafter assembled by both manual and automatic operations into, first, the headliner and thereafter the car body. Therefore, there are many potential root causes with different patterns that could affect the problem, such as the component itself, the car body, the headliner, the automatic assembly operation, the manual operations by the operators, or inspections, etcetera. The variety of factors that influence the component leads to an involvement of a variety of organizational functions and their relationships. Bryman and Bell (2011) suggest the selection of case should be based on the opportunity to learn from it. Therefore, this complex problem that is affected by many different factors and functions allows bringing learnings to other future projects.

1.2 Purpose

The purpose of the case study is to find areas of improvement from the root cause analysis of loose support bearings that can be generalized to solve additional problems and facilitate the problem-solving process. This case study also focuses on finding and eliminating the root cause of why some support bearings do not attach fully to the car body. Eliminating the root cause and implementing a Permanent Corrective Action (PCA) would minimize the amount of rework that leads to additional costs due to factors such as the lower amount of labor expenses and less discarded parts. Increasing the robustness of the support bearing assembly could also enable removal of the permanent controls, which are non-value adding work. If a PCA is implemented, it is less probable that a car with loose support bearing reaches the end customer, which will help to maintain a high level of customer satisfaction.

1.3 Delimitations

This thesis will only focus on one root cause analysis and thereafter, aim to generalize it. Since all the projects at Volvo are unique, the findings from this case might not be applicable in all other cases but can be used for increased understanding and an illustration of the methodology in action. For this specific case, no changes in the design or material of the support bearing will be considered. Neither will purchase decisions, and choice of supplier will be included, it will be considered as the incoming variation that needs to be neutralized. Existing equipment in the production, such as the palette attaching the support bearing can only be modified and cannot be replaced entirely.

Considering the time frame for this project, the implementation of the given recommendations will not be completed by the authors. This thesis is written during spring 2020, which is a time strongly influenced by the COVID-19 pandemic. Consequently, Volvo has reduced the working time for many of its employees, hindering this project from moving further and closing the project. Therefore, the authors will compile recommendations at the end of the project and hand them over to the responsible persons who need to take further ownership of the project. Additionally, the COVID-19 pandemic hinders the authors from accessing information from some of the other production plants due to temporarily shutdowns globally.

1.4 Research Questions

- What is the root cause of the problem with loose support bearings to the sun visor, and how could it be improved?
- What potential improvement areas exist for the successful performance of root cause analyses based on this case study?

2. Theoretical framework

This chapter aims to describe the theoretical background of the project. The chapter includes theory about *Quality Management, Customer Satisfaction, Production Systems, Lean Production, Organization, Knowledge Management,* and *Robust Design*.

2.1 Quality Management

To achieve competitiveness in today's global market, companies are forced to work with improved quality as a critical factor (Hietschold, Reinhardt & Gurtner, 2014). There are several definitions of the concept quality which means it can be understood in different ways (Bergman and Klefsjö, 2010). The understanding of the term quality has moved from the earlier “Free from defects” to “Fitness for intended use” (Sower & Fair, 2018). One common definition of quality for products is “The quality of a product is its ability to satisfy, or preferably exceed, the needs and expectations of the customers” (Bergman & Klefsjö, 2010, p.23). Hietschold, Reinhardt, and Gurtner (2014) state that companies apply different practices to achieve a high quality, such as *Total Quality Management* (TQM) and *Six Sigma*.

2.1.1 Total Quality Management

Total Quality Management (TQM) is a strategy for businesses to enhance organizational performance by focusing on the complete value chain that includes and emphasizes human factors (Hietschold et al., 2014). Bergman and Klefsjö (2010) describe TQM as a concept consisting of a combination of values, methodologies, and tools. The values are summarized as the six cornerstones of TQM and are shown in Figure 2 below. These six values are: committed leadership, focus on customers, base decisions on facts, focus on processes, improve continuously, and let everybody be committed. Each value is further described below based on their description by Bergman and Klefsjö (2010).

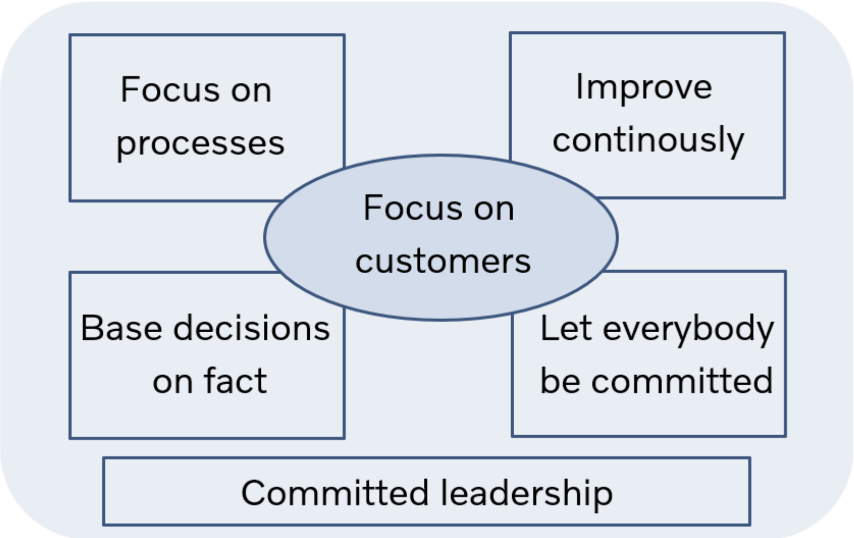

Figure 2. The cornerstone model (Bergman & Klefsjö, 2010).

Focus on customers is shown in the center of the cornerstone model since it is the central aspect of quality as the customers evaluate it. The focus should, although not only be on external customers, but the internal customers are also considered essential. Focusing on the customers include both understanding the customer needs and trying to fulfil them.

Base decisions on facts is about not base decisions on random factors but base them on true knowledge. It is argued that companies need to have strategies on how to base decisions on facts and use existing knowledge. To be successful, companies need to search for information that is compiled and analyzed actively. Typically, tools to gather data are through the Seven Improvement Tools and the Seven Management Tools.

Focus on processes is about understanding the process input and how it is transformed into the output. The primary purpose of every process is to satisfy its customers. The process view can help the company to understand how well each process satisfies the customer and link the future to the past.

Improve continuously is about continually improving the quality of products, processes, and methodologies with the goal of using fewer resources. The continuous improvements are often based on the Plan-Do-Check-Act (PDCA) cycle, which is an iterative workflow. One commonly used word describing continuous improvements is the Japanese word ‘Kaizen’ which usually describes smaller continuously made improvements.

Let everybody be committed highlights the importance of involving everyone in the organization in quality work. The organization needs to facilitate the opportunities for all employees to contribute to the quality work. For the employees to perform a good job, they need to feel responsibility, personal pride, and commitment. It is argued that employees who are given responsibility and authority have a higher chance of performing a good job with high quality when they are given recognition for it.

Committed leadership is in the bottom part of the cornerstone model as it is the base for the quality work. The role of committed leadership is to create a culture that emphasizes successful and sustainable quality improvements.

2.1.2 Six Sigma

Six Sigma was initially formulated in 1986 within the manufacturing division at Motorola, and thereafter, its applicability has evolved (Desai, 2010). Mast and Lokkerbol (2011) describe *Six Sigma* as a generic approach for problem-solving and improvements. They further argue that *Six Sigma* is related to a collection of practices and tools rather than one single practice. Schroeder, Linderman, Liedtke, and Choo (2008) state that even though many of the tools used in *Six Sigma* are similar to previous quality management practices, *Six Sigma* also provides an organizational structure that has not been seen before. Further, Carleton (2018) defines *Six Sigma* as a business philosophy that includes several improvement methodologies and performance metrics. When putting the methodologies and tools into a business philosophy, companies can achieve world-class quality and higher levels of customer satisfaction. This is done by aligning the organization's strategic goals and values to the needs and expectations of the customers.

Due to the variety of usage of the methodologies and tools used in *Six Sigma*, there exist several definitions. Schroeder et al. (2008) propose the following base definition: "*Six Sigma* is an organized, parallel-mesostructure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives" (Schroeder et al., 2008). However, they also state that according to contingency theory, no definition will suit everyone.

According to George (2005), two factors determine if the *Six Sigma* methodology is applicable to solve the problem. The first factor is that the problem is complex, which means that people from different areas need to be gathered. If the problem is complex it also implies that gathering lots of different data probably will be required before any pattern can be detected. The second factor presented by George (2005) is that the solution's risks are high, meaning that the solution needs to be developed, tested, and refined before it is implemented into the workplace.

2.2 Customer satisfaction

Customer satisfaction is considered crucial for future business success since satisfied customers are loyal and ensure a long-lasting cash-flow in the future (Matzler et al., 1996). Throughout history, the view of quality and the role of the customer has changed. Lengnick-Hall (1996) states that the customer's role has changed from viewing the customer solely as a buyer to giving the customer an active voice in product and service design and sometimes even viewing the customer as a potential partner. It is further argued that the customer determines what dimensions of quality are essential. Bergman and Klefsjö (2010) also argue that the ultimate measure of quality is through customer satisfaction. They further state that all organizations have several customers, both internal and external.

2.2.1 The Kano Model

Bergman and Klefsjö (2010) describe that the customer buys different goods to fulfill a need and therefore, highlights different types of needs. Some needs are more explicit and can be asked for by the customer, while the customers are unaware of others. Matzler et al., (1996) describes the Kano model shown in Figure 3 below. The model consists of three different types of product requirements: must-be, one-dimensional, and attractive requirements. The must-be requirements are the essential criteria of the product; if these are not fulfilled, the customer will be extremely dissatisfied. Although, these requirements are taken for granted by the customer and can, therefore, not increase customer satisfaction. One-dimensional requirements are usually the characteristics which the customer explicitly can state that they demand from the product. These are called one-dimensional because customer satisfaction increases proportionally to the level of fulfillment. Attractive requirements are those the customer is not aware of that they need or expect. Fulfilling these requirements do lead to a more significant increase in customer satisfaction but cannot make the customer dissatisfied.

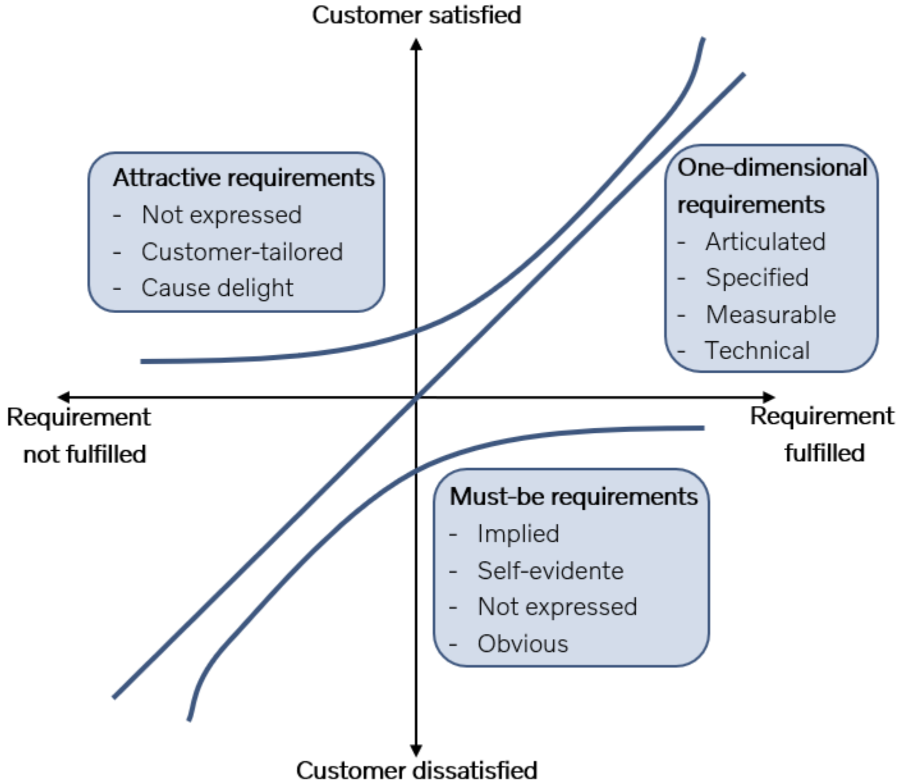

Figure 3. The Kano model with the three types of product requirements, must-be, one-dimensional and attractive requirements (Matzler et al., 1996).

The Kano model and the three types of product requirements can be used to understand how customers value different needs (Bergman & Klefsjö, 2010). It is further argued that it is essential for companies to understand what they mean by a satisfied customer. Bergman and Klefsjö (2010) highlight that in order for companies to be successful and competitive, they need to make sure they not only interpret “satisfied” as “not dissatisfied” but also exceed the basic needs.

2.3 Production systems

Manufacturing refers to transforming raw materials into useful products, on the factory floor, different production systems can be used for manufacturing (Li & Meerkov, 2008). Andersson, Audell, Giertz, and Reitberger (1992) state that the choice of a production system depends on a compromise of several factors. The decision about a production system affects several factors such as: throughput times, amount of tied capital, degree of utilization of machines and personnel, transportation costs, and the flexibility of the production system. It is impossible to focus on all the factors, and priorities must be done depending on the desired output. Börnfeldt (2017) describes that today a production line layout is the most common production layout in the automotive industry. This layout originates from Taylorism, with its roots in the first production line that enabled mass production of cars. This layout allows the manufactured goods to be assembled by going through different points where different operations are added (Börnfeldt, 2017). At the production line layout, different operations are performed, traditionally by workers, but in the modern industry, more and more automatization is installed.

Weisskirchen (2017) argues that substantial cost savings can be achieved in the industry sector by implementing useful production robots and machines. Automatization can replace workers and could lead to cost savings compared to using human labor. Brougham and Haar (2018) state that a robot can work around the clock every day, and do not have to be paid a paycheck. It can also perform tasks that otherwise would lead to ergonomic problems. Nevertheless, several reasons for not making a whole production line automatized have to be taken into consideration. Börnfeldt (2017) states that, for example, Toyota mainly uses manual assembly instead of automatic since automatic assembly often requires an expensive investment of machines. Furthermore, using automatization decreases the flexibility of a process since it is harder and more resource-demanding to change the process in the future.

2.4 Lean Production

Lean Production, referred to as *Lean*, originates from *Toyota Production Systems (TPS)*. Petersson, Olsson, Lundström, Johansson, and Broman (2015) states that *TPS* is about producing with the right resources, in the best way. Monden (2011) describes the time after the Second World War, when Toyota in Japan had to operate with fewer resources. Toyota could no longer fully adapt the American production techniques based on the Ford system, where the central part of cost reduction and increased profits comes from large scale production. Toyota managed instead to increase profits and cut costs by different methodologies such as reducing and eliminating waste. Monden (2011) further explains other essential elements of TPS, which are continuous improvements (Kaizen), the right quality (Jidoka), and Just in Time (JIT). Rütttimann (2018) defines Lean as “Kaizen-based JIT production” to highlight the importance of continuous improvements. The continuous improvement concerns all processes in an organization.

2.4.1 Waste according to Lean

According to Lean, activities are defined as either value-adding or waste, and reducing and eliminating waste are central aspects of Lean (Womack and Jones, 2003). The work is done continuously to eliminate: Muri, Mura, and Muda (Petersson et al., 2015). Muri is about overburdening people or equipment, which can result in safety and quality problems as well as equipment failure. Mura stands for unevenness and variations. When there is great unevenness, resources for the highest demands are needed, even if there are periods with less demand. Muda is about non-value-added activities and waste and is often considered the result of Muri and Mura (Liker, 2004). Muda is usually divided into eight different types of waste (Petersson et al., 2015). Toyota identified the following seven types of non-value-adding activities as waste: overproduction, defects, inventory, transportation, waiting, motion, and over-processing. Later on, unused employee creativity was also added as a form of waste. Therefore, they are nowadays more commonly referred to as “seven plus one wastes” (Liker & Meier, 2006).

2.4.2 Processes and standardization

Petersson et al. (2015) state the importance of having a process view when working with lean and clearly define who the customer is at each process step. In order to ensure that the right measures are taken to satisfy the customer, it is vital to not only define the customer but define what the customer wants and when the customer wants it. Bergman and Klefsjö (2001) argue that customer satisfaction is the best measurement to measure achieved quality.

Liker (2004) states that "standardized tasks are the foundation for continuous improvement and employee empowerment". Liker (2004) describes this principle as more important than making the operators' tasks repeatable and efficient. Instead, the author states that tasks need to be standardized for improvements to be made. If the operations are not standardized and the process stable, the improvements can be seen as just one more variation to the process. Standardization is also essential to minimize defects and one way to ensure high quality. Liker (2004) further states that the standards need to be specific enough to be used as guidelines, but also include some flexibility, depending on the task.

2.5 Robust Design

The interest in variation and its effect on the performance and output started with mass production during the industrial revolution (Arner, 2014). Although the concept of robust design was first introduced by Taguchi in the 1940s (Arvidsson & Gremyr, 2008). According to Bergman, Loren, and Svensson (2009) robustness is about increasing the system's reliability. They describe reliability as: "The ability of a product to provide the desired and promised function to the customer or user" (Bergman et al., 2009). Throughout a product's lifetime, it is exposed to several sources of variations that can affect its performance (Bergman & Klefsjö, 2010). Variations affecting the system are usually referred to as noise factors to the system. Noise factors can be categorized in several different ways, one way of categorizing them according to Bergman et al. (2009) is the noise generated from within the system (inner noise) and as noise generated from outside the system such as the environment or usage of the system (outside noise). According to Arner (2014), the noise factors are the factors that the response or outcome should be robust against, meaning that it should not affect the performance of the output.

2.5.1 P-diagram

The robust design is often illustrated by a P-diagram, shown in Figure 5 below. The diagram aims to illustrate how the input, which can be several different factors, affect the system's output and performance. Although not only is the input affecting the output, there are also two types of variations that impact the output; these are called noise factors and control factors (design parameters) (Bergman & Klefsjö, 2010). Arner (2014) further exemplifies typical noise factors such as manufacturing variation, customer and operator behavior, and environmental conditions. The author further explains that these factors cannot be controlled in real life; therefore, the system needs to be robust against them. Control factors, on the other hand, are factors that the engineer can choose to affect and change. Typically, control factors are geometry parameters, choice of material, etcetera.

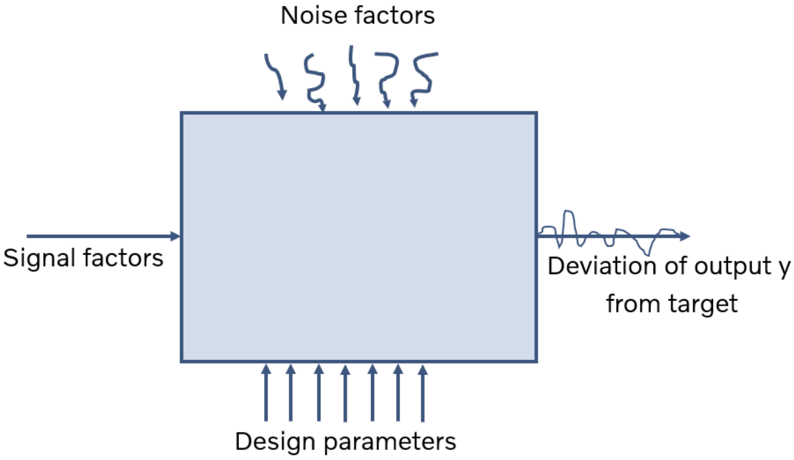

Figure 5. P-diagram showing how the process output is affected by signal factors together with noise factors and design parameters (Bergman and Klefsjö, 2010).

2.5.2 Goal with robust design

The goal with a robust design is to reduce the variations in the output and the product characteristics by making the process more robust towards the noise and control factors (Arvidsson & Gremyr, 2008). The goal is to avoid failures and increase reliability, which commonly has been done by separating the demand and capacity. Traditionally, this has been done by reducing the variations in the form of, for example, imposing different tolerances or limiting the use of the product (Bergman et al., 2009). Bergman et al. (2009) further argue that failures do not only lead to additional warranty costs for the company but also for losing goodwill from the customers.

2.6 Organization

Lindkvist, Bakka, and Fivelsdal (2014) describe the characteristics of an organization as the administrative rules, valuation, and the spread of work that together creates coordination and target achievements. Organizations exist in both private and public contexts all over the society, for example, religious and economic. A work organization is usually defined by the business and assignments being divided into groups depending on their function (Börnfelt, 2017).

2.6.1 Cross-functional collaboration

According to Tsai and Hsu (2013), companies need to possess resources and skills for successful product development. These resources are, although, usually spread over different functions within the organization. Therefore, they argue for the need for successful cross-functional collaboration. Wheelwright and Clark (1992) state that cross-functional integration must be more than a scheme linking the different functions together to be successful. Efficient cross-functional collaboration occurs on the working level and requires communication between groups and individuals working in related areas. It is further argued that the pattern of communication between different groups is essential. Four dimensions can describe the pattern of communication: richness, frequency, directing, and timing.

In order for organizations to achieve cross-functional collaboration, it is also required with focused actions from senior management (Wheelwright & Clark, 1992). For example, senior management can help to educate people and give them cross-functional experience as well as investing in tools and methods that create a common language between the different functions. Tsai and Hsu (2013) highlight that apart from the successfulness of cross-functional collaboration, it can also bring in problems into the organization. For example, cross-functional activities are usually time-consuming, and they can also create conflicts between the different functions. According to Schaubroeck, Tarczewski, and Theunissen (2016), and their study of 25 companies, cross-functional collaboration usually is made even more difficult due to fragmented ownership of processes and information.

2.6.2 The human factor

The human factor refers to multiple factors that might interfere with reaching the wished outcome from a process because of human actions (Feggetter, 1987). When people are put in a position where they have to use their own decision making, there is no guarantee that they will know and make the right decision for their future action. For example, a pilot needs to make several decisions on his own to fly an aircraft, and if he is tired or upset he will maybe try to land the plane too early. If the aircraft system is designed so the pilot cannot decide to land before a geographical sensor permits him, the risk of an accident will decrease.

Liker and Meier (2006) state that it is widely agreed within businesses that people make mistakes. The author further argues that companies need to shift the responsibility for errors from people, to the method and the system. When shifting the responsibility from the people, it enables them to improve the process and facilitates problem-solving.

One way of decreasing the risk of the human factor interfering with the wished outcome in the production is the implementation of Poka-Yoke. Pötters, Schmitt, and Leyendecker (2018) describe that the Poka-Yoke method originated from Lean manufacturing and was used for fault prevention. The method focused on designing work performed manually in a way that makes it almost impossible for the worker that is performing a task to make the wrong choice. The authors state that implementations of Poka-Yoke on floor level in manufacturing are significant to decrease the number of needed reworks on a produced good. Furthermore, it is essential to oversee existing Poka-Yoke in production since the human factor might create variations in the outcome if Poka-Yoke is not implemented correctly. Liker and Meier (2006) further state that it is impossible to use Poka-Yoke everywhere since the use of the mistake-proofing device usually adds layers of complexity. Increasing complexity can have consequences such as longer throughput times as well as causing problems in understanding.

2.6.3 Double-loop learning

Argyris (1977) states that an organization can handle problems that occur by two methods, either single-loop or double-loop learning. Single loop learning means that the symptoms of one problem are addressed directly, and the root cause of the problem is not questioned. Double-loop learning refers to a deeper questioning of why the problem occurred and how it can be prevented. Organizations that adopt double-loop learning become more efficient, and therefore all employees must have this mindset (Argyris, 1977). The right resource allocation can be made within the organization to come up with a long-time solution by learning about the root cause of the problem. When single-loop learning is used it can lead to enormous costs for the organization over a more extended period, since only the symptoms and not the cause of the problem is treated.

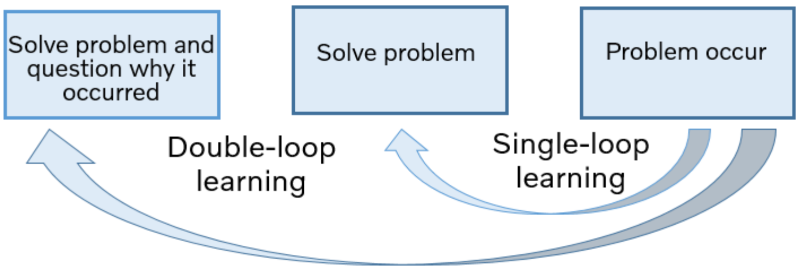

Figure 4. Model showing how single and double-loop learning works (Argyris 1977).

2.7 Knowledge Management

Knowledge is argued to be one of the most critical factors for competitiveness. Therefore, Börnfelt (2017) states that many organizations need to steer and use their knowledge in a more effective way. According to North and Kumta (2018), knowledge can be divided into explicit and tacit knowledge. Explicit knowledge is formal and structured and can, therefore, easily be stored and shared. Tacit knowledge, on the other hand, is more personal and experimental, consisting of knowledge gained from, for example, executing tasks and lessons learned from previous projects. Often the tacit knowledge is unconscious, which makes it harder to formalize and communicate. North and Kumta (2018) further state that according to the iceberg theory, there is a lot more tacit knowledge underwater than the explicit knowledge that can be seen above the water.

Knowledge management is defined as:

> Knowledge management enables individuals, teams and entire organisations to collectively and systematically create, share and apply knowledge to achieve their strategic and operational objectives. Knowledge management contributes to increase the efficiency and effectiveness of operations on the one hand and to change the quality of competition (innovation) on the other hand by developing a learning organisation. (North & Kumta, 2018 p.13)

2.7.1 The process of Knowledge Management

Börnfelt (2017) further argues that Knowledge Management is about creating, storing, spreading, and using knowledge more effectively. The knowledge is created by making knowledge more explicit, which will enable the knowledge to be stored. Storing knowledge can be explained by spreading it to other individuals in the organization or storing it with the help of information technology. The spreading of knowledge can be through interactions with people and through access to databases with gathered knowledge. Many employees have valuable knowledge that needs to be spread across the company. The author further argues that by spreading the knowledge obtained by individuals, the ownership of the knowledge is moved to the company and is not dependent on that one specific person being kept within the company.

2.7.2 Cross-cultural knowledge management

North and Kumta (2018) argue that an increasingly important factor in today's more globalized society is cross-cultural knowledge management. Many global companies are experiencing troubles with combining local differentiation and global standardization. The tacit knowledge usually differs between countries and cultures due to factors such as relations between people, motivational orientation, and attitudes toward time. Consequently, companies need to find out where new knowledge is created, safeguard this knowledge from competitors, make the knowledge useful within the company worldwide, and enhance it further.

2.7.3 Lessons Learned

One common method to make sure knowledge is not lost after the completion of a project is lessons learned. Lessons learned are defined as “key project experiences that have a certain general business relevance for future projects. They have been validated by a project team and represent a consensus on a key insight that should be considered in future projects.” (Schindler & Eppler, 2003). Schindler and Eppler (2003) further argue that the lessons learned are supposed to be used as a reference for coming projects to ensure that knowledge is not lost and the risk of performing the same mistakes again is minimized.

3. Methodology

This study was performed as a case study in two layers, firstly, exploring the root cause of the problem with loose support bearings and secondly, identifying improvement areas during the root cause analysis, as shown in Figure 6 below. According to Bryman and Bell (2011), a case study is about a detailed exploration of one specific case. It does not only consist of one methodology, but different research designs can be used within the single case study. The case study is distinguished by that it is focused on a bounded situation with an intensive examination of settings. The two authors performed the case study and the root cause analysis with assistance from VRT and other relevant functions, where *Six Sigma* methodology was used for problem-solving. *Six Sigma* is preferable for complex problems when the causes and the solutions are initially unclear (George, 2005). Therefore, this study followed the different *DMAIC* steps in *Six Sigma* and used both qualitative and quantitative methods. Because a similar method is used at Volvo, this case study also examined improvement areas that could make future root causes analysis more efficient.

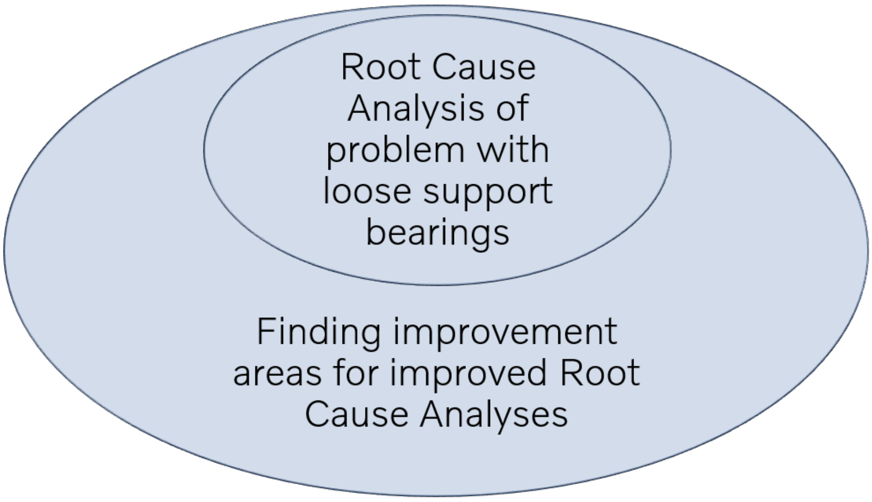

Figure 6. The two layers of research. Finding improvement areas by performing the root cause analysis of the problem with loose support bearings.

3.1 Six Sigma Methodology

Bergman and Klefsjö (2010) describe the *Six Sigma* methodology as a structured, iterative workflow similar to the previous *Plan-Do-Check-Act* (PDCA) methodology. The structured method consists of the five stages: *Define* - *Measure* - *Analyze* - *Improve* - *Control*, these are often referred to as the *DMAIC* cycle. Each phase of the *DMAIC* cycle consists of a set of tools to improve process performance based on comparisons between average and variation (Carleton, 2018). These stages are not considered a steady linear process but are performed iteratively during the project.

A summary of the workflow and some of the different tools used during the case study is shown in Figure 7 below. The gathering of data through observations, interviews, and secondary data was performed throughout all the phases. As described in the delimitations, the completion of the *Control* phase is not included in this project since the authors will not implement the improvements. The recommendations will be handed over in the form of a control plan to the responsible persons at Volvo, who will close the project.

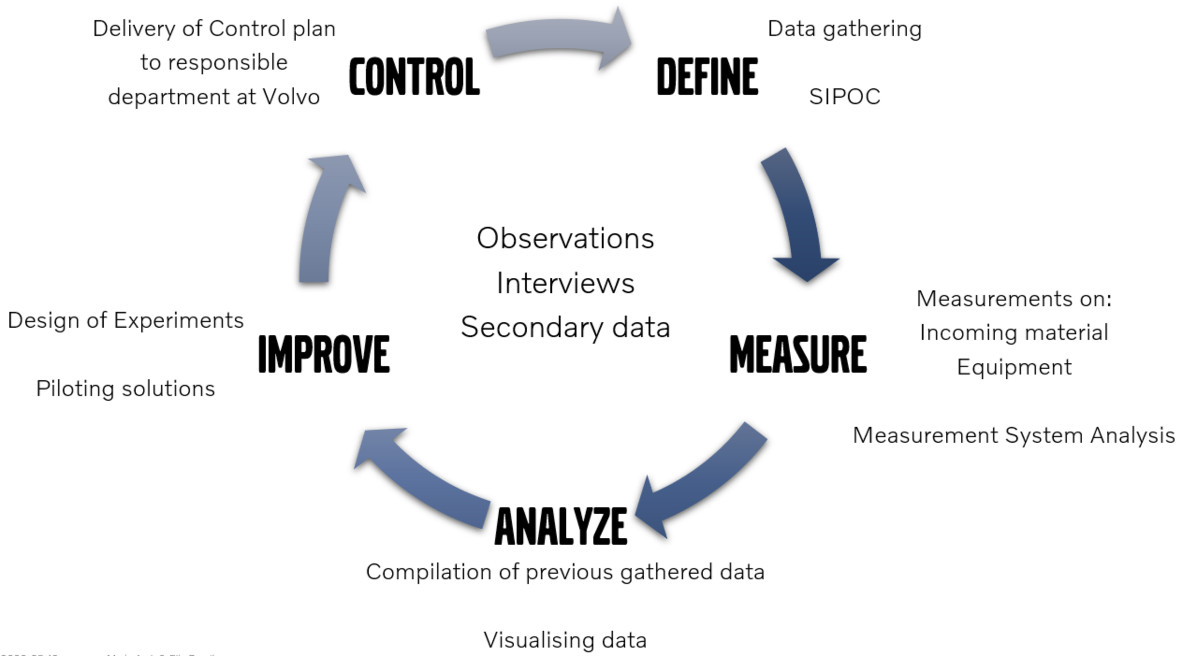

Figure 7. Visual representation of the used methodology including some of the used tools.

The project was started by the *Define* phase to define and understand the project and the problem from several perspectives such as the customer, the business, the process, and other significant stakeholders. To understand that the project focused on the right issues, the *Voice of the Customer* (VOC) was identified to describe the customer needs and expectations. The identification of the VOC was done through both qualitative methods such as observations and interviews as well as quantitative methods using existing data about the process.

When the problem was defined, the *Measure* phase was started. During this phase, the baseline of the problem was measured to understand the current performance of the process. Both the *Define* and *Measure* phases are about collecting data to understand the baseline of the problem (Carleton, 2018). The data gathered is then analyzed in the *Analyze* phase, where the goal is to understand what key x's affect the process outputs. The *Improve* phase consists of the implementation of solutions that were found in the earlier phases. The purpose of the *Control* phase is to make sure the gains from the implemented solutions are permanent.

3.2 Data gathering

The data gathering was mainly performed during the *Define* and *Measure* phases and is of both qualitative and quantitative nature. There was also a combination of primary and secondary data. New primary data was gathered mainly through observations and interviews. Another essential part is to use the secondary data already existing in the company, such as information about previous analyses and information regarding the defect cars. All gathered data was used to answer the two research questions. Gathering data about RQ1 and the root cause of the problem with loose support bearings also provided the authors with important information about RQ2 by finding more general improvement areas.

3.2.1 Observations

Observations were performed iteratively during the project throughout all the *DMAIC* phases. The observations have different purposes, depending on the phase. For example, initial observations in the *Define* phase were done to understand the process and define the real problem. After that, observations were done to collect and analyze data in the *Measure* and *Analyze* phases. Observations were also considered an essential part of the testing and implementation of changes during the *Improve* and *Control* phase.

According to Christoffersen and Johannessen (2015), the type of observation made can be divided into attendance, non-attendance, overt and covert observations that depend on the researchers' participation and the participants' awareness of the observation. Attendance and non-attendance observations are determined if the researcher participates in the observation, which means it can affect the situation. Holme and Solvang (1997) describe the difference between overt and covert observations as the researcher being hidden or open, meaning if the participants are aware of the observation or not. Waller, Farquharson, and Dempsey (2016) suggest that research does not need to fit into one category, instead several different can be used. In this study, all four types of observations were used in different situations. The majority of observations were performed within production to understand the process. A substantial part was non-participant, where the operators were observed while performing their job. Some participant observations were also made when the authors took part in production when performing a *Design of Experiment* (DOE), described further in chapter 3.2.2.

Due to ethical reasons, it is according to Waller et al. (2015) preferred to use overt observations. The use of overt observations can, although, decrease the trustworthiness of the result since the participants might change their behavior due to the knowledge of them being observed. For example, when observing the operators to understand if they follow standard operating procedure, they might change their behavior temporarily even if they usually perform the operation in another way. Although, this risk can be minimized by performing observations over a more extended time period. During this project, the authors spent much time within the production that helps to minimize this risk.

During this project observations were also performed on the material, both on incoming support bearings and replaced loose support bearings. These were done in order to understand if the defect were due to the incoming material or caused during the assembly process. Examples of observations made are measurements done on incoming materials and the gathering of replaced support bearings to observe what defects they have. Observations were also made on the equipment, such as the palette that assembles the inner ceiling to the car body. An example of an observation done at the palette was to examine the contact lugs.

3.2.2 Interviews

Interviews can be performed in different forms depending on the degree of standardization of the questions; the three most common forms are structured, semi-structured, or unstructured interviews (Waller et al., 2015). Bryman and Bell (2011) argue that face-to-face meetings are most appropriate in qualitative research in business. Therefore, most of the interviews in this study have been performed face-to-face. Due to the problem with loose support bearings being within running production, most of the interviews performed are semi-structured or unstructured. However, it is not always possible to have face-to-face meetings, such as when the interviewee is in another geographical location. In this study, some information was needed from the different production plants in China, the USA, and Belgium. Instead of authors visiting the different plants, information was gathered through email.

The persons interviewed were chosen by a purposive sampling strategy; only people who work in functions related to the support bearing were interviewed. The choice of participants for the interviews was done with guidance from the supervisors and people that previously had been interviewed. This sampling method is according to Bryman and Bell (2011) called snowball sampling. Examples of people that were interviewed for this study are operators, team leaders, manufacturing engineers, tooling engineers, geometry engineers, etc. During the study, approximately 35 interviews were conducted.

Spontaneous meetings and conversations were also considered as unstructured interviews that can provide valuable information to the researchers. According to Bryman and Bell (2011), these types of interviews can make the respondent speak more openly about the area since they feel more comfortable due to them being less likely to be affected by the researchers' expectations.

3.2.3 Secondary data

Secondary data refers to data that has been gathered or published previously (Bryman & Bell, 2011). The secondary data in this project consisted of a variety of data that is mainly published in different databases at Volvo. As a starting point, data from the previously made initial analysis named First Line Analysis performed by the production team was studied to understand what analyses already been done to find the root cause. Furthermore, data about the car assembly and the reported defects were downloaded from the deviation report program ATACQ. Information about the standardization and all the assembly steps were gathered in internal documents. These were studied to understand how the production process should look according to the standards and also to compare the standard with how the operators perform the work. Since the project involved several stakeholders located in different parts of Volvo, different types of information was also compiled from mail conversations with several functions within the company and with suppliers.

3.2.4 Literature studies

The literature studies were performed to find a theoretical background and get a deeper understanding of the studied area. Bryman and Bell (2011) state that it is essential to start a study by reviewing the existing literature to understand what has already been examined about the subject. The literature was also used as a base for understanding the findings. As a starting point in the literature review, the literature used in the authors' education has been used, for example, from the courses, *Six Sigma Black Belt*, *Quality and Operations Management*, *Lean Production*, *Work Organization,* and *Integrated Product Development.* Additional information in the form of both books and articles have been found through Chalmers library by searching for different keywords.

Example of keywords used in the literature study: *"Research Methodology", "Six Sigma", "Design of Experiments", "Kano-model", "Robust Design", "Knowledge Management", "Lean Production"*

3.2.5 SIPOC

Throughout the *Define* phase, a large amount of information was gathered. It is essential to compile the information and create a shared understanding of the problem before moving to the next phase (Carleton, 2018). For this purpose, the diagram or table shaped tool *SIPOC* is commonly used to determine the project scope. *SIPOC* stands for: *Suppliers, Inputs, Processes, Outputs, and Customers* (Carleton, 2018). Each of the categories have an impact on the process output, therefore the elements of each factor are identified and compiled. This can be done with the help of answering specific questions related to each category. These questions are answered in a specific order that forces the users to adjust from a push thinking to a pull thinking. Firstly, the outputs and customers are defined, later the processes, and, finally, the inputs and suppliers (Carleton, 2018). The categories and the order for the work procedure are shown in table 1 below.

Table 1. Showing the SIPOC categories.

Suppliers (5)	Inputs (4)	Processes (3)	Outputs (1)	Customers (2)

Using SIPOC helps stakeholders to understand process boundaries and provides a deep understanding of the process (Carleton, 2018). Carleton (2018) further argues that it is essential to understand the relationship between all the different categories and also how they affect each other. George (2005) states that the SIPOC can help verify that the process inputs match both the outputs of the upstream process and the inputs of the downstream processes. Later on, the SIPOC can also be used to achieve a balance of both input and output measures. During the authors Six Sigma Black Belt certification, an improved version of SIPOC was used, called Effective Scoping. The Effective Scoping is divided into the same categories as SIPOC but include several additional questions under each of the categories to further expand the problem definition (Hammersberg, 2019). The performed Effective Scoping can be found in the Appendix.

3.3 Analysis of data

The gathered data in the *Define* and *Measure* phases were compiled and used in the later *Analyze* phase. Conclusions were drawn from the gathered data using the knowledge from the literature studies. The performed analysis combined the two layers of the root cause analysis and the two research questions. One of the primary steps in this phase was to create a list of potential root causes to identify different x's that affect the output (Carleton, 2018). The goal was to eliminate the potential causes that do not affect the output and confirm the root causes of the problem. The list of potential root causes also included information about additional improvement areas.

During the *Analyze* phase, several tools were used to visualize the data gathered in the previous phases. For example, data from production was compiled and visualized in a variety of diagrams using the statistical software JMP, which helped the authors to base their decisions on facts and draw relevant conclusions. To understand the reliability of the previously done measurements, a *Measurement System Analysis* (MSA) was done on the size of the support bearing. To further understand how several of the identified x's affected the process outputs, the authors conducted a *Design of Experiment* (DOE) in the *Improve* phase. The goal of this phase is to identify potential solutions and eliminate the number of defects (Carleton, 2018). The following two chapters aim to describe the methodology used in the performed MSA and DOE.

3.3.1 Measurement System Analysis MSA

To understand the trustworthiness of the measurements done in the *Measure* phase, a MSA was performed. A MSA "is a series of designed tests that allow an organization to determine whether its measurement system is reliable in terms of bias, linearity, stability, discrimination, and precision" (Carleton, 2018). According to Carleton (2018), the term bias refers to a difference between the measured value and a known standard; if bias exists, the measurement system might need calibration. Linearity, on the other hand, determines if bias exists over its operating range. The measurement system might not measure consequently over a more extended time period, and therefore its stability is analyzed. Discrimination seeks the measurement systems' ability to detect and measure small changes. When observing the term precision, the repeatability, and the reproducibility of the measurement system are taken into consideration. By performing an MSA, it is possible to detect the trustworthiness of a measurement system. It is preferable to perform a MSA on all measurements systems that are used during the measure phase. Carleton (2018) suggests measuring ten randomly chosen components when performing a Continuous Gauge MSA. The author further argues that ten units are usually enough to span the range of long-term variability in the process. Furthermore, three operators should measure the units and perform at least two measurements of each component to estimate the repeatability and reproducibility of the measurement.

At the moment when writing this thesis, no known measurements of the support bearings' dimensions had been done at VCT. Instead, the supplier provided the company with data of measurements. In order to measure the support bearing at VCT for this project, a *Measure System Analysis* (MSA) was conducted. The MSA was performed on ten randomly chosen components, and each component was measured two times by three different operators leading to 60 measurements in total.

The result of the measurements showing the width of the component from the MSA are further presented and discussed in chapter 5.1. Analysis of the repeatability and the variations between the operators are presented in Figure 8 below. The Figure shows the standard deviation for each operator for each measured component. The MSA indicates that operator number 2 has a high uncertainty in its measurements and that the two other operators have more stability in their measurements, and therefore the results from their measurements are more trustworthy. Although, as presented before, these measurements were not usually done or used as a go/no-go decision. Therefore, no changes were made in the measurement system, but the instability of the system was considered when further performing measurements on components.

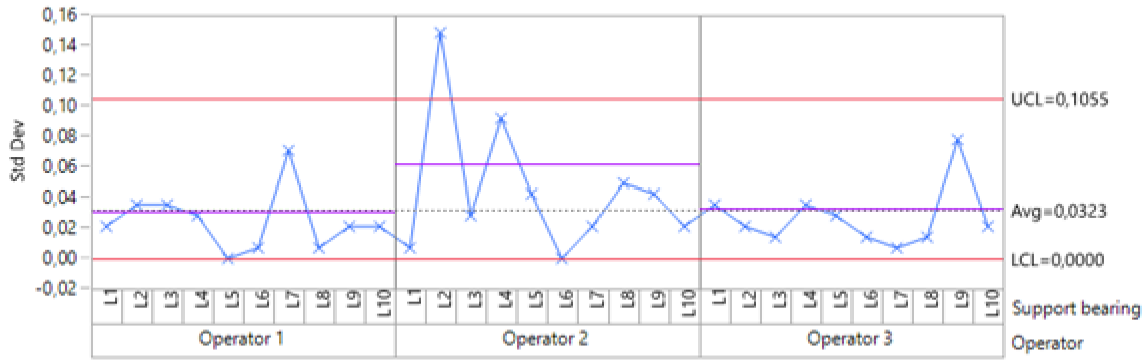

Figure 8. MSA performed during the project, showing instability of the measurement system.

3.3.2 Design of Experiments

In the *Six Sigma* methodology, it is essential to base decisions on facts, but the facts do not always exist from the beginning of a project but have to be collected (Bergman & Klefsjö, 2010). Several experimental methods to collect and analyze data exist that are commonly used. One common method is one-factor at a time testing, meaning that one factor's effects are tested with different settings, but by testing one factor at a time, there is a risk of missing interactions between multiple effects (Bergman & Klefsjö, 2010). Instead, the authors suggest testing multiple factors at one time, such as *Design of Experiment* (DOE), which can help to find interactions between the factors.

3.3.2.1 Different types of DOE

Depending on the nature of the test, multiple factor testing can be expensive and time-consuming. Multiple factor testing can be full factorial, meaning that every possible combination of factors is covered (Carleton, 2018). Full factorial tests are ideal for studies with very few factors. The disadvantage of full factorial testing is that the cost of the experiment increases as the number of factors increases, and many resources are used on tests that might not be interesting. Fractional factorial designs can be used instead of full factorial design for a test, where only some interactions are included. By using a fractional factorial design, fewer test runs are necessary, and more runs can be added after analysis of the initial data.

3.3.2.2 The performed DOE

A DOE is used for investigating effects and combinations of interactions that might affect the output of a process (Carleton, 2018). In this project, a DOE was planned, to test factors that could affect the support bearing during the assembly. Three factors were chosen to be tested at two levels with consideration of observations, interviews, and information about previous tests conducted in the production. The choice of factors were determined based on their impact on the problem together with the authors ability to easily adjust the factors. For example, it was not possible to use the car body as one factor due to the long lead time from stamping until assembly. The three chosen factors were the width between the lock pins, expanding of the lock pins, and the placement of the support bearing in the contact lug. These factors were chosen since all of them were considered to have an impact on the problem. The result for each test run was measured by determining if the support bearing were loose, had a press mark on the front or rear lock pin and it was notified if any other defects were encountered.

When using DOE, extreme-value settings are preferred to study the factors; if the factors do not give a positive result in an extreme setting, they will probably not give it when acting in standard settings (Bergman & Klefsjö, 2010). Therefore, the authors choose to use extreme-settings on the three factors. The first chosen factor was the size of the support bearing determined by the width between lock pins. The size was chosen after the MSA, which showed that the size of the support bearing differed. Support bearings with a width wider than the upper control limit were defined as big and those with a width smaller than the lower control limit as a small support bearing. Both of the authors measured each component in order to ensure that the used components could be defined as smaller or larger. The second factor was if the lock pins were expanded or not, this factor had previously been tested by the production team, where they concluded that an expanded support bearing did not lead to any defects. The third factor was the placement of the support bearing in the contact lug on the palette; the operators have some freedom to put the support bearing differently in the contact lug. Therefore, the factor was chosen to investigate the operators' ability to affect the assembly by potentially misplacing the support bearing into the contact lug.

The design of the DOE was made with the help of the statistical software JMP, which helped to create a randomized test plan. The test was conducted with a full factorial design with one replication leading to 16 attempts in total. During the test, each support bearing was disassembled for further observations in order to measure the result for each test run.

Table 2. The test design used for the full factorial experiment performed by the authors. It consisted of 3 factors with 2 levels each and one replication leading to 16 experiments in total.

Pattern	Expanding	Size of support bearing	Position
221	Not expanded	Smaller	Front
122	Expanded	Smaller	Back
222	Not expanded	Smaller	Back
121	Expanded	Smaller	Front
211	Not expanded	Larger	Front
112	Expanded	Larger	Back
111	Expanded	Larger	Front
212	Not expanded	Larger	Back
221	Not expanded	Smaller	Front
122	Expanded	Smaller	Back
222	Not expanded	Smaller	Back
121	Expanded	Smaller	Front
211	Not expanded	Larger	Front
112	Expanded	Larger	Back
111	Expanded	Larger	Front
212	Not expanded	Larger	Back

The result of the DOE was analyzed through a logistic regression with help from the statistical software JMP. The logistic regression helps to determine if each factor, by itself or through interactions, has a significant effect on the result, which in this case is measured if the support bearing is loose or having press marks on any of the lock pins. "The output of a regression analysis is a prediction equation that allows us to estimate an output Y given an input x" (Carleton, 2018). If a strong cause-effect relationship is found, accurate predictions can be made about a factor and its behavior.

3.4 Research Quality

Evaluating the quality of research consists of several factors, such as research trustworthiness, reliability, and validity. According to Bryman and Bell (2011), the trustworthiness of a study can be increased by triangulation. In this study, the cross-checking of the findings was done through qualitative and quantitative methods. The study also combined primary and secondary data to make sure the data previously gathered represents the current situation. One example of when the methods were combined was when all defect support bearings were gathered for one week. From this week, secondary quantitative data was gathered from the internal data system about the number of loose support bearings and the number of produced cars. The observation of the gathered support bearings were also used for qualitative studies, which provided the authors with primary data.

Bryman and Bell (2011) further state that traditionally the reliability and validity have been used for evaluating research. Therefore, the following two chapters aim to describe how the authors of this report have considered these for the research.

3.4.1 Reliability

Reliability is according to Bryman and Bell (2011) about consistency of measures and is related to stability, internal reliability and inter-observer consistency. Stability is about variations in the measures over time to ensure the results would be the same if the same tests were to be performed again. Internal reliability is about making sure the scale of measures is consistent. Inter-observer consistency is concerning translation of data into categories, when there are several observers involved (Bryman & Bell, 2011).

In order to increase the reliability of this study, all work has been performed jointly by the two authors. No measurements or observations have been made at one single occasion. Instead, these have been performed at several randomly chosen occasions. This makes the results less dependent on one single variation. In other words, if observations in production only were to be done at one single point, there is a risk that the observer only sees a variation of the process. If the observer instead returns to the process and observes it at different times, the understanding of the process is likely to be closer to reality and not as affected by variations. For example, observations in the production have not been made under one single event but instead during different times of the day, under an extended period. This allows the authors to detect possible abnormalities.

3.4.2 Validity

Validity is about the external characteristics of the study and is about ensuring the the performed test measures the right parameters (Björkqvist, 2012). Bryman and Bell (2011) describe that validity is usually divided into internal and external validity. Internal validity concerns if the found relationship between x and y incorporates a causal relationship. External validity concerns how well the findings can be generalized. According to Bryman and Bell (2011), it has been widely discussed how one single case can be used, and the learnings generally applied to other cases. They further state that there never is any possibility to use all the learnings from one case and apply it to other cases, since they never will be exactly the same. Although, the main goal of the case study analysis is not to generalize the findings but to concentrate on the uniqueness of the case and understand its complexity. The case study can, though, be used for theoretical generalizability, which could be applicable in other cases as well.

3.5 Research Ethics

Ethical aspects must always be taken into consideration when performing a study. In this study, many covert observations were performed. As described previously, a covert observation refers to when the studied people are not fully aware of their participation in the study (Holme & Solvang, 1997). Waller et al. (2015) describe that covert observations can ensure that the studied people will not change their behaviors depending on their gain. In this study, covert studies were used to observe how the operators worked, and if they worked according to instructions in their standard operating procedure.

Furthermore, the observations were not registered to a specific employee to protect and respect their integrity. This meant that even if the employees did not follow their standard operation procedure, they would not be personally held responsible or confronted about the issue. If the employees would have been aware of the fact that they were observed, they could change their normal work procedure into the one described in their standard operation procedure, possibly resulting in misleading data. Covert observations were also used in cases when a whole process involving a considerable number of people was studied. It would have been challenging to inform each person on the shop floor about the study and would also interfere with them performing their work tasks correctly. Before this report was published and distributed it was presented to the company who gave their approval of the presented details. This is an important ethical consideration to ensure that the data presented in this report represents the situation at the company correctly.

4. Problem definition by mapping the current state

During the year 2019, the VRT department at VCT has received information about 18 cars that have been delivered to customers or retailers with loose support bearings. The customer complaints are sent to VRT through either a retailer or a repair shop when the part is replaced. These complaints have been regarding the car models V90, V90CC, XC60, and XC90 with the majority of defects on the V90. Although, the real number of cars with loose support bearings can be higher since it is not assured that everyone turns in their car with only smaller defects that do not affect the performance of the car. The problem with loose support bearings has been noticed in production for a long time, but the root cause has not been found. The following chapters aim to describe the current state and the problem identified within the production plant. It will cover the component, the production process, the organizational structure, how defects are reported, and the current state in other production plants.

4.1 Description of the support bearing

The support bearing is a plastic component with two functions, the first one helping to attach the headliner to the car body and the second one as a hanger to the sun visor. The support bearing attaches to the car body but needs to let go in case of a collision. Furthermore, the same component is used for both the left and right sun visor and is located towards the center of the car. On the other side of the sun visor, another support is used, which is attached by screws. The support bearing is delivered to VCT by the supplier Daimay. The support bearing comes in two different colors, blond, and charcoal. All car models use the same support bearing, and the issue can be detected in all the car variants produced in VCT.

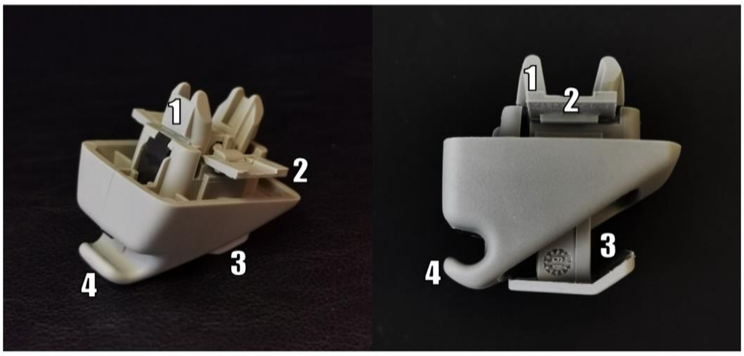

Figure 9. Pictures of the support bearing. The four marked parts are 1: lock pin, 2: transport clips, 3: pushpin, and 4: sun visor hook.

A blond variant of the support bearing is shown in Figure 9 above, including numbers for the different functions. The lock pins that are numbered as 1 in the Figure expands into the car body when the pushpin, marked as number 3, is pressed up (see Figure 10 below). The support bearing also has two transport clips, marked as number 2 in the Figure; these are solely used as a support when moving the headliner between two stations. Number 4 in the Figure above is the sun visor hook and is where the sun visor is fastened.

The lock pins are supposed to be pushed right up into a premade hole in a console in the car body, and the upper part of the lock pin should not get any contact with other parts in the car. After the support bearing is positioned inside the console hole, the pushpin is pressed up, and the lock pins expand, leading the steel to fasten in the gap under the lock pins. The steel in the console is represented by the white lines in Figure 10 below.

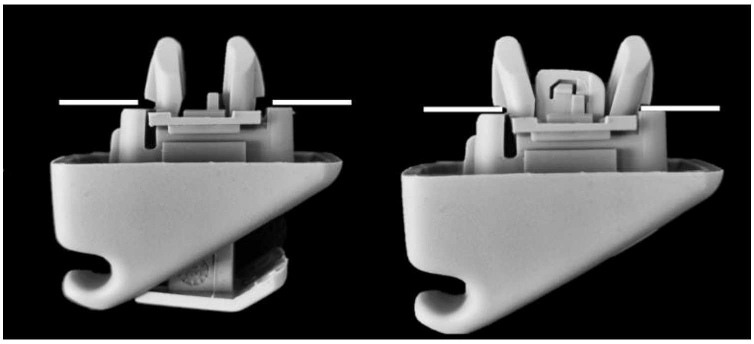

Figure 10. Pictures of the support bearing. The first picture shows the support bearing in a natural position and the second in an expanded position.

Since the problem with loose support bearings has been present for a longer time with variating consequences, many short-term solutions have been used, instead of finding the root cause. When a loose support bearing is identified within production, the team leader either presses up the support bearing manually or replaces it. Most commonly, the component is totally replaced due to the defect part's inability to reattach to the car body.

The importance of finding the root cause has increased due to several customers receiving cars with loose support bearings. A loose support bearing can be detected by the customer by the sun visor being loose or mishanging, although this is only the symptom of the real problem. When observing all replaced support bearings for one week, they all had similar defects. The support bearings have press marks on the front lock pin, which also is slightly pressed down, see Figure 11 below. Observations show that the same problem occurs both on the left and right support bearing.

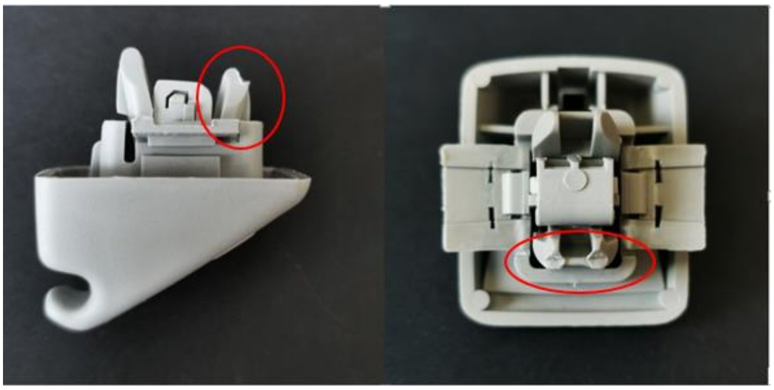

Figure 11. Pictures showing a damaged support bearing.

If the upper part of the lock pins is not entering the attachment hole correctly, it can result in a damaged lock pin, as shown in Figure 11 above. The support bearing is attached to the car body by being pressed up by a palette. If the lock pins are misaligned and pressed onto a surface in the car body, the plastic will deform due to the high pressure. One damaged lock pin on the support bearing increases the component's risk of not attaching to the car body since the gap that constitutes the attachment point for the car body is missing.

During the authors' observation of the damaged support bearings that are replaced within production, additional defects on the sun visor hook have been noticed, see Figure 12 below. This defect does not affect the function of the support bearing but can be visible to the customer that can affect the customer's perception of the car and the customer satisfaction. This issue has not been noticed by the production team previously, the defect varies in size but occurs among a majority of the analyzed replaced support bearings. The press marks occur both on the left and right part of the support bearing. Observations within production and non-defect support bearings assembled to the cars show that there are press marks on several of the support bearings. Although, these marks are not identified on the incoming material, which indicates that they emerge during the assembly at VCT.

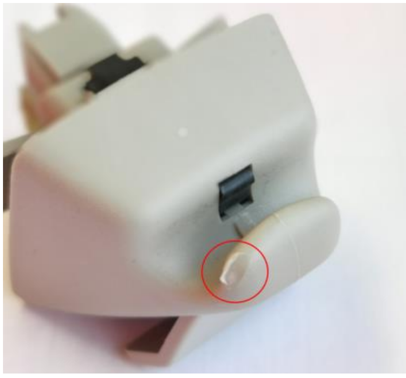

Figure 12. Picture of the defects identified on the sun visor hook.

4.2 The car body

The car body is produced and welded at Volvo's plant in Olofström, Volvo Cars Body Components (VCBC). In the car body, several holes have been stamped out. There are different purposes with the stamped holes, some work as attachment points, and others as positioning holes, which make sure that the positioning of the equipment is correct during assembly. At VCBC, they are responsible for the arrangement and size of the attachment and positioning holes. Depending on the car model, the car body is different; examples of differences are the thickness of the steel and placement of the holes for the support bearing. Although, the size of the holes for the support bearing should be equally big. One of the consoles is shown in Figure 13 below. The attachment points for the support bearings are shown in the two red squares, and one positioning hole is marked by the red circle. The positioning hole's purpose is to make sure the palette, with the headliner on, gets correctly positioned into the car when it is attaching.

Figure 13. A picture on one of the consoles to the V90 where the support bearings attach. The two holes marked by red squares are where the support bearing attaches and the hole in the red circle is one positioning hole.

4.3 The headliner

The headliner is delivered from two different external suppliers to VCT but is assembled within production. A headliner ready for assembly into the car body at the palette is shown in Figure 14 below.

Figure 14. Picture of the headliner before it is put onto the palette and attached to the car body.

The headliner has two pre-made holes where the support bearings are attached. The support bearing is put through the hole, and the transport clips are folded out to make sure the support bearing is in place throughout the transportation between the stations. The dimension of the pre-made holes is slightly bigger than the support bearing, as shown in Figure 15 below. The holes are slightly bigger to make sure that the support bearing can be adjusted and more easily attached to the car body. This gives the operator the opportunity and space to adjust the components positioning in the hole to place down the support bearing into the contact lug correctly.

Figure 15. Showing the placement of the support bearing to the headliner, it is attached by the transport clips to make sure it does not fall off during the transportation between the stations.

4.4 Assemble of the support bearing

The support bearing is assembled into the headliner and car body at a production line through several steps, some manual performed by the operators, and one automatic operation. For these process steps, there are three different workgroups, each with their team leader that work during each of the three working shifts. This means that many different people are involved in the process. The team leaders have the responsibility to act upon and solve problems that occur during the shift. All stations at Volvo have standard operating procedures that are gathered in documents that are called Work Element Sheet (WES). These are gathered in an internal database and printed out at each station enabling the operators to easily check how the operations should be done. There are several instructions for each station, both regarding the support bearing and all the other assembly steps. A simplified version of all the operations and production steps that include the support bearing at the production at VCT are summarized and shown in Figure 16 below. All stations consist of manual operations except for station 5, which is an automatic robotic operation. The last station is a control station called SIP, where several controls of the produced car are performed.

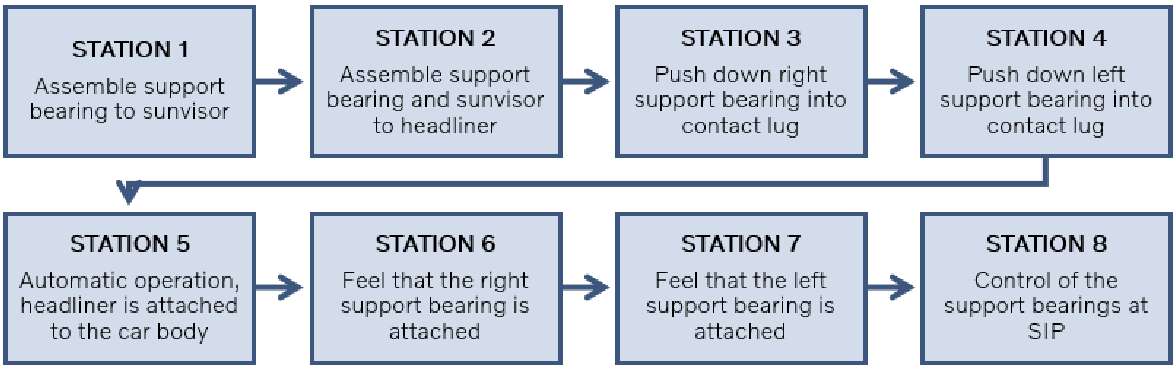

Figure 16. A simplified version of the process steps that involves the support bearing.

Before the first station, the specific components for each car are gathered in boxes according to the production sequence and brought to the station. At station 1, an operator assembles the sun visor and support bearing together and places it at the headliner for the operator at station 2. Both the left and right sun visors are attached to the headliner at station 2. This is done by putting the support bearing through a hole in the headliner to fold out the transport clips. The headliner is then moved to station 3 and 4, where it is positioned onto a pallete that later will push up the entire headliner to the car body at station 5. At VCT, there are three different palettes within the production, one for V90 and V90CC, the second one for V60, and the last one for XC60 and XC90. A picture of one of the palettes is shown in Figure 17 below.

Figure 17. Picture of one headliner placed on a palette ready to be moved into the car and attached to the car body.

At station 3 and 4, the operator assures that the support bearing is correctly placed in a fixture in order for it to align with the car body. The support bearings are put into a contact lug, shown in Figure 18 below. When the palette moves into the car and presses up the headliner, the support bearing's pushpin expands into and attaches to the car body.

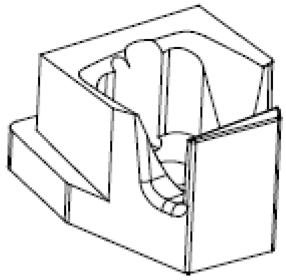

Figure 18. Visual representation of the contact lug where the support bearing is placed when attaching to the car body.

Station 6 and 7 are performing the same operations but on different sides of the car. At those stations, operators sit in the car and check that the support bearing is correctly attached by both a physical and visual control. Further on in the process flow, there is a control called SP3 where multiple controls are made, and here another control of the support bearing is conducted. These controls have been implemented due to problems with loose support bearings and should assure that no defect support bearings leave the factory. If the operators did not have to do the controls, they could have used their time for value-adding activities. Therefore, these could be considered as non-value-adding activities and waste for the company.

4.5 Organizational structure

The organizational structure at Volvo is complex due to the size of the company. This section of the report aims to describe the different parts of the organization that are affected by the support bearing and its attachment. It is although essential to understand that within each function, several people are working, who have a wide variety of responsibilities, which makes it hard to describe each department and their responsibility with a few words. These descriptions are based on internal databases from Volvo, along with the authors' knowledge gained from interviews.

This case study was performed at the department VRT. This department is a cross-functional department that collaborates with several functions to deal with a wide variety of customer complaints. Examples of collaborations that exist are between VRT and the production, as well as with suppliers and the Research and Development (R&D) department, among others. Initially, when a customer complaint is received, the responsible department within production is contacted and performs a First Line Analysis. If no root cause is found through this analysis, the problem is escalated back to VRT, who performs a more in-depth root cause analysis, using the Six Sigma methodology.

The R&D department designs the different components used in cars. They are responsible for the design of the component and that the different parts should fit geometrically. When a car is introduced in the factory, the department of Manufacturing Engineering (ME) is responsible for the equipment and that the designed car should be producible. ME is a global function with the responsibility to introduce and launch new car programs and processes in Volvo Cars' plants. For example, from this department, there are manufacturing engineers who are responsible for designing the equipment. They are also involved if there are product changes and verifying that these still can be produced with high quality. In this project, manufacturing engineers, for example, have designed the palettes, and they are also involved in verifying the new support bearings that should be delivered in mid-2020. The daily work on the assembly line is performed by the production personnel, divided into three different shifts. They are responsible for running production and continuous improvements. For example, the operators should initiate an alarm if they encounter deviations, and the team leader should, after that bring the issue further. If there are deviations on the equipment, Production use helps from Maintenance, which is responsible for both preventive maintenance and more acute maintenance depending on the need of the equipment.

Apart from these functions that are working closely with the support bearing, several other functions occasionally get involved in questions regarding it. For example, there are persons responsible for the quality of incoming material; this group of people should be involved if deviations of the material are found and keep contact with the supplier. The support bearings are delivered to the assembly line by the logistics department. When measurements of the equipment should be made, there is a geometry department that can help with these types of tasks. The data from the program ATACQ is not accessible for everyone, and to get access to that data, help is needed from the responsible person. There are also certain people working with the rejected parts in the plant, which helps with these types of questions.

4.5.1 Problem solving procedure at the organization

The organization has implemented several principles from different methodologies into its daily operations. When a problem occurs in production, the people working close to the problem start the problem-solving by performing a First Line Analysis, which is a method based on lean principles. The goal by performing this analysis is to detect the root cause for a problem, however, this measure is not always enough to find the real root cause. If the problem is complex, people with different types of knowledge need to be addressed, depending on the nature of the issue. When the First Line Analyses are performed, they are presented during a daily meeting with the person responsible for quality. In this way, it can be assured that all problems are brought up and given attention. The person responsible for the quality must decide if further actions are required to handle the problem.

When a problem occurs, the desired action is to implement a PCA that is a long-term solution that eliminates the root cause of the problem. Since the root cause is not always clear or can be adjusted directly, the problem's symptoms have to be addressed in other ways. This is done by implementing an ICA, which is a short-term solution that hinders the symptom of the problem. The ICA is supposed to be temporally implemented if needed but should not replace a PCA. Implementing a PCA will decrease the probability of a car with a specific defect reaching the end customer. For example, in this project, the controls made to ensure no loose support bearings are leaving the factory could be considered as the ICA. This hinders the symptom of the problem, cars with defects reaching the end customer. The PCA would although lead to the elimination of the root cause, and after that the controls could be removed.

4.6 Deviations reported in ATACQ

The different operations, their time of execution, and the operators at the stations are registered in a program named ATACQ. The team leaders should manually register deviations in the production in ATACQ, making them traceable for each car that is assembled. For example, when an operator identifies a loose support bearing at station 6 or 7, they make an alarm to the team leader, who replaces the support bearing. After that, the team leader should make registration on that specific serial number in ATACQ and also specify if the problem was on the left or right support bearing. Furthermore, since the deviations are registered manually the reliability and validity of the data can be questioned. If the team leaders do register all cases of deviations in the program, the data will show the current state and the number of defects in the car. The ATACQ data is used for traceability and often as the starting point for many different types of changes within the production. For example, if the number of deviations of a specific part suddenly increases, it can initiate an analysis to find the root cause and eliminate it. This is not the case for this analysis since this project was initiated due to cars with loose support bearings reaching the end customer.

4.6.1 General compilation of ATACQ data for loose support bearings

The data used for the analysis in this case study was from week 33, the year 2019 until week 11, the year 2020, and consisted of 367 reported defects. The data from ATACQ can be sorted by several factors such as the car model, the production time, the working shift, side of defect, etcetera. At VCT, the following car models are assembled; V60, V60CC, XC60, V90, V90CC, and XC90. The different car models will be used as the main factor when analyzing the gathered data.

A compilation of the ATACQ data of the number of reported loose support bearings, categorized after the different car models, weekly from week 33, the year 2019 to week 11, the year 2020, is represented in Figure 19 below. The number of defect support bearings varies each week, but V90 and V90CC have the highest total number of cars with reported loose support bearings. V60 and V60CC have the lowest number of cars with defects. The same palette assembles the car models XC60 and XC90, and as shown in Figure 19 below, the number of defects follows a similar pattern. During week 45, the First Line Analysis was conducted by the production team. After this analysis was initiated, the number of reported loose support bearings increased drastically, especially for V90 & V90CC. Because of a significant lack of data before week 45, the following analysis will focus mostly on week 45 and onwards. Furthermore, an apparent increase can also be seen for week 6. During this week, the team leaders were under the instructions that they should not only report the broken support bearings but also collect them. These two occasions indicate that the number of reported loose support bearing increases when the problem is given more attention. Therefore, the real number of defect support bearings could be higher for the other observed weeks, since it is possible that not all the cases with defect support bearings are registered into ATACQ. This is always the risk when the data is registered manually since it depends on the human factor.

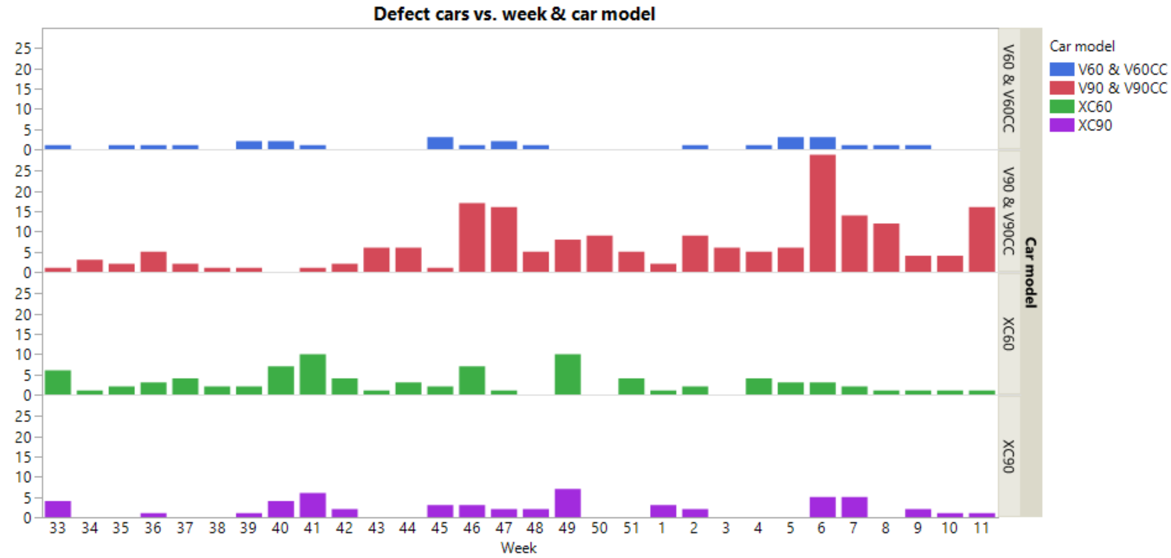

Figure 19. Amount of reported loose support bearings compared against production week and car model.

4.6.2 Side of attachment

Since the support bearings are present at both sides of the cars, the defect can be reported on either left or right side. Figure 20 below shows the number of reported defects from week 33, 2019, until week 11, 2020, stratified into the left or right side, along with the car model. The left support bearings are slightly overrepresented, with 64 percent of all the reported defects. One interesting observation is that for V90 and V90CC, there is an equal distribution between left and right, with only 51 percent of the defects being on the left side. For both XC60 and XC90, most loose support bearings have been reported on the left side. This leads to a potential hypothesis that both the right and left attachment sides need to be considered for the V90, who also has the highest number of reported loose support bearings.

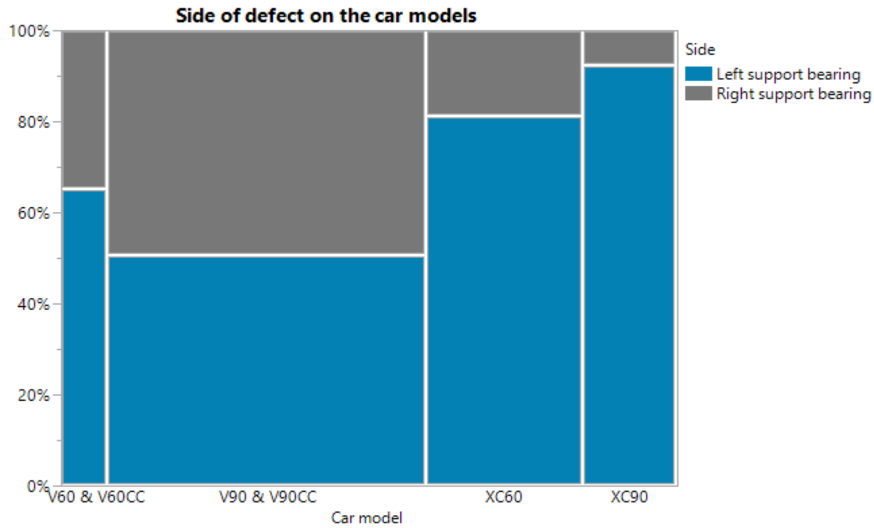

Figure 20. Visual representation of the number of reported loose support bearings. The Figure shows the left support bearings in blue and the right support bearings in grey. The bars vary in size due to the variating number of loose support bearings.

Four different codes can be used when a loose support bearing is encountered in production, and information about it is registered in ATACQ. These codes depend on the side of the defect as well as where the defect is encountered by the production team or by the controls later in the production flow. This data, together with the car model and reporting team, is shown in Figure 21 below. When comparing where the defects are reported for the different car models, some differences can be identified. For V90 and V90CC, which are the car models with most defects, many loose support bearings are identified by the production team itself, even if many defects are encountered later in the process. For both XC60 and XC90, very few defects are registered by the production team, especially on the right side. Although, there is a much higher part registered later in the production flow at the SIP stations. This indicates that it is more common for the production team to encounter and report the defects of loose support bearings at the left side of a V90 or V90CC compared to in an XC60 or XC90. One potential explanation for this could be the geometry of the different car models.

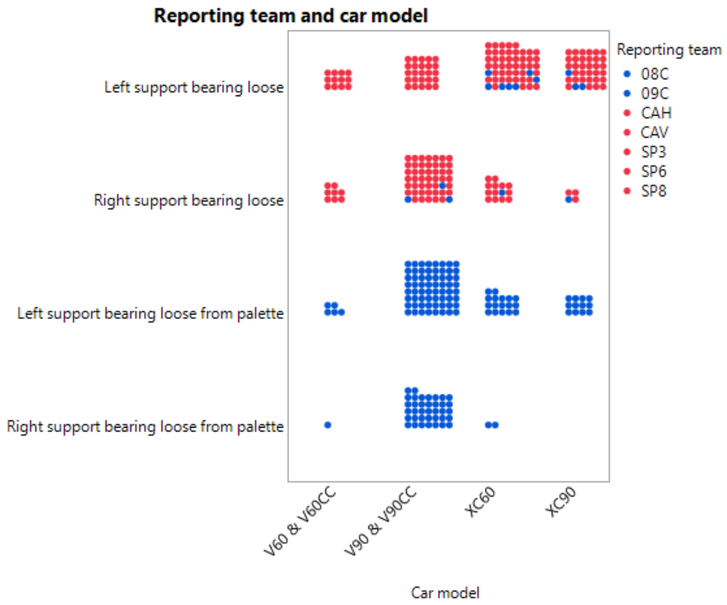

Figure 21. Amount of loose support bearings divided into the four different reporting codes in ATACQ together with the different car models and the reporting teams.

4.6.3 Throughput yield of different car models

VCT produces different amounts of each car model. The most-produced car models at VCT are at the moment XC60 and XC90, while the least produced car models are V90 and V90CC. Therefore, the yield for each car model was considered. Figure 22 below shows the percentage of cars with defect support bearings considering how many cars of each car model have been produced during a particular week. The car models V90 & V90CC stand out with the highest percentage with almost ten times as many loose support bearings as the other car models. Over the total period (week 45 to week 11), 1,06 percent of all produced V90 and V90CC had loose support bearing compared to around 0,1 percent for the other car models. During week 6, above 4 percent of all the V90 & V90CCs had a defect support bearing. As mentioned earlier, there is also a possibility that all cases of defect support bearings are not correctly reported and that the real percentage is even higher.

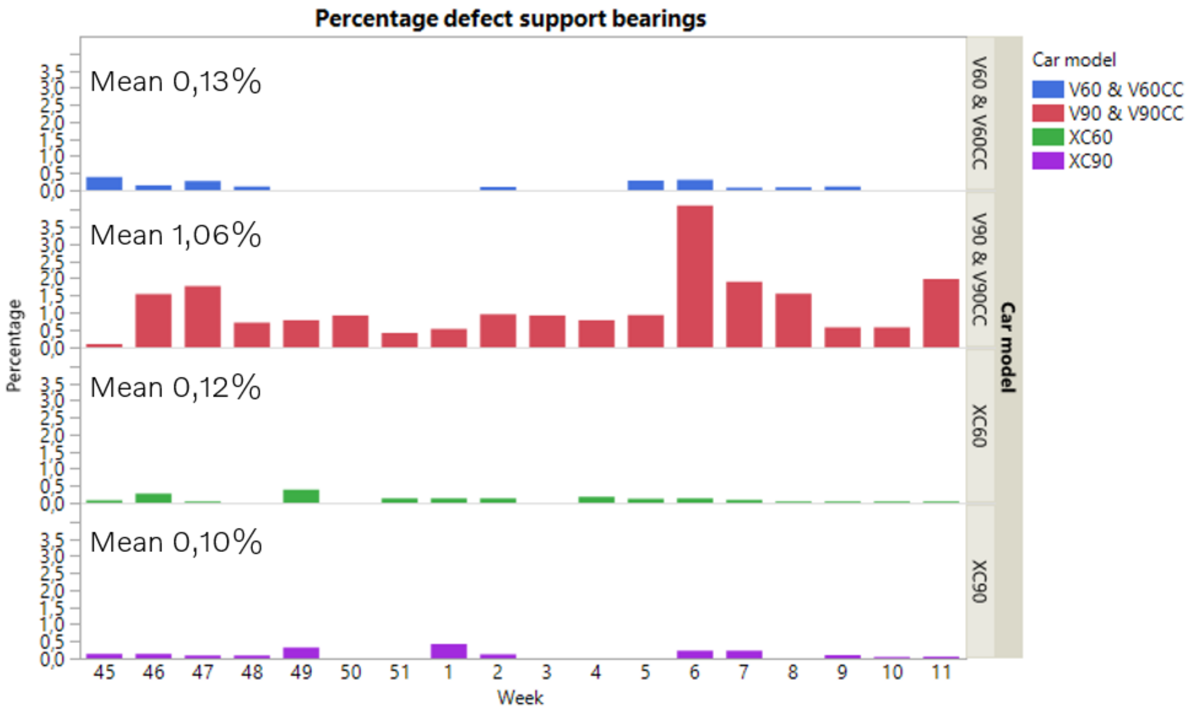

Figure 22. Percentage of produced cars with defect support bearings

The car models V90 and V90CC have a similar car body and are assembled on the same palette. Figure 23 below shows the difference in the number of loose support bearings between the two models. As the Figure below shows, there is no significant difference between the number of defects for the two-car models, and they are continuously analyzed together.

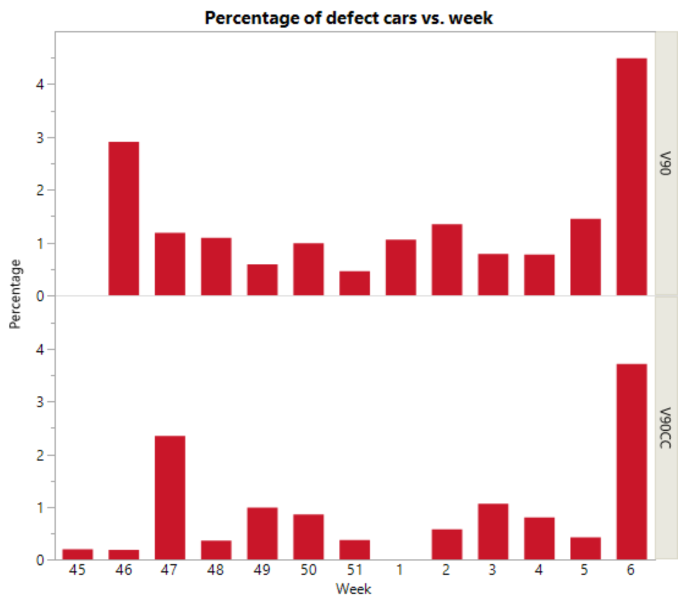

Figure 23. Representation of the percentage of defect cars for each week for the car models V90 and V90CC.

4.6.4 Dependence of the human factor

The loose support bearing can be noticed by the production personnel or noticed later in the assembly line at the control station called SIP. From the ATACQ data, it is possible to compile information about what and when a shift reported a defect. In Figure 24 below, the number of defects reported by each work shift is shown. Each dot represents a reported loose support bearing; the defects marked in blue are cases noticed by people working in the teams at the assembly line while defects marked in red are noticed and reported by people working in the SIP controls.

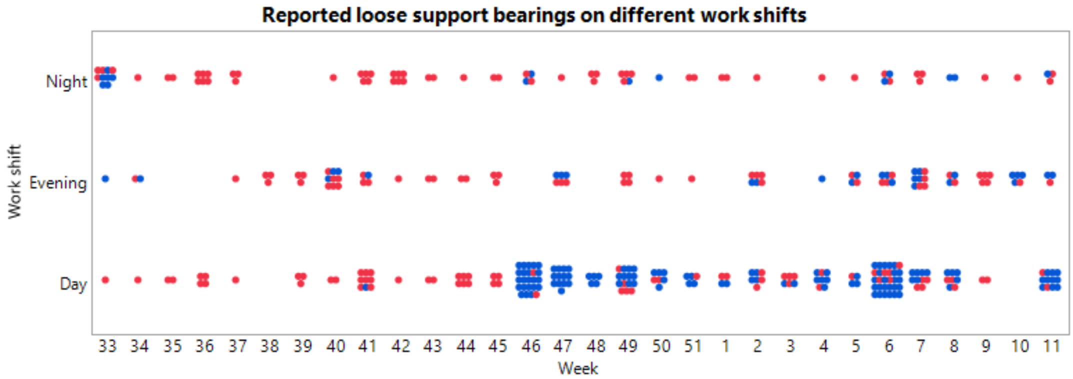

Figure 24. Representation of the number of loose support bearings registered by each shift. The blue dots represent defects registered by the production team themselves and the red dots defects found in the later controls.

From week 33 to week 45, almost all defects were registered at SIP. When the First Line Analysis was initiated in week 45, the number of cases reported by the day shift working at the assembly line increased drastically. After that, it slowly decreased until it increased drastically once again, week 6. As described above, the team leaders were during week 6 under instructions to save all the defect support bearings. These instructions increased the attention to the problem and could explain the increase in registered cases in ATACQ. All team leaders, from the three shifts, were instructed through the same email. Although, the authors were present in production more during the daytime, which could affect the team leaders' understanding of the severity of the problem. This could explain why the day shift has a higher amount of reported loose support bearings during this period. Furthermore, almost none of the cases reported from the assembly line are from the evening nor the night shift but instead noticed and reported by SIP. There is no explanation for why the evening shift or night shift would have fewer problems with loose support bearings. Instead, this also indicates that there is a vast number of unreported defects in ATACQ.

Furthermore, the data reported in ATACQ could be connected to the team leader’s willingness and time to report deviations. This is visible during weeks 9 and 10 when the day shift reported no loose support bearings. During these two weeks, two of the ordinary team leaders were missing, and other personnel took their roles. There are no reasons why the problem would have improved during these two weeks as the supplementary team leaders mention that they have replaced several support bearings. This indicates that there are barriers related to knowledge management within production since all production personnel do not have the same understanding of the work instructions, which means that the uncertainty of the reported data is high since it depends on who is responsible for reporting it.

Many factors from the ATACQ data indicate that there are a vast number of unreported defects in the data; it is not possible to calculate precisely how big the issue is. Since the component is not manually discarded, the number of defect components is not registered anywhere. One attempt to compare the number of support bearing components entering the factory during a specific time period versus the number of assembled cars leaving the factory was conducted. However, the uncertainty of the number of components in the factory was so high (uncertainty of 4 500 support bearings) that the result would not be probability salient.

4.7 Current state in the other plants

Currently, Volvo has running car production in six different plants; apart from VCT, these are located in Ghent, Belgium (VCG), Charleston, the USA (VCCH), Chengdu (VCCD), Daqing (VCDQ) and Luqiao (VCLQ) in China. Different issues with the support bearing have been raised in other Volvo plants, and several root cause analyses are being performed parallel. Information about the current states in the other plants has been gathered to reduce the risk of potential rework in this project. When contacting the VRT departments in the other production plants, some of them highlight problems with the component. Because of the occurring pandemic during this thesis work, it has not been possible to gather information from all the different production plants. Therefore, the following text will focus on the available information and the plants that have other problems with the component.

VCT is the only production plant that has an automatic assembly process of the headliner and support bearing. In the other plants, the operators press up the pushpin manually, which makes it attach to the car body. None of the other plants experience the same problem as in VCT. Table 3 below shows a summary of the current state in the other plants, including what car models are produced and what problems they are experiencing. The same component is used in all the cars assembled by the company, but Volvo is using multiple suppliers for the different plants. Although, the same supplier of the support bearing is used in VCT as in VCG. Therefore, this comparison of the different plants will focus on the current state in VCG due to the usage of components from the same supplier.

Table 3. Showing a summary of the troubles experienced in the different production plants regarding the support bearing.

	Produced car models	What problems?
VCG - Ghent	XC40, V60	High assembly forces leading to loose support bearings
VCCD - Chengdu	XC60	No problems with damaged or loose support bearings and no high assembly forces.
VCDQ - Daqing	S60L, S90, S90L	Sun visor do not attach correctly to the support bearing hook. Loose feeling of sunvisor due to thickness of steel in car body. No problems with high assembly forces.

The support bearing is delivered to VCT and VCG from the supplier Daimay who currently produces the components in France. The supplier was previously named Motus, which was recently acquired by the company Daimay. In VCG, the support bearing is attached manually by operators, and in the year 2018, VCG raised awareness about an ergonomic issue due to high assembly forces. This also results in problems with loose support bearings, which is due to the operators not successfully pushing up the pushpin. Their analysis from 2018 included measurements of the component and showed that it is outside of specification limits. More specifically, the size of the lock pin is approximately 1 mm wider than the measures at the drawings. VCG concluded that the assembly forces would decrease with a modified component that is within specification limits. The supplier chooses to address this issue in connection with the recent acquisition of the company. Due to the acquisition, the production of the component is transferred from France to a new position in China. Because of the location change, new tools for the production are implemented, and the new tools will be adjusted, keeping the component within specification limits. The newly produced components from China were estimated to be introduced in the production in VCT and VCG in April 2020. Due to the spread of Coronavirus, the scheduled delivery is postponed to the end of May 2020. When VCG received prototypes of this new component, they still experienced too high assembly forces (measured forces on 100 N, ergonomic specification is on 15 N). They have concluded that the high assembly forces are the cause of the body thickness and therefore raised the problem with the Research and Development department. They are mainly having problems with XC40, which have a body thickness of 1,4 mm compared to the V60, which only has a thickness of 1 mm.

The plants in China receive the support bearing from another Chinese supplier, and all the plants assemble the support bearing manually. According to the VRT department in Chengdu, where they produce the XC60, they do not have any known problems with high assembly forces, loose or defect support bearings. In the Daqing plant, they do not have any trouble with high assembly forces, but they have experienced several other problems with the component.

Firstly, they have been experiencing troubles with the hook, which has been outside of specification limits. This leads to that the sun visor sometimes falls down due to the sun visor rod not attaching to the support bearing. Secondly, they have had troubles with support bearings with a loose feeling on the S60, meaning that the support bearing is slightly moveable when attached to the car body. This is explained by the steel being thinner, which allows some space for the component to move. They solved the issue by optimizing the attachment hole in the car body for a better fit.

5. Potential x's

This section will focus on the identified x's that could be the process input that causes the problem with loose support bearings. The identified x's are; the support bearing, the operators, the palette, the headliner, the car body, and the communication within the organization.

5.1 The support bearing

According to the drawings of the support bearing, the width of the lock pins should be 16,81 mm (see Figure 25 below). The DMAIC project performed in VCG in 2018 indicated that the component was almost 1 mm wider than the specifications according to the drawings. During the project, the authors have tried to access information about the tolerances of the support bearing. Since no one could provide these to the authors, no conclusions can be drawn regarding whether the support bearing is within tolerances. To understand if the incoming material still differed from the drawings, new measurements were performed by the authors on incoming material in VCT.

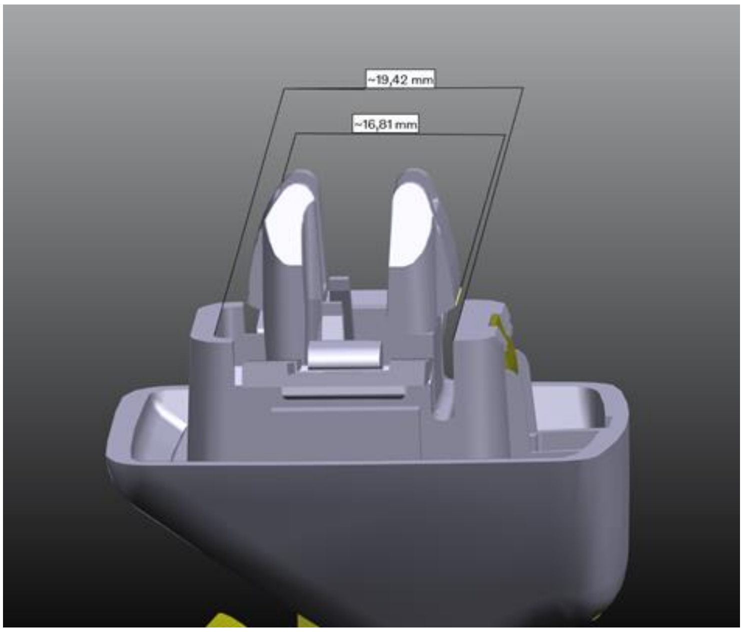

Figure 25. CAD illustration of the support bearing showing the measure for the lock pins.

The measurements were performed with a digital caliper by three operators with one replication, as described in Chapter 3.2.1. The average width between the lock pins of the ten measured support bearings was 17,53 mm that is 0,82 mm larger than the specification. There was also a high variation between the parts with the smallest at 17,17 mm and the largest at 17,95 mm. A visual representation of the measurements is shown in Figure 26 below.

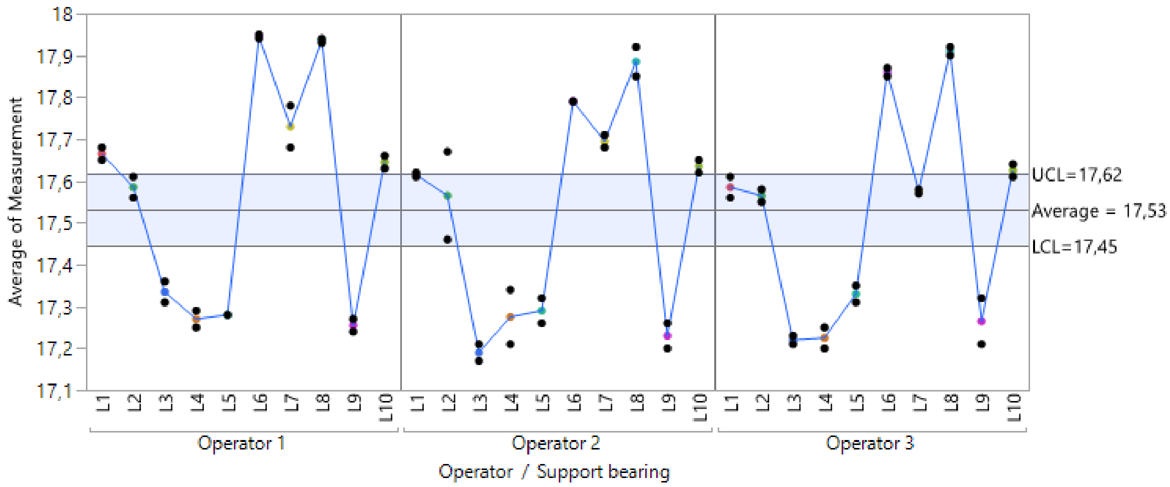

Figure 26. Visual representation of the measurements performed on incoming material. Shows measurements of 10 randomly chosen components by three operators with two replications.

If the width of the lock pins is larger than the specifications, there is a risk that the support bearing touches the edge of the car body when entering the hole, leading to defects such as the loose support bearings.

5.1.1 Adjustment of the component

As described in chapter 4.6, an adjusted component should be delivered to VCT and VCG in mid-2020. The adjustments of the component could possibly decrease the ergonomic attachment problems at VCG but, according to the responsible engineer at ME this change should not affect the problem of attachment in VCT. The defects on the support bearing in VCT indicate that they should not occur from the component solely being 1 mm outside of specification limits in its natural form. To test if the width of the lock pins are causing the defect, one of the defect support bearings were chosen. Since the component had already been expanded previously and then returned to the neutral position, it was far wider than the measured unexpanded components (1,75 mm wider than drawings). When putting the defect against the car body, it is clearly shown that there is space on the other side of the lock pin. The support bearing was tested against 10 different car bodies and fitted into the attachment hole for all of them. This indicates that the loose support bearing's root cause depends on more factors than solely the width of the lock pins.

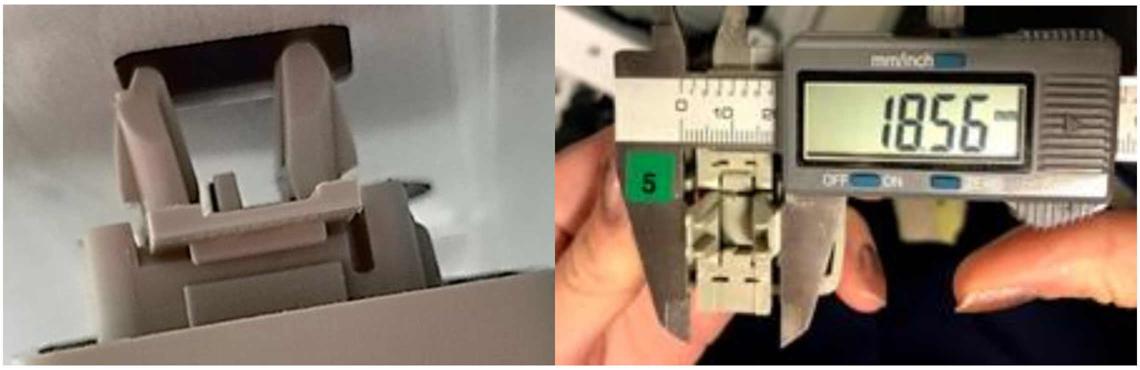

Figure 27. Picture showing an example of one defect support bearing with press marks on the lock pins. This support bearing has already been expanded and is therefore far wider than the average, and there is still a lot of space for it to enter the hole in the car body.

If the pushpin is slightly pressed up, the lock pins start to expand, making it even wider. A slightly expanded support bearing outside specification could although lead to the support bearing being too large for the attachment hole in the car body. This could lead to the lock pins touching the edge of the car body and not attaching correctly.

5.2 The manual assembly process

When people are involved in a process, it is important to be aware of their ability to affect the outcome. The operators at the production line have many opportunities in their daily work where they could potentially make mistakes, such as, occasionally forget to assemble a component. Standardized instructions are, for example, one way of decreasing the risk of mistakes occurring, and forces everyone to work in the same way. This requires the standard to be written, so it mirrors the actual handling of the operators. However, a Poka-Yoke design of the assembly could be recommended for highly repeatable operations.

5.2.1 Standardized instructions

As described above, all assembly operations at Volvo are gathered in documents called WES. These documents have been reviewed in detail due to the problem with the support bearing. At some places, the instructions in the WES are inconsequent. For example, at stations 3 and 4, the operators are performing the same task regarding the support bearing, but on different sides of the headliner. The instructions for these operations should, therefore, be the same, but the terms used in the instructions are different, and the order of the operations is not the same. This could create confusion and varying working procedure both within single operators over time and between operators, which creates instability in the process. When talking to the team leaders and operators at these stations, it appears that they are under the impression that there also are instructions on that they should press the support bearing towards the front of the car after positioning it in the contact lug. Some operators say they only should do it on the V60, some say they do it for all models, and some seem to not know about this. When checking the standard procedure operations in WES for the three different palettes, it is not mentioned anywhere that the operators should change the positioning of the support bearing after placing it in the contact lug.

According to the instructions for stations 6 and 7, the operator should grab the support bearing and feel that it is attached to the car body. Observations of these stations show that very few of the operators follow the standard operating procedure and check this, instead many grab the sun visor and feel that it is attached. This is a risk since it is not ensured that the operator notices if the support bearing is loose and not fully pressed up.

As described in chapter 2.5.2, the human factor refers to human nature and that people can make mistakes. Liker and Meier (2006) stated that companies need to shift the responsibility for errors from people to the method and the system that did not prevent the error. In this case, it is essential to oversee the routines and why everybody is not following the WES instructions. It is also worth pointing out the potential risk that instructions written by someone else, not conducting the operation, easily miss its target.

5.2.2 Traceability between loose support bearings and operator

At Volvo, all work performed by each operator at the stations is registered in ATACQ that increases traceability. Since the support bearings are assembled at several stations, which of one is automatic, it is hard to trace the problem back to one specific station. Data was gathered from occasions when there were many loose support bearings at the same time to understand if the operator impacts the number of loose support bearings. Data about the defect support bearings was combined with the operators at the different stations to see if there was a pattern. For the examined cases (32 cars), there was no correlation between the operator and loose support bearings. This indicates potentially that there is no significant difference in the outcome between different operators for the studied sample of data. At least does not lack of reproducibility seem to be one of the more potent root causes of variation.

5.2.3 Reassembly of loose support bearings

Interviews with team leaders indicated that they sometimes push up the pushpin of a loose support bearing to attach it. This is not always possible, and most of the support bearings are replaced. Observations of the defect support bearings show that they are slightly pressed together, meaning that they cannot attach to the car body properly. If a defect support bearing is pressed up, there is a risk that it does not attach correctly, which possibly could explain the defects identified by customers and not in the internal controls. Although, all the serial numbers of the defects identified by customers have been compared to the reported data in ATACQ, which shows no correlation. However, as stated previously, the reliability of the data registered in ATACQ could be questioned.

5.3 The automatic assembly process

There are several factors regarding the automatic assembly process that are performed by the palette that could affect the problems with loose support bearings. These include the assembly pressure, the position of the palette, the contact lug where the support bearing is placed before assembly, together with how the equipment is taken care of by, for example, preventive maintenance.

5.3.1 The palette

The automatic assembly process of attaching the headliner to the car body is performed at previously described station 5 in chapter 4.3. The headliner is put onto a palette by two operators, see the picture of one of the palettes in Figure 28 below. The operation begins by the palette moving forward into the car body, and thereafter it presses up the headliner into the car body and makes it attach to several attachment points. To ensure that the positioning of the headliner aligns with the car body, the palette has several fixtures and tracking pins where the different parts of the headliner are positioned by the operators. The two support bearings are placed into contact lugs with the purpose of making sure the headliner is correctly placed at the palette (see Figure 28 for placement of contact lugs). As described previously, the palette is pushing up the headliner and the pushpin in the support bearing, which makes the support bearing expand and attach to the car body. Within production in VCT, three different palettes exist, the first one is used for XC60 and XC90, the second one for V60 and V60CC, and the third one for V90 and V90CC. The function of all palettes is the same, but they look slightly different depending on the car body's geometry.

Figure 28. Picture of the V90 palette, the contact lugs to the support bearing are the white fixtures in the red circle.

5.3.2 Pressure

When the palettes were designed an initial specification was made regarding the pressure for the different fixtures. The palette has several fixtures that press up the headliner, and the nominal pressure varies for the different positions. The specifications of these pressures can be found in the rear front of the palette for two of the palettes, but the third one (the V60 palette) is missing this document. This document seems not to be found anywhere else since the values are not used as master values. The pressure is sometimes adjusted due to different problems such as loose support bearings and pressure marks on the headliner. These changes in pressure are not formally documented anywhere, meaning it is not possible to see when the pressure has changed and the reason for it. One example of a registered pressure change was on a DMAIC project performed by production about "unclicked clips". All different pressures were measured, but the focus and changes were only made on two of them. The knowledge about these pressure changes was not found in an official platform but came from the person who performed the project. Therefore, this can be considered tacit knowledge in the organization, since the information about this DMAIC project was more experience-based and not available for everyone. If the person performing this project were to leave Volvo, there is a risk that this knowledge is lost for the organization.

When the First Line Analysis of the problem with loose support bearings was made by the production personnel, it was noticed that the pressure for the V90 palette was 4,8 bar instead of the 2,4 bar that the other palettes had. Before lowering the pressure, they had more problems with broken support bearings since they were pressed into the car body with a higher pressure. According to the production personnel, the decrease of pressure led to less broken support bearings, but the problem with loose support bearings remained.

5.3.3 Position

The three different palettes were introduced at three different times in connection with the launch of new car models being released the year 2015, 2016, and 2017. These palettes were bought as a turnkey, meaning that Volvo buys the whole function, by the supplier Movomech. At these times, measurements were made on the palettes to make sure they were within the tolerances of the drawings. These measurements were performed by the supplier who delivered the equipment. The measurements were performed on several points of the palette, but the most interesting for this project is the position of the contact lug in which the support bearing is put within. For the XC60 and XC90 palette, these measurements were far out of the tolerances that indicate that the fixture is moved forwards in relation to the car body. There is no information about if changes to the equipment were done after these measurements. Measurements of the equipment are not done continuously, and no measurements have been made on the palettes after these initial measurements, even though several adjustments have been made. This results in no one knowing if the palettes are up to specifications and how the different fixtures relate to each other. Consequently, this could lead to drifting misalignment between the palette and the attachment points in the car body.

5.3.3.1 New measurements of the palettes

There is one internal department at Volvo that works with geometry and measurements of the cars and equipment. To understand if the palettes were up to specifications, the authors took help from these to perform new measurements. The measurements were done using a Leica machine that measured the different points on the palette using a laser. These measurements were connected to the CAD-drawings of the different palettes and could give very precise measures of the position of the different parts. The focus of the measurements was on this one due to the majority of problems being with the palette that assemblies the V90 and V90CC.

The loose support bearings' observed defects indicate that the support bearing does not enter into the car body correctly. Since the defects are on the front part of the support bearing, it indicates that the positioning in the x-direction would be inaccurate. Several measurements were done on both sides of the contact lug to see how it deviated from the specifications. The most critical part is although the side that is towards the front of the car since it is this side that the support bearing aligns with before assembly into the car body. None of these measurements in the x-direction were further than 0,4 mm from the CAD-drawing. The measurements for the left contact lug at the V90 palette are shown in Figure 29 below. When the support bearing is put into the contact lug, it touches the points that are marked as surf pt 24 and 23 in the Figure.

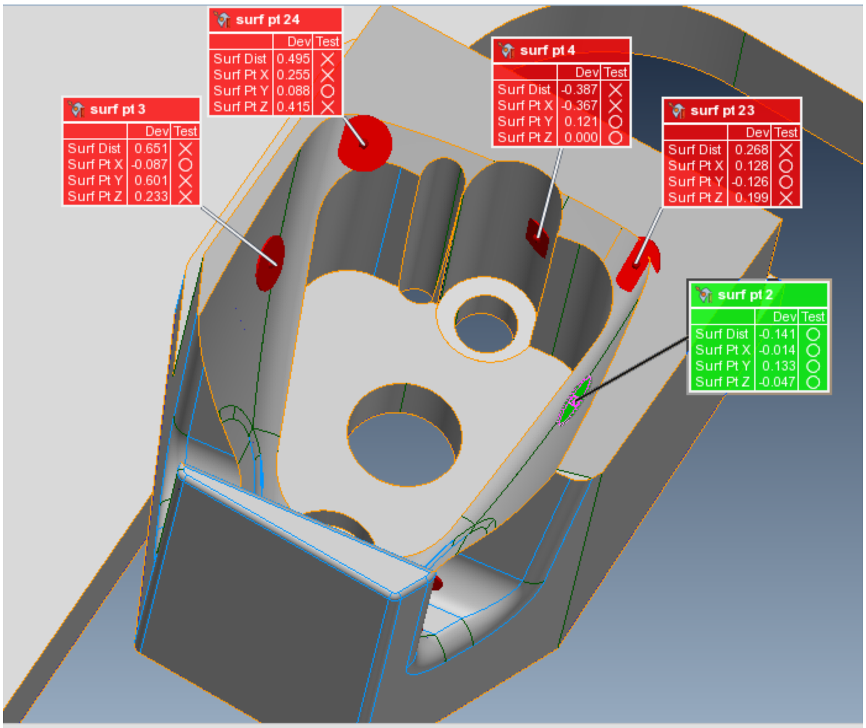

Figure 29. Picture from the CAD-drawing of the support bearing including the performed measurements on the V90-palette.

When the measurements were to be performed at the other two palettes, it was realized that the reality and the drawings were different that made the measuring complicated. The main problem was that the values in z-direction were incorrect that made it impossible to use the Leica machine to find the different values. This further indicates that several changes have been made to the palettes without being registered anywhere, explaining why. There was, although possible, to complete the measurements of one of the contact lugs on the V60 palette. The position of this contact lug did deviate more from than for the V90. The deviation in x-direction measured on the contact lug was at different values and directions. This indicates that it is not an equal dislocation in one single direction but instead that the geometry is slightly different than the drawings. There is although no found information about if this is something that has been changed intentionally or by chance. Since the V60 palette is one of the palettes with the least defects, this indicates that the latest documented drawings or standards might not be the optimal ones since they have not been updated.

5.3.4 Preventive maintenance

Maintenance is performing regular preventive maintenance every seventh week on the equipment. These include checking the function of the equipment and performing a general review to examine if there are any damages. Although, the positions of the different parts, such as the fixture to the support bearings, are not examined in any way. The different pressures used are not examined since there is no master value of what the pressure should be.

5.3.5 Contact lug to support bearings

The support bearings are put into fixtures onto the palette that further presses up the pushpin. There exist two slightly different contact lugs, one for the V90 palette and one for the two palettes that assemble V60, XC60, and XC90. The drawings of the two different contact lugs look very similar but have small differences in the measures (see Figure 30 below). For example, the height varies between 33.9, 34.6, and 34.5 mm. During the case study, no one could explain the difference between the two different contact lugs. The difference in height could although probably be described by the contact lug not being symmetrical, leading to different heights on the two sides. The contact lugs for the V90 palette were exchanged during the project to the same type of contact lugs as the other palettes. This did not affect the number of loose support bearings but decreased waste since the company could only store one spare part instead of two.

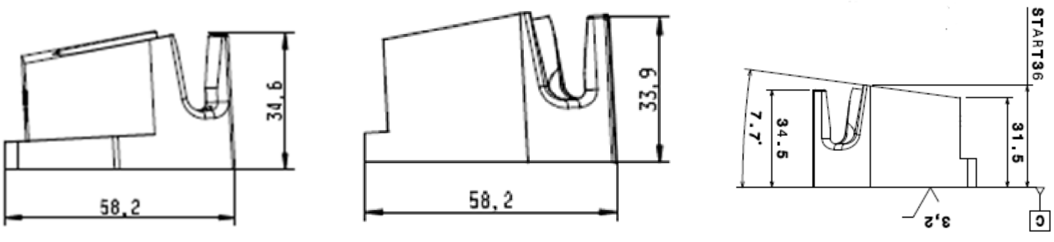

Figure 30. Three different drawings of the contact lug, the first two are for the V90 palette and the third one is used for V60, XC60 and XC90.

Maintenance states that these fixtures have not been replaced since the equipment was installed. When observing them, some wear can be seen inside them close to a screw, as seen in Figure 31 below. This makes the fixture have some sharp edges that come in touch with the support bearing. Those are not affecting how the support bearing is pressed up and is therefore not likely to be the reason for the loose support bearings. These sharp edges could although lead to other visual defects on the support bearing, such as press marks identified on the hook.

Figure 31. Picture showing defects in the contact lug.

The support bearing is as mentioned earlier attached to the headline, and later the headliner is put on to the palette. The support bearing should then be placed into the contact lugs. When the support bearing is attached to the headliner, it will not always go down entirely into the contact lug but instead hangs down to a certain extent in the contact lug. This positioning makes it possible for the support bearing to be positioned differently into the contact lug, depending on its positioning into the headliner. Observations of the positioning of the support bearing in the contact lug show that it can be moved by the operator, making the process less standardized and increasing the variation.

5.4 The headliner

The geometric design of the headliner does not guarantee that the attached support bearing will be placed correctly into the contact lug, as described above. This could, later on, affect how the support bearing is attached to the car body, see chapter 5.3.6. As mentioned in chapter 4.3, the headliner has pre-made holes that are bigger than the support bearing. This increases the possibility of the component attaching correctly to the car body since the component can be moved slightly to fit into the car body even if the geometry of the headliner has some variations. Although it can also increase the risk of the operator misplacing the support bearing into the contact lug.

To understand if there have been any quality-related issues with the headliners, the authors took help from Incoming Material Quality (IMQ) that works with the quality of incoming material. According to IMQ, the only quality issue that has been reported is with the headliners to XC60 and V60 that previously have been longer than specifications. Further, both suppliers send in continuously made measurements of the headliners that indicate that they are delivering with the right quality.

5.5 The car body

The support bearing is attached and expanded into pre-made holes in the car body, as described in chapter 4.1. The attachment holes for the support bearings are measured in order to make sure that the holes are up to specification limits, see Figure 32 below for an example of one measurement. Initially, it was told by VCBC that the attachment-holes for V90 were produced one dimension bigger according to an agreement with VCT. Further investigations showed that this was not the case but rather a misunderstanding. The measurements performed by VCBC on the holes, although it shows that they are slightly larger than the specifications. If the holes are larger than the specifications, it would probably not lead to additional problems, since the risk of the support-bearing touching the hole's edge would decrease.

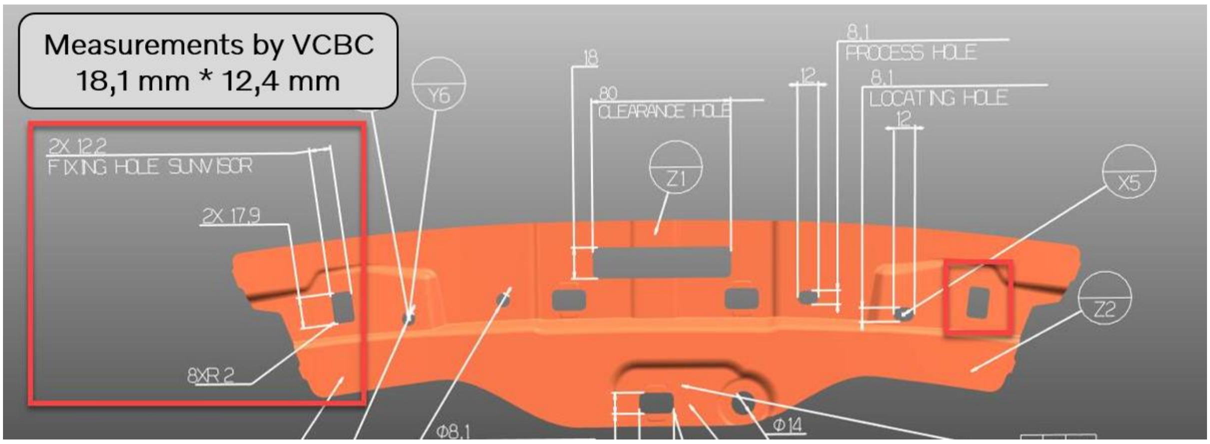

Figure 32. Measurements performed by VCBC on the hole for the attachment of the support bearing.

VCBC is continuously performing measurements of their produced parts and the position of the different holes. Although, the position of the holes to the support bearings is only measured on XC60 and XC90. According to the received information, the holes are not being measured for neither V60 nor V90. During the project, new measurements were received from VCBC regarding the positioning for V60 and V90. Although, these only included one single measurement for each hole. This makes it hard to perform any comparisons since it is not possible to validate the data and ensure it is not only one variation shown.

One hole that is continuously measured is the positioning hole, described in chapter 4.2. The measurements on the V90, which have the highest amount of reported loose support bearing is compared to the XC90, which have the lowest amount. Figure 33 below shows the measurements and their variation during the last year. Measurements of the positioning hole, for the V90, during the last year shows that it is positioned in average 0,4 mm towards the rear part of the car. Contrary, for the XC90, the measurements show a positioning in average, 0,14 mm towards the front of the car. This indicates that the difference in geometry of the car body could possibly affect the alignment with the palette when the support bearing is assembled, which in turn could affect how the support bearing is attached.

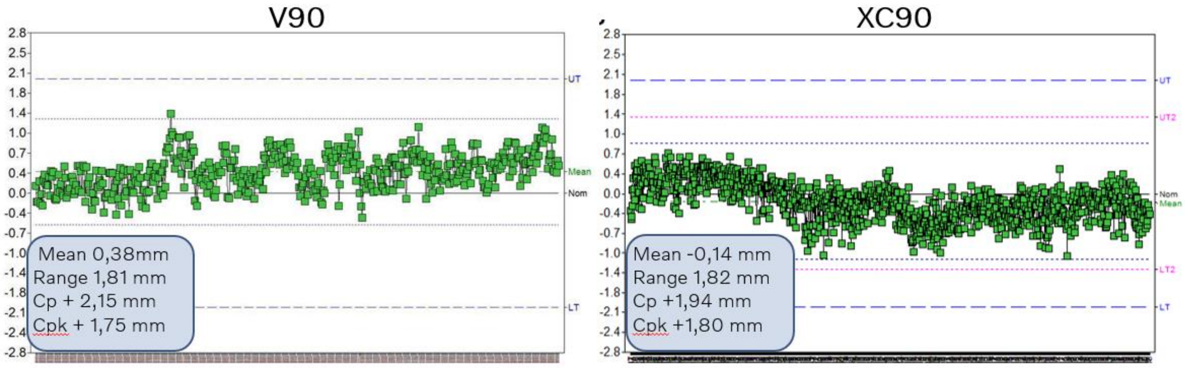

Figure 33. Measurements of the position of the positioning hole in the car body for V90 and XC90.

5.6 The organization and communication

Since the organization is large, it consists of multiple different functions that need to cooperate together. This chapter aims to describe detected abnormalities both in the communication within and between functions in the company, and also to describe the difficulties in the communication between different plants around the world.

5.6.1 Communication within functions

The findings from this case study indicate that the communication within the functions at VCT is not consistent and clear. Shorter unstructured interviews with the people working in the production at station 3 and 4 at the palette indicated that the workers do not only follow instructions from the WES, but also additional oral instructions. Further, interviews showed that workers from different teams interpret the oral instructions differently depending on their team leader. One example of this is about interpreting instructions about pushing forward or backward the support bearing into the contact lug, as described in the chapter. XXX. These types of inconsistencies in the standardization and guidelines of the process can decrease the process stability. Inconsistent work instructions could, therefore, lead to more significant process variations that, in turn, leads to quality issues.

The ATACQ data indicated, as mentioned in Chapter 4.4.1, that all identified loose support bearings are not reported into the system. This also shows that the communication about the importance of reporting data into the ATACQ system does not reach the right persons. For example, the people working at the day shift have more frequent contact directly with people from other functions since a majority of the other functions work during the daytime. In this case study, this can be exemplified by the authors being present at daytime leading to more frequent face-to-face communication. This increases the awareness of the problem with loose support bearings, and this could possibly affect the frequency of reported cases.

5.6.2 Communication between functions

As mentioned previously, a palette is used for the attachment of the headliner to the car body. Different parts of the organization are responsible for different functions of the palette. Although, these responsibilities are not clearly specified, making it hard to judge who is responsible for what part and where the interface to the next responsible party or person is. Some parts of the organization that are responsible for the different functions of the palette overlap in their responsibility, leading to difficulties finding the right person responsible for a certain area. As mentioned in Chapter 2.1.1, one of the cornerstones in TQM is to let everybody be committed. In order to make sure that people do a good job, they need to feel a responsibility, personal pride, and commitment. When people work without getting recognition for their performance, it might lead to lower quality on the performed task. In this case with the palette, the functions are not aware of each other's work, and therefore they might not get the recognition they need to feel responsible for their specific work area The Six Sigma built-in know-how indicates that there is a delicate balance between specifications and instructions versus the use of guidelines to strike the right level of standardization. Instructions tend to reduce the feeling of responsibility, whereas guidelines empower it.

Furthermore, these different functions do not always communicate with each other, meaning that they are not aware of the other functions or people's jobs. For example, one person might change the pressure, and another person might change the position of the fixture without communicating with each other. This can lead to massive issues when the different functions affect each other by changes, but these are not reported and stored in an easily accessible way. Interviews with people from different functions also showed that there exists much misunderstanding and misinterpretations of what someone else is doing. For example, several people referred to documents that did not really exist.

In this project, a lot of the knowledge about the palette was held by the person that implemented it into production. This person has later changed the role within the company without transferring the knowledge to a new responsible function. Future decisions regarding the palette could, therefore, not be based on facts since a lot of knowledge is lost. To base decisions on facts is another important TQM cornerstone; without knowledge about how the palette works, it is impossible to know what should or should not be changed. Knowledge management in an organization must be handled with care, otherwise, there is a risk of losing valuable knowledge.

In each function at Volvo, there are several guidelines for how a problem should be addressed. For example, as mentioned in chapter 4.4.1, a First Line Analysis should be conducted by the production team. In this analysis, the team has clear instructions about how and what questions they should answer. The purpose of having this kind of standardization of handling problems can facilitate double-loop learning, as described in chapter 2.5.3. If the information is not accessible in an easy way to the right persons after it is created, it will result in single-loop learning for the organization. Through the case study it was visible that the result from the First Line Analysis was not always used correctly. There is a risk that standardized tasks are done by routine, and thereby, its purpose is lost. In this case, it was focusing on answering all the questions instead of finding the root cause. One example from the First Line Analysis is that it was recognized that there were issues with incoming quality; the size of the support bearing was far wider than specifications at the drawings. It was also noted that similar problems with the component were present at VCG. This information was noted in the First Line Analysis by an attached email from another function, but no further actions were taken. Therefore, it is important to make sure that the information shared between the function is having the purpose of being shared and used correctly.

5.6.3 Communication between plants

Volvo is a global company with plants all over the world. As stated by North and Kumta (2018), many global companies experience troubles with gathering and sharing their knowledge. It is essential to make sure the information and knowledge stored in a global company are accessible worldwide, according to the Act phase in PDSA. At Volvo, many similar processes are performed on multiple locations parallelly, and it is common that more than one plant experiences the same problem. The company has shared platforms for sharing knowledge between the employees, for example, VIRA. During this project, it has been noticed that much rework is still done. The information uploaded in VIRA does not necessarily get to the right person but is only uploaded to be stored in a cloud without reaching the person looking for information in another plant, which indicates information pushing. It is impossible and unnecessary for everyone knowing everything; therefore, it must be clear who possesses what kind of information and how another person might get it. Problems with non-effective knowledge sharing through information pulling lead to rework and that the company loses valuable knowledge. In this case, interviews indicated that many plants experienced issues with the same component without being aware of it.

5.7 Combination of several x's

One way to test how several factors affect the process output is through a Design of Experiment (DOE). As described in chapter 3.2.2, a DOE was performed in this study to test the significance of several factors, both by themselves and the interactions between them. The three factors that were tested, on their extreme settings, were the width between the lock pins, expanding of the lock pins, and the placement of the support bearing in the contact lug. Observations of all 16 tryouts were made, and all support bearings from the experiment were disassembled for further analysis. Since the problem production experience is loose support bearings, the DOE response was registered if the support bearing were loose or not. Previously done observations on defect support bearings showed that they had press marks on either the front or rear lock pins. Therefore, these factors were chosen as measures to the DOE. The result of the DOE is shown in table 4 below. For each of the tryouts, the support bearing was observed, and it was determined if it had been loose and if it had any press marks. Each row in the table below shows the setting for each experiment and the result. The result from the DOE was analyzed using the statistical software JMP were a logistic regression was used to understand each factor's significance.

Table 4. The design and result of the performed Design of Experiment.

Pattern	**Expanding**	**Size of support bearing**	**Position**	**Loose**	**Press marks rear lock pin**	**Press marks front lock pin**
221	Not expanded	Smaller	Front			
122	Expanded	Smaller	Back	X	X	
222	Not expanded	Smaller	Back			X
121	Expanded	Smaller	Front	X		X
211	Not expanded	Larger	Front			X
112	Expanded	Larger	Back	X	X	
111	Expanded	Larger	Front	X		X
212	Not expanded	Larger	Back		X	X
221	Not expanded	Smaller	Front			
122	Expanded	Smaller	Back	X	X	X
222	Not expanded	Smaller	Back			
121	Expanded	Smaller	Front	X		X
211	Not expanded	Larger	Front			
112	Expanded	Larger	Back	X	X	X
111	Expanded	Larger	Front	X		X
212	Not expanded	Larger	Back			

5.7.1 Expansion and Positioning

When analyzing the y-value of if the support bearing were loose or not, the results showed that it was only affected by if the support bearing was expanded or not; neither of the other factors were significant. All support bearings that were expanded did not attach at all to the car body.

The result from the experiment also shows that it was possible to move the defect from one side of the lock pin to the other by adjusting the placement in the contact lug. When analysing the outcome press marks on the rear and front lock pin, it was shown that the position was a significant factor for press marks on the rear lock pin, with a p-value below 0,05. For the outcome press marks on the rear lock pin, the factor expanding was also significant, with a p-value below 0,05. This indicates that the defects on the rear lock pin were dependent on both if the support bearing was expanded as well as the position in the contact lug. The operators have a great ability to change the position of the support bearing before assembly, which leads to excessive variations. This further implies what is stated in chapter 5.3.5, that there is a risk that the support bearing is not placed correctly in the contact lug, which leads to unnecessary defects. There is currently no knowledge about what is the best position of the support bearing in the contact lug.

5.7.2 Size of the support bearing

The size of the support bearing does not show any significant results on any of the analyzed y-values. This indicates that even if the size of the support bearing is outside the control limits, it does not affect the problem with loose support bearings, nor the defects identified on them. It is essential to highlight that this test only included 16 support bearings collected randomly during a short period of time. The previously done MSA performed on 10 randomly chosen components indicated that huge variations on the width between the lock pins exist. Possibly, even bigger variations could be identified if there were larger variations over time that could have affected the problem previously. The size of the component will, although, be changed and produced closer to the specifications when the supplier moves their production. This, together with the non-significance of the factor for this experiment, indicates that the support-bearing size could be overseen in this project.

5.7.3 Further experiments based on DOE

To further understand how the expanding of the support bearing affects the problem with loose support bearing additional tests on the palette were done using center points. The first setting that was tested was the support bearing being partly expanded, the second setting was if it was fully expanded and then returned to the natural state before assembly. The second setting was chosen due to the support bearing being slightly wider after the first expansion. This was also an important factor due to this event occasionally occurring in production. The support bearings that were partly expanded resulted in loose support bearings. No result was seen for the support bearings that first had been expanded and later returned to the natural position, all of them attached correctly to the car body, maybe successful thanks to the extra attention it gets.

6. Discussion

The following section aims to provide a discussion around the two research questions based on the case specific findings together with the theoretical background. Apart from the root cause to the problem with loose support bearings, additional improvement areas are presented. These are discussed due to their negative impact on the performed root cause analysis. Improvement on these areas could possibly lead to future gains for Volvo who could improve their root cause analyses. The discussion will further be used as the base for conclusions, where the research questions are answered, and recommendations to the company are given. In this chapter the chosen methods will also be evaluated and discussed and suggestions for future research will be given.

6.1 Root cause to the problem with loose support bearings

This chapter provides a discussion about the findings from this case study in order to answer the first research question.

Research question 1: What is the root cause of the problem with loose support bearings to the sun visor, and how could it be improved?

Finding and eliminating the root cause of the problem with loose support bearings may not increase the overall customer satisfaction since the function of the support bearing can be considered a must-be requirement according to the Kano model. Therefore, the fulfillment of the requirement does not necessarily increase the customer satisfaction, but if the requirements are not fulfilled, it certainly decreases the customer satisfaction. Finding the root cause is, therefore, considered important in order for Volvo to maintain a high customer satisfaction and a high perceived quality. As described in chapter 5, several root causes (x’s) have been identified during the project that can affect the problem with loose support bearings. During this case study, the identified x’s are the support bearing, the manual assembly operations, the automatic assembly process, the headliner, the car body, the organization, and the communication. The performed analysis shows that the root cause of the problem with loose support bearings is mainly related to the support bearing’s alignment when assembled into the car body.

The alignment of the support bearing and the car body is, however, not determined by one single factor only. One significant factor in the performed DOE was the positioning of the support bearing into the contact lug. The positioning is not only determined by the geometry of the contact lug and the headliner, but it is also affected by the interaction with operators who can slightly change its position. It is also unsure if the palettes have the correct geometry since no updated standards exist that make the results from measurements insignificant. Since the problem origins from the alignment between the palette and the car body during assembly, another important factor could be the geometry of the car body. For example, the placement of the attachment holes to the support bearing to all car models are not measured continuously and confirmed to be according to the standards. The attachment holes are according to measurements performed by VCBC slightly larger than the specifications. The width of the lock pins itself does not seem to be the root cause, even if it is wider than the specifications. This could be explained by the attachment hole that is considerably larger than the component. This means that even if the component is wider, it should still attach correctly if positioned correctly. Although, the size could, together with the above-mentioned factors have a negative impact on the problem. The supplier of the support bearing is currently moving their production and should in the near future deliver components within the specification limits, therefore, this factor is not considered significant to the root cause in this analysis.

If the assembly of the support bearing were to have higher reliability, there would be a decreased need for the controls performed within production. The controls used today could be seen as non-value added work since the operations do not add any value to the customers. Although, since the current process does have larger variations meaning that not all support bearings attach correctly the controls are important to ensure that no cars with loose support bearings reach the end customer. If a customer receives a car with smaller defects it will lead to lower customer satisfaction since the function of the sun visor could be considered a must-be requirement. Therefore, the controls are considered meaningful as long as the reliability of the assembly process is not increased.

6.2 Improvement areas

When performing the root cause analysis to the problem with loose support bearings several improvement areas were found, that was used to answer the second research question.

Research question 2: What potential improvement areas exist for successful performance of root cause analysis based on this case study?

During the analysis of the empirical findings several areas for improvements were found that affected the root cause analysis and its outcome. In order to structure the result these were divided into four larger areas. Each of these areas are discussed separately in this chapter and are thereafter used as the foundation for the company specific recommendations. The four improvement areas are:

- Base decisions on facts
- Standardization
- Knowledge sharing
- Communication and collaboration.

6.2.1 Base decisions on facts

The findings from this case study show that at the moment, the organization fails to fulfill the criteria to base decisions on facts, which is an essential cornerstone in the TQM model (Bergman & Klefsjö, 2010). In order to base the decision on facts collection of data is required, furthermore, the types of collected data should be chosen carefully. New problems often require new metrics or new ways of visualizing and interpreting already collected data. The issue at the organization concerns both collection of data that is not used correctly, and the lack of reliable data and a lack of an elevated discussion of how to define new metrics that sets the foundation for many decisions. Before the launch of this specific case study, a First Line Analysis was conducted that required a collection and compilation of many kinds of data. Data in itself cannot solve any issues if it is not interpreted correctly. This First Line Analysis consumed time from people with limited understanding of how this data could and should be used. As a result, the First Line Analysis did not succeed in finding the root cause since the analysis ended after data collection without making any further impact on the issue. Therefore, it is essential to not just gather data without any purpose, but instead make sure that the collected and stored data can and will be used.

As mentioned previously, the interpretation of data from ATACQ often constitutes the starting point for corrective action. Here, the principle to base the decision of facts is adapted, but findings from this report indicate a considerable number of hidden statistics in the ATACQ data. The data is registered manually, which demands that the team leader remembers the relevant information is registered in the computer. The team leader often has to address smaller issues at the moment they occur in the production line, which could hinder the team leader from having the time to register the defect in ATACQ immediately. This could lead to prioritization of other more urgent tasks than registering them into ATACQ. The analysis performed in this case study shows that the amount of data registered depends on the responsible person's knowledge about the importance of registering all relevant issues. They are probably not aware of the registrations' purpose and how the data can be used for basing decisions of facts.

Since one control of the support bearings is done at the production line, it should not be necessary to have a second control station. Although the data from ATACQ shows that many loose support bearings are detected at the SIP control station, later in the production flow. This could be partly explained by observations that showed cases when the workers at the production line did not fully follow the standard operations instructions from WES. Furthermore, another explanation could be physical differences between the operators, together with a combination of the size of the car body, could lead to diverse ergonomic positions in the car that are not equally advantageous. When the operator sits in the car on the production line to control the support bearing, he or she could have trouble getting a good vision and reaching to the headliner area and therefore miss defects. This issue can be connected to the human factor (Feggetter, 1987), and to the fact that no system that is totally dependent on humans, such as operators within a production system, can be without variations. The ergonomic issues with the controls could possibly also affect in what car models the loose support bearing is detected. This could explain why less loose support bearings are found on XC60 and XC90 on the production line compared to V60 and V90. Instead, the majority of these are identified at the later SIP control station.

6.2.2 Standardization

Standardization of work procedures can transfer the responsibility for errors from people to the system and the used methods, as stated by Liker and Meier (2006). Standards can form the foundation for future improvements, and adjustments should be compared against the standard. Standards can only be applied if they are used correctly, meaning that significant changes must be registered and traceable. Through the implementation of more standardization in the process, the process could get more robust and resistant for different forms of noise that create variation.

At the production line, multiple examples of problems with standardization can be identified. Most notably, this issue was seen at the palette that has multiple functions that can be adjusted, for example, positioning of the contacts lugs and the assembly pressure. At each of the palettes, a specification of the recommended pressure should be present, but this was only found at one of the palettes. Furthermore, the specification for one of the palettes indicated that the pressure should be 1,2 bar, but at the moment, the pressure is adjusted to 2 bar. Interviews indicated that no employee knew exactly who and why the pressure had been adjusted. In this case, 2 bar seems to be a suitable tuning, but it can easily be lost since it is not registered anywhere. If, for example, a worker would by mistake change the pressure, he or she would not know what pressure should be tuned in and would look at the misleading standard in the specification showing 1,2 bar. The positioning of the contact lugs is of huge importance of how the support bearing will be placed against the headliner. Therefore it is essential to be able to measure the relationship of the positioning. In this project, all required measurements could not be executed due to the lack of updates in the palette standard in its CAD model. This meant that multiple changes had been done to the palette without being updated in the CAD model, increasing the risk of possible rework since the changes are not traceable.

Moreover, the WES is used to standardize the performed work by the operators, but after analyzing the current WES it appears that they need to be updated. For example, the different WES does not use the same formulations for the same task that should be performed, which could lead to misinterpretations and variations in the process. During the case study, it was also shown that all instructions were not present in WES since some operators and team leaders told the authors about orally communicated work procedures. Changes in WES can be done by different people in the organization, but all changes in the instructions are not clearly communicated to the concerned operators. This both makes it hard for them to use the standard correctly, while it also hinders the possibility of finding and fixing the root cause for issues that might occur.

6.2.3 Knowledge sharing

A lot of the people involved in the case study possessed valuable knowledge for the project, and their knowledge helped the authors to understand the current state and identify potential x’s to the problem. The interviews performed at Volvo showed that a large part of the knowledge present within the company is in the form of tacit knowledge. This is in line with the previous theory presented by North and Kumta (2018), who expresses that companies usually have a lot more tacit knowledge than the expressed explicit knowledge. It is further argued that for companies to have more efficient knowledge management they have to make sure that the knowledge also is stored and shared with others in the organization. This could also be considered by Volvo since it appears that not all valuable information is stored in shared platforms and available for relevant employees.

When most of the knowledge about a specific area is only kept tacit within people there is a risk that a great part of the knowledge is lost along the way. During this project, several of the stakeholders have referred to the same person. This person has previously worked closely with the palette and the assembly process and, therefore, possesses a lot of valuable information. Unfortunately, this person has changed their role within the organization and no longer works with the same questions. The responsibility and knowledge this person possess has although not been transferred to someone else. Therefore, this knowledge was very hard to access due to this person working with other projects and not having the time to put time into this case study. Luckily, this person was still working within Volvo, which enabled the authors to get an answer on some of the questions. If this person instead had changed job to another company, all the knowledge this person possesses probably would have been lost and not found anywhere. This agrees with the theory presented by Börnfelt (2017) that it is essential to move the ownership of the knowledge from individuals to the company to ensure that critical knowledge is not lost.

Several of the interviews performed together with the production personnel made it clear that the problem with loose support bearings is not a new phenomenon, but rather a problem that has been present for several years. It is also noticed that several smaller projects have been performed earlier, trying to solve the problem. These projects and what has been done at these times are although not stored anywhere meaning that it is hard to ensure that the lessons learned and the knowledge from these are used in future projects. For example, when information about the different pressure at the palettes was searched for several persons referred to a previously done project. It was said that this project should include some type of tables showing tests done at different pressures. When the information from this project was accessed, it was realized it was only regarding the pressure for two completely different points on the palette. Finding the information from this project was also time-consuming for the authors since it was not accessible directly but was instead sent by the person who had performed the tests. If the information is not easily accessible, it is also easy that it gets misunderstood, as in this case, when several persons said that there was information about the pressure to the support bearings, when in fact, there was no previous information about this.

6.2.4 Communication and Collaboration

Complex problem solving requires the gathering of people from different areas who possess different knowledge (George, 2005). In complex organizational structures, communication and collaboration are essential to solving problems (Wheelwright & Clark, 1992). This project involved several different stakeholders from different functions who had a variety of knowledge about the problem and the identified x's. However, neither person's responsibility nor the type of information they possessed was very clearly communicated to the authors. Interviews with several people at the company indicate that the same issue is experienced for many of them. Therefore, much time is put into finding the right person and receiving information from them. This could be argued to be a considerable amount of waste since it includes a lot of non-value adding work contacting a variety of persons when identifying the right people who could help the project move further.

The non-value adding work did not only affect the authors, but also several of the other persons that were thought to impact the project. For example, interviews were performed with several persons that other persons had recommended for interviewing. During these interviews, it was sometimes noticed that the person did not have any relevant information regarding the problem. Consequently, this could be seen as waste and non-value adding work, not only for the authors but also for the interviewee. This indicates that the communication between the functions is not efficient since it is not clear for everyone what kind of responsibility the people within the different functions have. If the communication is not clear about the responsibility and ownership of each function, there is a risk that urgent issues are not prioritized.

Since the authors communicated with a huge amount of people during this project from different functions an understanding of how the communication at the company worked was given. Most of the respondents were helpful and responded fast to the different questions the authors had. Although, during some instances, the authors did not receive any responses and had to contact the respondents several times. This could although also be explained by the lack of communication about each role and their responsibilities. As described above, the authors did not always get in touch with the correct people, and then the respondent might need to check with someone else to provide the authors with the information. Another explanation could be the experienced fragmented ownership of processes and a lack of feeling of responsibility. Then the respondent might feel that it is not their responsibility and think that someone else should be doing it instead. Another explanation could be by the cornerstone, let everybody be committed from the TQM theory. Bergman and Klefsjö (2010) state that it is argued that employees perform a better job with higher quality when they are given recognition for it. For example, when the respondents helped the authors in their project, they did probably not feel that the work favored their own project, which means that they would not be given any recognition for the result, which could decrease their motivation. This could affect the collaboration between different functions negatively and make it less efficient.

This case study did not only encounter problems with the communication between functions, the communication between the different production plants could also be considered fragmented. During the case study, no natural communication channels between the people working in the different plants regarding the assembly of the support bearing were found. When the VRT-departments were contacted in the other plants, it was found that several of them were working or had worked with issues regarding the same component. Information about these issues was stored in the internal program VIRA. Due to the variety of names that existed on different issues, it was although hard to find them without previous knowledge about their existence. If a more common language, or organizing principles within, for example, VIRA were to be used, it would probably be easier to find other relevant projects. The communication between plants is essential for effective and efficient problem solving since much learning could be used from each other.

6.3 Method evaluation

This case study followed the DMAIC methodology that was familiar to the two authors who have a Black Belt in Six Sigma. DMAIC is a structured method for improvement projects. Therefore, it helped the authors to facilitate problem solving. The methodology provided the authors with useful tools to both define the project as well as drawing conclusions. Additionally, a similar methodology is used at VRT today, which means that a majority of the stakeholders have knowledge about DMAIC projects. This facilitated the collaboration between the authors and stakeholders at Volvo since there was a shared understanding of the methodology. Although, the authors had no previous knowledge of the exact used methodology at VRT, which means that the performed analysis might deviate slightly from how the analyses usually are performed.

Since both the authors were new to this project, they did not have knowledge about everyone who had been working with relating projects. Problem-solving of complex problems requires collaboration between people from different functions. In this case, it could have been useful to gather all relevant people in one meeting to discuss the problem. Nevertheless, this was not possible since neither the authors nor stakeholders had previous knowledge about all the relevant persons. Therefore, snowball sampling was used, and the authors learned about the different functions' responsibilities throughout the project. Since the organization is large and includes many people with different roles, there probably are additional persons who possess the knowledge, which could have been useful for the result of the study. If the same project were to be done again, it cannot be assured that the exact same result would be found. This could be explained by the fact that a lot of the knowledge gathered in this project was tacit and only present within certain people. If other people were to be interviewed, it is not sure that they possess the same knowledge or experience of the problem.

6.4 Future research

In this study, it was not possible to complete the whole project and finish the Control phase due to time limitations. It would be valuable to complete all the DMAIC phases to understand the whole process of root cause analyses performed at Volvo. The Control phase is an essential part of improvement projects since it essential to make sure that the problem is solved and the result maintained. Therefore, future research could be to investigate how Volvo works with implementing solutions in improvement projects.

In order to verify and implement solutions to loose support bearings' root cause, more data gathering is needed. For example, more analysis of the car body's geometry can be done to make sure that variations in the geometry do not affect the issue.

During this study, it was noticed that the data registered in ATACQ was not always reliable. Therefore, it would be interesting to perform further analysis, not only including one component to understand the reliability of the data and how Volvo can use this data in a better way. This analysis could include variations between, for example, different working shifts and components.

7. Conclusion and recommendations

The conclusions presented in this chapter originates from the findings discussed in the previous chapter and are presented as recommendations to Volvo. The recommendations are separated into two parts in order to answer the two research questions. First, recommendations to solve the root cause of the problem with loose support bearings are presented and, secondly, recommendations of how to improve the performance of coming root cause analyses.

7.1 Recommendations for the problem with loose support bearings

The following section aims to answer RQ1 and to provide Volvo with recommendations that enable them to solve the problem with loose support bearings.

Alignment between the palette and car body
Verify that the alignment between the palette and the car body is correct to avoid loose support bearings since it is confirmed to be the root cause of the problem. When the palette and car body are correctly aligned during assembly, it decreases the risk of the support bearing not entering the attachment hole correctly. Therefore, there is a need to determine the best position of the support bearing into the contact lug to minimize the opportunities to misplace it by the operators.

Reattachment of loose support bearings
Do not reattach a loose support bearing since there is a risk that it does not attach correctly and only attach temporarily. There is a risk that the support bearing attaches only at one of the two sides if it is reattached and later falls off when the car has been used for some time.

Standards
Update the standard operating procedures for the manual assembly operations and make sure that the standards are followed. Furthermore, missing standards regarding the palette need to be defined and updated, including the CAD-drawings with positions and the pressure used.

Removal of the second control
When the assembly process is reliable, one of the two controls could be removed to decrease non-value added work. Before the control can be removed, it needs to be determined what is considered a reliable process and how it is measured.

7.2 Recommendations for improvement root cause analyses

The performed analysis has beyond finding the root cause of the problem with loose support bearings also identified improvement areas for coming root cause analyses when answering RQ2. These were divided into four areas:

- Base decisions on facts
- Standardization
- Knowledge sharing

- Communication and collaboration

7.2.1 Base decisions on facts

Reliability of the data
Ensure that the data that exists is updated and reliable. This case study showed that not all deviations found in production were reported in ATACQ and that the data was dependent on the team leaders' willingness to register it. In order to base decisions on facts, the data needs to be accurate and represent reality. Therefore, the importance of registering data needs to be communicated to all affected functions, creating a shared understanding of its usage.

Quality of analyses
It needs to be ensured that analyses should be performed by personnel with relevant competence to both understand the data and base decisions on facts. In this case study, it was noticed that few conclusions were drawn from the initial analysis performed by production. Therefore, it is suggested that production is given more knowledge in root cause analyses or provided with assistance when they need to perform a complex analysis.

7.2.2 Standardization

Ensure that standards represent the reality
Verify that all standard operating procedures in WES are documented. All operations performed needs to be documented in order to be used as a baseline and enable more efficient continuous improvements.

Availability of standards
Make sure that the information in standards is stored in shared platforms and easily accessible for everyone. For example, when the standards are updated for the palette, these together with eventual changes, needs to be available for all affected functions.

7.2.3 Knowledge sharing

Explicit knowledge
It is crucial to transform the tacit knowledge into explicit knowledge within the organization and to make sure that valuable knowledge is spread and not only present within one single person. This would enable freeing time, which today is spent on finding the right individuals and the relevant information.

Common information sharing structure
To learn more efficiently from previous projects and avoid rework there is a need to structure the information gathered on shared platforms and use a common language, both within and between plants. This allows different functions to find relevant information more efficiently and reduce the amount of rework.

7.2.4 Communication and Collaboration

Efficient communication

Creating and implementing natural cross-functional communication channels can enable efficient collaboration between different functions. One suggestion could be to have regular meetings between the functions, which enables more efficient problem-solving.

Ownership

Clarification of each role and their ownership is necessary to increase responsibility and facilitate communication between functions. Increasing ownership can also increase the organization's efficiency since it ensures that essential tasks are considered and prioritized.

7.3 Implementation of recommendations

The recommendations are handed over in the form of a control plan to each relevant stakeholder for the different areas. The control plan includes the recommendations and the function responsible for each recommendation, together with a proposed time frame for the implementation. It is recommended for the involved stakeholders to work cross-functionally to prioritize and implement the proposed recommendations. The authors consider all of the recommendations mentioned above to have high importance in solving the issue with loose support bearings and increasing the efficiency of future root cause analyses performed at Volvo. It is of importance to make sure that the implementation of these recommendations aligns with other work already planned at Volvo together with future strategies and visions. For example, there would be little value updating the CAD-drawings for the palette if future strategies were to involve changing the equipment.

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Appendix

Supplier	Input		Process	Output		Customer
8b. Who supplies the inputs?	Q8a. What are the inputs to the system?	Q9. What does the system require of the inputs?	Q7a. Team/project jurisdiction of changes	Q1. What comes out (of the physical flow) - OUTPUT?	Q3. What is required of the output from this particular user (List of big Y's and improvement proposals)	Q2. Who uses the output?
The support bearing is delivered from the supplier Daimay. This is later delivered by logistics to the place of production. The support bearing is further put into the headliner by an operator which also puts the headliner onto the palette. The car body is delivered from the previous steps in the assembly line.	The inputs consists of delivered support bearings, that are attached to the headliner and labor from the operators. Another input is the car body which is delivered automatically from the previous step in the production line.	The system requires a support bearing that is rightly attached to the headliner by the transport clips. Thereafter, the headliner is placed on the palette and the support bearing is placed into a fixture to ensure it should be pressed up into the attachment point in the car body. The car body needs to have a stamped attachment point in the correct position for the support bearing being able to attach to it when expanding.	The operations within the production line and standard procedures (WES) can be modified. The palette pushing up the headliner can be modified, although, not replaced completely. Changes in the dimension and placement of the attachment point in the car body can also be considered.	A car with a functioning support bearing directly after assembly. The support bearing should be fully attached to the car body to hold up the sun shield. It should though also be crashproof in case of an accident.	Quality of the car - number of defect parts Number of defect parts found at the assembly line Number of defect parts found at the SIP control Amount of re-work, replaced support bearings within production Amount of re-work, replaced support bearings on delivered cars	There are two users of the output. The first is the operators working with the following assembly steps where controls are made that the support bearing is attached, it is also here the support bearing often is replaced. The second customer is the end customer who gets frustrated when they experience problems with their new car such as the sun shield not being fully attached due to a loose support bearing.
			Q7b. What competences are needed in the team (WHO)?		**Q4. <u>What ONE MEASURE (y)</u> should be understood and improved? The y that scope the project and drive further exploration. Each small y has its own underlying system of influencing parameters, sometime overlapping. Use one template per y to reduce complexity Scope on y (not x - upstream) and don't proceed until Q1-Q4 is thoroughly understood!**	
			Competence from team leaders and production personnel will be used as knowledge about the process. Personnel from Manufacturing Engineering, Tooling etc. will be used to understand the automatic operation and its specifications.		Reducing the number of damanged and replaced support bearings.	
			Name of the underlying system that build up the y to be improved:		Q5. What is the baseline of the y and can that precis y be measured today (and can old data be trusted)? In other words: What is the facts behind the problem that form the base for our improvement promise? Show the data/proof of a problem!	
			The production process of assembling the inner ceiling		Existing data shows number of damanged support bearings both within production and reported from retailers and repair shops. Several factors indicates that the old data, mainly from production, only show a fraction of the real problem. All damanged and replaced support bearings should be registred manually in ATACQ. Before the problem was raised, very few were registered and directly after the first analysis was started the amount of registred rework increased. Although, the production personell estimates that the problem has not increased, but their awareness of the problem which leads to more registrations in the system.	
			From where is the physical output shipped?		Q6. What other Y can not be lost in the process (constraints)?	
			From the production process.		The function of the support bearing cannot be forgotten, it should also let go of the car in case of a collision. Because of this it is not possible to attach the support bearing more permanent by for example screws.	

Figure 34. The effective scoping used in the Define phase of the project using template from Hammersberg (2019).