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Costs of an offline repair strategy

-A case study at Volvo Trucks

Master of Science Thesis in the Production Engineering Programme

MARIE-HELENE STÅHL
LISA THORSELL

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Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden

Cover:
The picture illustrates a truck produced by Volvo, where this case study taken place (www.volvogroup.com).

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Abstract

Using the right repair strategy in an assembly plant can decrease costs and increase quality and productivity. In order to go from a more traditional offline repair strategy to an online repair strategy, commitment from the top management is necessary. A way to gain their commitment is to translate the current repair strategy into costs.

This case study has been taken place at Volvo Trucks' factory in Tuve, Gothenburg where there is an awareness of moving resources upstream from the more traditional way of using an adjustment station. The online repair strategy is originated from the philosophy of Toyota to build-in quality in the processes. Therefor to calculate the cost for an offline repair strategy has got a high priority in this case study:

The purpose of this master thesis is to: *"provide guidelines that are based on cost calculations of an offline repair strategy that can support decisions for solving internal deviations at the origin".*

By collecting data from literature studies, interviews, questionnaires and secondary data costs for the current repair strategy was calculated. A benchmark was also carried out at the factory in Umeå were cabs are produced. The same process of handling internal deviations was compared between the factories in Tuve and Umeå. From this it was stated that both Umeå and Tuve use a combination of both an offline repair strategy and an online repair strategy. To answer the purpose of the study costs of the tendency of an offline repair strategy were in focus. The two largest costs parameters were the personnel costs and cost for tied-up capital. In order to analyze the personnel cost further a cost model for a certain type of deviation was constructed. The model compares the costs for repairing a type of deviation offline vs. online. The ambition was that the cost model will work at any assembly plants with minor changes.

The result from the cost model shows that it is more efficient and cheaper to repair deviations online by using Andon-personnel and finding the root cause upstream than downstream. From the cost calculations were guidelines stated for future work at Volvo to put more resources earlier in the production process to prevent same deviation to occur again. Detected deviations needs to be paid attention to directly, one way of doing this is to stop the process and work directly to find the root cause and then put prevention methods into action.

Foreword

This master thesis performed at Volvo Trucks has been very interesting and a good learning experience. To our help, a lot of important people have contributed to the final result. We would therefore like to take the opportunity to thank these people for their kindness and nice accommodating.

Big thank to our supervisor Kajsa Torgå that has guided us and contributed with valuable tips, ideas and advises along the way. We would also like to thank Andreas Lundberg that is the initiator for this master thesis and made it possible for us to realize. Also a big thank to all persons at Volvo Trucks helping us in the best possible way and taking time to always answer our questions.

Thanks to the personnel that we visited and interviewed at the Umeå factory. We are thankful that we could take part of your way of working and your opinions regarding how to handle internal deviations. It was a very valuable input to our work.

We would also like to thank Mats Winroth, our supervisor at Chalmers for the opinions and discussions we had during this time period.

In the completion of this master thesis work we now finalize our education. We would therefore like to take this opportunity to thank each other for a nice and successful collaboration.

Gothenburg, June 2013

Lisa Thorsell

Marie-Helene Ståhl

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1 Introduction

Making it right the first time is a common expression among industrial companies. In order to clarify why this is important consider the following scenario:

"Consider the time it takes to make Truck A. Then, in final finishing, inspections discover a deviation in the product and the truck needs to be repaired and parts needs to be disassembly and reassembly again. Much of the time employees spent on working on the truck in the assembly line are lost. While the employees, usually at a separate adjustment station, are busy repairing and rebuilding Truck A for the customer, they could have been busy building Truck B for another customer. This results in loss in time involved making the faulty Truck A, which can get very expensive..."

1.1 Background

The scenario described above is a traditional way of handling deviations in a manufacturing company; this is also referred as an *Offline repair strategy*. The responsibility of quality assurance of products is put at a quality specialist or a final inspector in the end of the production process. This is a way of handling different deviations separately from the assembly line at another station downstream, instead of dealing with them where they are detected like an *Online repair strategy*. At the adjustment station the defective products are reworked or replaced followed by retested and re-inspected. This separate adjustment station is sometimes called a "hidden plant" because of its 15%-40% of the total production capacity of machines, equipment and workers (Feigenbaum, 1991, p. 711). The offline repair strategy is a way to avoid major disruptions of the assembly line and continue to keep a high speed of the production, although different deviations in the production process occur.

Many companies have shown a willingness to improve their attention to quality during the last decade. The increased focus has its reasons in a wider knowledge of the consequences of poor quality, such as high costs and customer dissatisfaction (Dooyoung & Hokey, 2008, p. 709). To easier understand the consequences of using an offline repair strategy the effects could be translated into costs connected to poor quality (Dooyoung & Hokey, 2008, p. 715). There are several fields of application when it comes to calculate the cost of poor quality (Sörqvist, 2001, p. 32). One thing is that it can ease the understanding for co-workers and management to see the effects of poor processes. Successful quality and processes in an organization demands large management commitment and therefore to show the costs of the current process of handling deviations can help to focus on the subject and make improvements.

This case study was performed at Volvo Trucks final assembly plant in Tuve, Gothenburg. Volvo Trucks is the leading company of producing trucks in the heavy weight class. Their customers are located all over the world and their trucks are produced according to the customer's wishes and requirements.

At Volvo Trucks today exist an understanding that the way of handling deviations in the production process will affect the whole company. In addition they are also aware of the importance of handle the deviations in the best way possible to reduce their impact on their organization and on the customers.

1.2 Problem analysis

The heart of all problem solving methods, such as Lean, is to understand the cause of a problem and finding a suitable solution to it (Juran, 2010, p. 388). A quite new industrial trend is to build quality into the processes as much as possible in order to prevent unnecessary rework and scrap. As mentioned earlier the traditional way of handling unstable processes is often to have a quality inspection after the assembly line and repair deviations at a separate adjustment station. According to Dooyoung and Hokey (1995, p. 104) offline repair often cause longer repair times and high operational costs for extra machines, equipment, workers, floor space, etc. Robinson et al. (1990) state "the rule of 10" that means that offline repair costs ten times more than online repair. But the main drawback of the offline repair is that attention is not paid to the cause of the deviation immediately because of the very nature of the continuously moving assembly line. Most deviations go unnoticed during the assembly line until they reach the final inspection area and are send to the adjustment station.

Despite the drawbacks of the traditional way of handling poor quality by using an offline repair strategy many companies still apply this way of work. The ambition at Volvo Trucks today is to solve all deviations as early as possible. But it becomes difficult due to the continuously moving assembly line, the introduction of new products and the size of the truck. This result in that trucks are repaired at the adjustment station and therefor there is an ambition to know how much their offline repairs costs today. Based on a cost calculation the company can see if, and in that case what, actions need to be taken. Right now they don't have this type of cost calculations to fulfill their ambition.

1.3 Purpose

From the problem description the purpose of this project is to:

Provide guidelines that are based on cost calculations of an offline repair strategy that can support decisions for solving internal deviations at the origin.

1.4 Research questions

In order to accomplish the purpose of the project following research questions will be investigated and analyzed:

> RQ1: What type of deviations occurs in the production process at the factory in Tuve and how are they treated today?
>
> RQ2: What are the costs for using an offline repair strategy?
>
> RQ3: How do other factories within in the Volvo group handle internal deviations?

1.3 Limitations

In order to narrow down the scope of this case study the focus was on deviations originated internally inside the factories four walls. The portion of deviations originated from suppliers and design will only be mentioned, then the focus will be on the internal deviations. This was a request from Volvo.

The focus was also not on all deviations originated in the factory but rather those deviations that have been repaired at the adjustment station. This limitation was made in order to investigate and provide cost calculations of an offline repair strategy. The study did not include the deviations that were detected by the customer.

1.4 Outline

Chapter 1
Introduction: This chapter will introduce the reader to the project and it's purpose. First a background will present the reader to the subject of the study. Further on a problem analysis will formulate the purpose and related research questions. Finally the project's limitations and the outline of the report will be presented.

Chapter 2
Method: Here the method of the project is described. First of all the choice of research strategy is discussed followed by the selected reasoning style for this project. Further on the different ways of data collection was described and out of that the process of analyzing the gathered data. At last the reliability and validity of the method is discussed followed by strengths and weaknesses.

Chapter 3
Theory: The theory considered relevant to this study is here presented. An introduction to the Lean philosophy is followed by different repair strategies. Finally theory regarding costs that is relevant in this project is presented.

Chapter 4
Company presentation: Here is a presentation of the chosen company to perform the case study at. A brief introduction to Volvo Trucks AB is followed by a description of their own production system, VPS. At last the chosen factory of the study is presented.

Chapter 5
Empirical findings: This chapter contains all gathered data for this study. A description of the current state at the chosen factory, Tuve, is followed by the founded cost parameters regarding an offline and an online repair strategy. At last the outcome from the benchmark study is presented.

Chapter 6
Analysis: The gathered data from previous chapter is here analyzed in order to answer the research questions. Initially the current repair strategy at the Tuve is presented followed by the costs of an offline repair strategy. Finally the comparison based on the benchmark is described.

Chapter 7
Guidelines for future work: Based on the analysis some guidelines for the future work have been summarized in this chapter. The guidelines in this chapter are suggestions and could work as a base for discussion at the company for future work.

Chapter 8
Discussion: This chapter contains a discussion of the empirical findings and the results of the analysis. Further on presents a discussion regarding the future work based on the guidelines.

Chapter 9
Conclusion: The final conclusions based on the empirical findings and the analysis is described in this chapter. Finally suggestions of future research are proposed.

2 Method

This chapter describes the methods used in this case study in order to answer the purpose and the research questions. Each methods will be explained and also their weaknesses and strengths. Finally is the methods reliability and validity discussed.

2.1 Research strategy

Many researchers agree on the statement that the research method should be adapted to the purpose of the project (Williamson, 2002, p. 37). In order to investigate the way of handling deviations, a case study at Volvo Trucks was an appropriate method for this research. According to Yin (1994, p. 13), a case study is an empirical enquiry that investigates a contemporary phenomenon within its real life context, especially when boundaries between phenomenon and context are not clearly evident. The research was limited to a single case study because of the limited time plan of the research. A single case study also allows an in-depth investigation to provide rich description and understanding (Williamson, 2002, p. 115). However, a benchmark was carried out in order to compare the process of handling deviations at another plant.

In this case study, a combination of two different investigation strategies was applied in order to get a broader analysis of the purpose. The chosen research method had therefore both a *qualitative* and a *quantitative* approach. A qualitative research approach is used to gather data that is not quantifiable, e.g. different behaviours and opinions. Tools for collecting this type of data could be through interviews, discussions and observations (Satyaprasad & Krishnaswami, 2010, p. 7). The qualitative research approach was used to study the thoughts at workers at Volvo Trucks and how it could affect different ways of handling deviations internally.

The quantitative research approach is based on quantity or the amount of values (Satyaprasad & Krishnaswami, 2010, p. 5). This approach can be used to analyse different types of numerical data or statistics taken from different sources. The results of the analysed amount of data can thereafter be generalized into bigger fields than the project range. In this case study, this research approach was used to study large amount of data that has been taken from systems, programs and documents within the company.

There exist two types of research reasoning styles that are associated to the different research approaches (Williamson, 2002, p. 26). One of them is called *deductive* reasoning style and is mainly connected to a scientific research approach. This type of investigation should be based on theory and is in many ways a structured method of testing an existing hypothesis. The other type of reasoning style is the *inductive* and is, on the contrary to the deductive, based on observations and data collections. Out of that a hypothesis is stated based on the gathering data and assumptions. A drawback with this reasoning style is that the inductive conclusion can't be generalized to another specific situation (Gummesson, 2000).

This project has used a deductive reasoning style where the interviews, questionnaires and benchmark where based on theory. The questions were formulated to test an existing conclusion regarding the comparison of an offline and an online repair strategy.

Throughout the project's all observations, there was a focus to get a clear picture of the current situation at the factories studied. Therefore, an inductive reasoning style was also a feature in this research method. The choice of parameters to the cost calculations was both based on theory and empirical studies and therefore the inductive feature was visible during that process too.

2.2 Data collection

This chapter describes closer which methods that were used in order to answer the research questions. The different methods to each questions is presented in Table 2.1.

> RQ1: What types of deviations occurs in the production process at the factory at Tuve and how are they treated today?
>
> RQ2: What are the costs for using an offline repair strategy?
>
> RQ3: How do other factories within the Volvo group handle internal deviations?

Table 2.1 Aim for data collection

Research Questions	**How the question is answered**	**Aim**	**Data collection**		**Analysis**
RQ1	Current situation analysis	Achieve understanding	Interviews, Questionnaires, Quality information system, Observation	Literature analysis	Triangulation
RQ2	Cost calculation	Present an economic foundation to the problem	Economic data, Interviews		Triangulation
RQ3	Benchmark	Compare the process to a similar one	Interviews, Observations		Comparison

2.2.1 Literature analysis

A literature study was carried out mostly in the beginning of the project in order to collect appropriate theory and information for this case study. Theory was found in relevant scientific papers and books. In order to find the scientific papers databases, like Emerald, Google scholar etc. was used. Pressed literature was mainly found at Chalmers Library and the engine source Chans.

2.2.2 Secondary data

According to Arbnor and Bjerke (1994, p. 241) secondary data is information that have been collected for another purpose. In this case study secondary data was collected through systems, programs and documents that the company uses for other purposes.

Quality information system

Volvo uses a quality information system to register and follow up deviations in the production process. The system was used in order to analyze and gather data for the following:

- How deviations are handled today in the production process
- Type of deviations that occur in the production process
- Frequency and problem owner of the deviations
- Number of deviations that are corrected after the assembly line (offline repair)

Programs

Impact3 is a program made by Volvo containing guides for service and repair of Volvo's trucks. In the program, there are instructions of how to adjust several parts of the truck for different models available. There are also reassembly and disassembly guidelines to get an overall work instruction for different deviations regarding the truck. There are also standard times for the different operations. Impact3 was used in order to analyze and gather data for the following:

- The work procedure of repairing different deviations including possible components needed to dis- respective reassembly
- Time needed for an operator to manage the repair operation
- Different parts connected to each other on the truck

Documents

The adjustment station possesses reports containing different parameters they measure continuously. These reports were used to gather data for the following:

- Number of trucks delivered to, adjusted and delivered from the adjustment station every week
- Number of trucks in queue waiting for the adjustment operations
- Number of trucks delivered late from the adjustment station

The economics department at the factory in Tuve has data regarding all equipment and machines at the adjustment station. The documents were used to gather data for the following:

- The purchase cost of all equipment and machines related to the adjustment station
- The year of acquisition for every device
- The average lifespan for the devices

The economics department at the factory in Tuve also has general data concerning the production. The documents were used to gather data for the following:

- Number of working hours, both at regular- and overtime
- Cost of an operator, both at regular- and overtime
- Cost of space utilization
- Cost of capital

2.2.3 Primary data

Interviews

Interviewing is a technique for collecting qualitative data and is commonly used in case studies. According to Williamson (2002, p. 424) there are three different types of interviews; structured-, unstructured- and semi structured. For this case study, semi structured interviews has been carried out. It means that the interviews have a standard list of questions but also allows an open discussion between the participants concerning the subject. Interviews have been done with multiple employers from different departments at Volvo in order to gain a holistic perspective of the current problem. Some key persons in the area of quality, financial and production have been interviewed in order to get their perspective of the problem but also to gather data to the cost calculation model (see Chapter 6.2.2).

Questionnaires

Questionnaires were also used to get information from operators working on the assembly line. The questions were made in a simple and quantifiable character. According to Williamson (2002, p. 274) it's easier and less time consuming than an interview, however he suggests that qualitative research should be carried out first. The purpose of the questionnaires was to gain the perspective of an operator working on the assembly line. The questions involved if they detect deviations in the assembly line and how they solve them today, see Appendix 1.

Observations

Observations were carried out mainly in the adjustment station separate from the assembly line in order to gain an understanding of their behavior and work structure. Notes were taking during the observations. Afterwards, the findings were categorized and used in the interviews to ask complementary questions to the observations. Observations were also done at the assembly line and at subassemblies in order to gain understanding for the assembly sequence and how parts are connected to each other. The observations were then used as one of the source to the tree diagram for disassembly and reassembly (see Chapter 6.2.1).

Benchmark

Benchmark is a working method in order to find possibilities for process improvements (Bergman & Klefsjö, 2002, p. 255). The idea with benchmark is to make a comparison between one of the organizations processes with another similar process. In this case study was an internal benchmark carried out. Internal benchmark means to compare the same process on another site or department within in the same organization

(Bergman & Klefsjö, 2002, p. 256). A benchmark was made in Umeå where Volvo produces cabs to the truck. Tuve's way of handling deviations in the production process was compared with Umeå's.

2.3 Analysis of data

Data gathered concerning types of deviations in the production process that is repaired in the adjustment station, gave a complex impression. All types of deviations were described in the quality information system, where the data was gathered. Therefore, has a tree diagram and a FMEA been used to analyze the data and categorize the different types of deviations to find the most serious ones.

2.3.1 Disassembly- and reassembly tree diagram

A tree diagram of the main parts of a truck was constructed. This tree diagram, called *"dis- and reassembly tree diagram"* visualizes which parts that need to be disassembled and reassembled in order to make a repair operation of another particular part. This will show how much extra assembling time deviations of a particular part will need to even be reached before the actual repair operation. The factor would also indicate how much more the deviation would cost to repair offline compared to online, due to the extra assembling time at the adjustment station. The tree diagram was used for defining the severity of the parts in FMEA.

2.3.2 FMEA

A Failure-Method-Effects-Analysis, FMEA is a method to identify deviations in products and processes. The method is stating all possible deviations that can occur on a product, their severity and also their chance to be detected. Based on that, the purpose of using the method is to prioritize and find ways to prevent different deviations before they occur in reality (McDermott et.al, 2009). This analysis was chosen to prioritize the most serious type of deviations that can occur in the production process at Tuve based on previous statistics of deviations at the factory.

There exist different types of FMEA considering the field of application and in this analysis the *Process-FMEA* was chosen as a base. This typical method focuses on the deviations of a product and how they are originated in the process (Bergman, Klefsjö, 2002, p. 116).

To help prioritize, the method contains a ranking of the deviations through a risk priority number, *RPN* (Carlson, 2012). This number is a result based on factors of the deviations' frequency, severity and chance of detection, defined as the *Probability factor (P), Severity factor (S)* and the *Detection factor (D)*. The calculation of the risk priority number is one of the last steps during the FMEA.

First of all, the FMEA in this case study focus on some of the larger parts, due to the complexity of the truck. Therefore only deviations of those parts were analyzed. The probability factor was based on the frequency of the different deviations and based on statistics from 2012. The factor was set from 1-5 with the highest number to the most frequent type of deviation to a particular part of the truck.

The following factor to set was the severity factor that was based on the amount of dis- and reassembly time to reach a particular part for adjustment. This factor was based on the tree diagram that visualizes the main parts of a truck. The severity factor was set from 1-5 with the highest number to the deviations of a part that needs longest time of disassembling to reach. The times for dis- and reassembly was collected from service program Impact 3.

Statistics from 2012 of where the deviations were detected helped to state the detection factor for each type of deviations. Detection could either occur somewhere in the production process or at the final inspection area. Deviations detected by the customer were not considered in this case study. This factor was set from 1-5, given the highest factor when the deviation wasn't detected until the final inspection area. This data was collected from the Quality information system.

2.4 Method Validation

2.4.1 Reliability

The reliability of the study depends on if another researcher would perform the same research strategy, including study the same questions in the same setting, and would come up with the same results (Blaxter, 2010, p. 245). A high reliability of a study means that the independent on the researcher and no matter the time of performing the study, the result would be consistent. Because this project was a case study the exact result will probably not be repeated even if the same research process would be performed. The reason for this is that the reality continuously changes and also the people's opinions and way of thinking, including the project's writers. The reliability of this study is therefore low. Further on, an advantage when using a quantitative research approach instead of a qualitative one is that it is easier to get a higher reliability hence to the base of statistics and data (Satyaprasad & Krishnaswami, 2010, p. 5). However, when using a qualitative research approach, with focus on a specific group instead of a wider population, the reliability can be questionable because of the research's unique result. The qualitative research approach is based on philosophies, attitudes, impressions and different ways of thinking among a group of people. This means that the result will most likely change dependent on the focus group and the individuals in it.

2.4.2 Validation

A study's validation depends on how the current research actually measure and study the demanded purpose (Blaxter, 2010, p. 245). In other words, how well the study can answer the scientifically questions that was intended to answer. To increase the validity of the case study a use of a triangulation method can help (Satyaprasad & Krishnaswami, 2010, p. 32). This method contains multiple sources to gather wanted information and help proving the findings. In this project, a triangulation was made containing different types of information collection such as interviews and observations to increase the validity of the project. Through the features of a qualitative research approach in this project, the validity could decrease hence to its narrow focus area.

The questionnaires were dispatched to the participants and unsupervised through performing. The validity could be questionable due to the fact that no confirmation of that the wanted participant actually answered the questionnaire.

According to the interviews held during this project, the occasion was first announced to the participants before the meeting. The main reason for this was to ease the preparation to the interview for the attendants. During the interviews the participants got information of the possibility to be anonymous in order to create a more relaxed atmosphere. Another reason to this was also to increase the chances of getting honest and reality-based answers. During the interviews the attendants had unlimited time to answer the questions and because of the semi-structured type attendant questions could occur, which increased the validity of the research.

2.4.3 Strengths and weaknesses to each method

The methods used in this case study were selected with different main reasons. Hence all methods have their strength and weaknesses. They were selected with the aim to be the most suitable to answer the research questions. Table 2.2 presents an overview related to the methods.

Table 2.2 Strength and weaknesses of chosen methods

Method	Main reason for use	Strength	Weakness
Use data from quality information system	Collect data for what type of deviations occurring in the production process.	Gives a high reliability and validity through the base of statistics.	Statistics are dependent on how the system is constructed and how it is filled in.
Literature analysis	Deeper understanding of previous findings.	Good to compare similar cases.	Hard to find a direct suitable case.
Semi-structured interviews	Receive information of the current situation.	Shows the reality and peoples different thoughts.	Can include a lot of non-value adding information.
Observations	Deeper understanding of the process and the product.	Can quickly identify problem areas.	Are dependent on the size of sample and can interfere with workers.
Questionnaires	Get a broader view of people's opinions and thoughts.	A quick way of getting information.	Often requires simple, clear and quantifiable questions.
Benchmark	Compare the process to a similar one to get a broader perspective and ideas.	Gives a bigger picture of the current problem and opens minds to new ideas.	Can be very time consuming and give communication problems.

3 Theory

This chapter presents the theories used in order to support the research in this case study. The theory was used both to gain a deeper knowledge about the problem and to make a comparison between the reality seen in this case study with previous research in the same area.

3.1 Toyotas Philosophy

The car manufacturer Toyota is the founder of the term “Lean production”, which basically means a smooth production by eliminating waste (Liker, 2009, p. 22). Toyotas philosophy is something almost every industry around the world wants to adapt. The ground to the philosophy is Toyotas 12 principles. The principles is divided into four main chapters; long-term thinking, right process gives right result, create value for the organization by develop people and suppliers and by continuously find root causes to deviations drives the learning process within the organization.

Principle five contains of building up a culture where the process stops in order to solve deviations and to make quality right from the beginning (Liker, 2009, p. 62). The principal of stopping the process is to build in quality, also called Jidoka. This demands methods for detecting deviations at the source and stop the production so the employees can fix the deviation before it continuous downstream. At the same time as the process stops, usually flags or light signals together with music is played in order to get help to solve the deviation. This signal system is called Andon (Liker, 2009, p. 62).

“If the assembly line moves continuously without any disruptions it means you don’t have any problems. But all assembly plants have problems. Therefore you hide your problems.”
-Fujio Cho, CEO at the Toyota motor corporation Kentucky

A production stop is something that the management in a traditional mass manufacturer never would approve (Liker, 2009, p. 164). Defect components, if they are detected, are in traditional industries, only noticed if they are put aside in order to be repaired at another adjustment area. The mantra is:

“Produce in large amounts, to every price, and take care of the problems later.”
-Gary Convis, CEO at the Toyota factory in Georgetown Kentucky

Even if the assembly line at Toyota sometimes stands still they are the most productive car manufacturer (Liker, 2009, p. 165). How can this be? They early understood that if you understand the root cause to a deviation you will both save time and money downstream. By continuously rise problems to the surface and solve them at origin will eliminate waste and increase productivity.

3.2 Repair strategies

There are different ways of handling deviations when they occur in a production process. Traditionally in mass production, the focus is on producing the mass and produce high numbers of products every day at any cost (Liker & Meier, 2006, p. 171). With this strategy when a deviation occurs, someone else will fix the problem later. But as mentioned earlier, according to the Lean philosophy, if you have a problem it is better to directly correct it, and then prevent it. This will improve quality and decrease costs.

3.2.1 Offline repair strategy

According to Shin and Min (2008) when handling deviations the traditional way it is called to have an offline repair strategy. Within the strategy the primary responsible of quality assurance is in the hands of quality specialist and final inspectors. An assembly line that applies an offline repair strategy tags incomplete and nonconforming parts and send them further to a separate repair shop. In the repair shop parts are reworked, retested, re-inspected and replaced (Carter and Silverman, 1984). Feigenbaum (1991) names the repair shop as a "hidden plant", which typically accounts for 15% to 40% of production capacity. A traditional offline repair strategy stresses full capacity utilization such as manpower and machines/equipment and tries to avoid line disruptions as much as possible by keeping the assembly line moving at all costs (Shin & Min, 2008). This strategy contains a mind-set of that high production numbers gives a low unit cost (Liker & Meier, 2006, p. 172). But it doesn't contain the consideration that products are half-made after the line and needs more work to be able to be delivered to the customer.

The main benefit of an offline repair strategy is that it does not cause any major line disruptions or loss of the production rate. Although, it can result in longer repair times such as disassembly, repairs, re-inspection, retesting and reassembly. It also brings higher operational costs such as machines, equipment, workers and floor space etc. (Shin & Min, 2008). According to Robinsson et al. (1990) the offline repairs costs ten times more than offline repairs, what he calls the "rule of 10". He means that this should discourage the plant from using an offline repair strategy and instead encourage the plant to use an online repair strategy. The main drawback of an offline repair strategy is that the workers are not actively involved with quality assurance activities. Workers that discover defective or incomplete parts may not be able to pay immediate attention to the causes of the deviation because of the moving assembly line. This results in that most deviations are overlooked and go unnoticed through the line until it is discovered in the end and transferred to the repair shop.

"The offline repairs costs ten times more than online repairs" (Robinsson et al. 1990)

3.2.2 Online repair strategy

On the contrary to an offline repair strategy, according to the Lean philosophy the deviations are supposed to be solved directly when they're detected to avoid further damage or non-value adding time (Liker & Meier, 2006, p. 171).

One way of doing so is to apply a so called online repair strategy or line-stop strategy (Shin & Min, 1993, p. 43). The strategy can assure quality at the source by implement responsibilities to all employees to not pass defective products to upcoming workstations. This way of working will help prevent later repair work and extra arrangements to prevent defective products to reach the customer.

The procedure of stopping the line when a defective product is detected is the foundation of this strategy. As mentioned previously, the philosophy that acts as a base to these actions stands for eliminating waste and to continuously improve quality of the products. To involve all employees and consider them the main trust is a qualification to make this strategy work. Hence, it's necessary to align the philosophy of the online repair strategy throughout the company. The employees are delegated to be responsible of the quality at every phase of the production process and therefore be a part of the total work of preventing defects and solve problems in the production. An important part of the work is to after the repair work of the defected product, go to source and find the root cause of the deviation to avoid the same deviation to occur again. When continuously trace the causes, a reduction of the occurrence of problems will be seen.

Using this type of strategy, when a deviation is detected the first action won't be to stop the line. If the operator considers it's impossible to solve the deviation during available time the Andon-button should be pushed, that means a call for assistance. Then a specific Andon-person will come and support the situation. If outside assistance isn't enough to solve the deviation, a minor delay or a line-stop will occur. The length of the stop will obviously depend on the severity of the deviation. The root cause and following preventive actions will then be carefully studied to avoid the same deviation to be repeated. The "five whys" is a technique to ensure the root cause to the problems is sought out (Bicheno, 2004, p. 152). It's simply requires that the user asks "why?" several times. The name of the technique is invented of the Toyota company that considers that the question "why" needs to be asked successively five times before the root cause is stated.

Implementation

To implement an online repair strategy in an organization requires a lot of work and time (Shin & Min, 1993, p. 44). The main part of the changes is the mind-set of the workers throughout the company. To change the way of work and start stopping the line at every detected deviation, will at first probably lead to short-term losses. Therefore it's important for the succession to apply an understanding and acceptance to this among the workers and set the perspective long-term instead. The top management and leaders has an important role to play according this. Further on to create an overall philosophy and common mind-set in the company, training and education is a prerequisite to sustain the strategy.

The implementation will most likely lead to better quality, lower scrap and increased employee morale (Shin & Min, 1993, p. 45). The direct repair at the source is in general faster than an offline repair due to the extra dis- and reassembly. The following results of less rework, inspection, safety-inventory, labor and space in the adjustment station, will reduce the overall production cost at the same time as the product quality raises. Also when adapting an online repair strategy, the work of continuously solving deviations will involve all workers and create a feeling of belongingness and also use all knowledge and experience the company contains. Stopping the line will increase the attention of the deviations and aware all workers of the effects and consequences. The workers commitment and responsibility will also increase to their work task. The collaboration of solving deviations will also lead to a better work environment and a feeling of more fellowship.

The strategy of handling deviations online comes also with some drawbacks. When interrupt the production flow a temporary decline of the production rate can occur at the same time as higher worker and machine idle time (Shin & Min, 1993, p. 46). The risk of late delivery to customer can also increase. Another drawback is that in early stages of implementing this type of strategy, line-stops may occur frequently and then lead to many disruptions and distractions. The need of education and training and different types of self-checking devices will also create extra costs.

3.3 Cost of poor quality

When it comes to the cost of poor quality in products and processes it could be defined as all costs that wouldn't appear if all activities in the production were performed perfectly every time (Juran, 2010, p. 161). Another definition of the lack of quality is non-valuable costs and means all costs that don't lead to any added value for the final customer. According to Juran it exists three major types of costs of poor quality in organizations; *Appraisal and inspection costs, Internal failure costs and External failure costs.* According to Feigenbaum, a forth type of costs of poor quality is *preventive costs* that is costs of all preventive actions that might occur in an organization. This cost is not related to poor quality but rather to the cost of actions to prevent failures to happen (Sörqvist, 2001, p. 36). Of several purposes to this extra category, was one to show that an increase of this category could decrease the total costs of all categories. This means that when focusing more on the preventive activities, fewer deviations will appear and a reduction of the total cost of poor quality can be seen (see Figure 3.1).

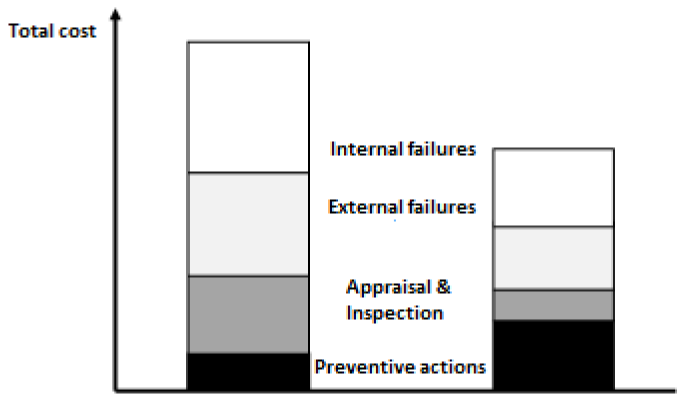


Figure 3.1 Total cost of poor quality divided into four categories (based on Sörqvist, 2001)

The cost of appraisal and inspection will always exist due to avoid the occurrence of different types of deviations along the production process (Juran, 2010, p. 161). However to discover deviations at an early stage can decrease large amount of costs that would be experienced later on due to repair and problem solving. This type of costs of appraisal and inspection contains costs of controlling and testing activities to eliminate the risk that deviations in the production will affect the final customer.

Internal failure costs are defined as the costs of the consequences when the current quality level is lower than the wanted one, somewhere in the process *before* the product is delivered to final customer (Sörqvist, 2001, p. 37). This type of costs can e.g. be costs of repair work, replacement of parts, retesting, late deliveries or discarding of defected items.

External failure costs is also defined as the costs of the consequences when the current quality level is lower than the wanted one, somewhere in the process *after* the product is delivered to final customer. This type of failures affects the customers directly and is usually the most expensive ones because they are observed at the latest stage (Juran, 2010, p. 162). The effect of the failure could be a late delivery or a lack of the product's quality. The failure costs could contain reclamations, warrants, recalling products, fines and discounts. Another important part of this category is the cost of lost sales and customer trust, i.e the goodwill-factor (Sörqvist, 2001, p. 37). This cost is hard to measure and therefore it usual turns out as estimation. This category can also include a reduction in potential customers that also affects the goodwill-factor. A negative attitude of a customer can be spread a lot faster than a positive one (Sörqvist, 2001, p. 40). Therefore, it is of importance to consider this part in the external failure cost.

3.4 Type of costs

Cost can be classified after their way of acting depending on the volume (Gapenski, 2008). Those costs that are independent of the volume are called fixed costs, meaning that the cost doesn't change if the volume varies. Another type of cost is called variable costs and are, on the contrary to the fixed cost, changing with the volume (Olhager, 2000). This means that when the volume increases or decreases, the variable cost will follow while the fixed cost will stay the same. The different types of costs are shown in the Figure 3.2.

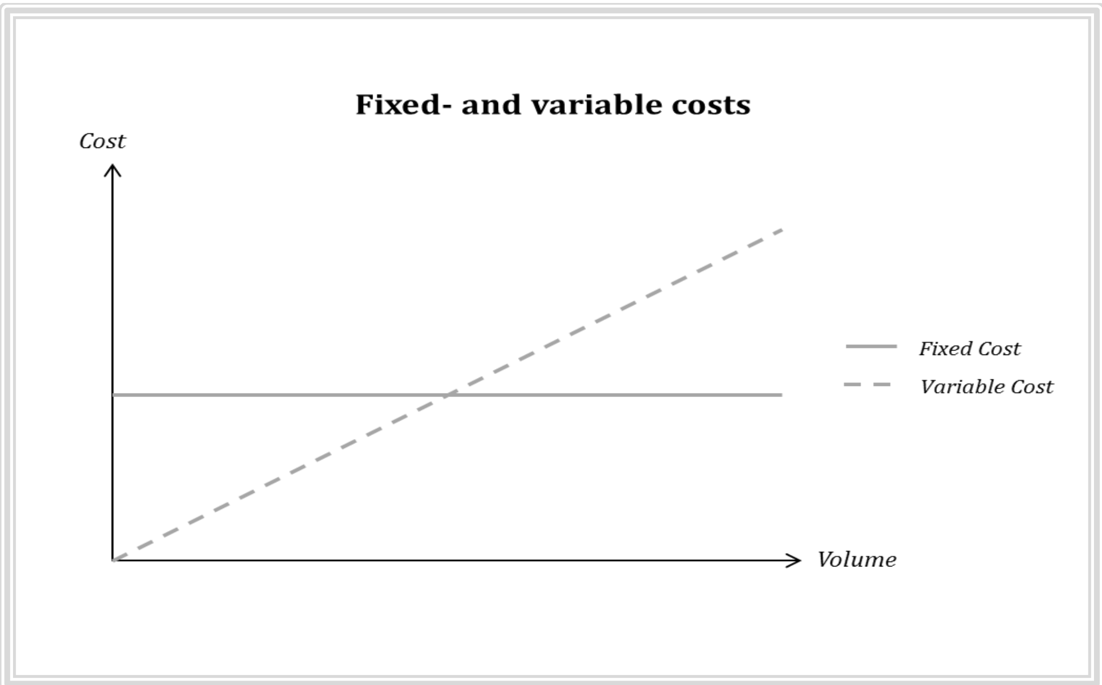


Figure 3.2 Illustration of fixed- and variable costs (based on Gapenski 2008)

4 Company presentation

Following chapter presents the company where this case study is taken place. First a short introduction of Volvo Trucks and their production system will be given followed by a description of the product and the final assembly plant in Tuve.

4.1 Volvo Trucks AB

Volvo Trucks AB is a global truck manufacturer with assembly plants in countries such as Sweden, Belgium, the USA, Australia, Brazil, India, Thailand and South Africa. The company has 17 000 employees globally and their head office is located in Gothenburg, Sweden. Volvo's trucks are sold on more than 120 markets worldwide. More than 95% of the produced trucks weigh above 16 tons and therefore belong in the heavy weight class. Volvo is the world's second largest producer of heavy trucks and offers their customer products based on safety, quality and environment (volvotrucks.com 28/3-13). A truck consists of thousands of components and they are delivered to the assembly plants from a large number of suppliers. Some main components such as engines, cabs and gearboxes are supplied already preassembled by Volvos own factories in Sweden (Production Gothenburg, Sweden).

4.2 Volvo Production System

Volvo Production System (VPS) is their production system to provide a structured way to analyze and improve operations. The VPS triangle (see Figure 4.3) consists of three different levels; *the vision*, *the principles* and *tools & techniques*. In the top of the triangle is the customer, with aim of the best quality, at the lowest cost, in the shortest possible time. *Built in quality* to the left in the triangle means doing thing right from the beginning and that quality should be built in from the start, not adjust. To the right is the J*ust-in-Time* it means producing only the right quantity at the right time. In the center of the triangular is the *Continuous Improvement*. According to Volvo the core of continuous improvement is that everyone should contribute to and be involved in the improvement work. *Teamwork* is an important part of the foundation for continuous improvement and *Process Stability* is to aim for a stable and reliable processes. Finally, *The Volvo Way* is based on the conviction that every individual has the capability and the desire to improve operations and by doing so, also be developed professionally. Energy, passion and respect for the individual help to achieve the Group's objectives, and to develop as individuals (Volvo Trucks internal website).

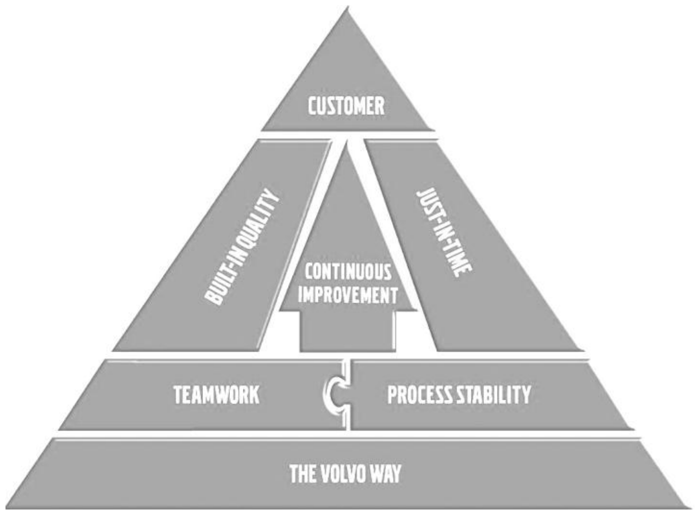


Figure 4.3 The Volvo Way

4.3 Final assembly at Tuve

The final assembly plant in Tuve is located close to Gothenburg in Sweden. The production system is entirely regulated by customer orders; seldom there are two trucks in row leaving the factory with the same specifications (Production Gothenburg, Volvo). For each truck there is a specification of how it is to be equipped in order to meet the customers various wishes. At the factory, they constantly improve their operations to develop new production methods that make their work more rational and increase the quality of the products (Production Gothenburg, Volvo). The process of building a truck from the beginning to the end takes place at a number of different stations in the factory, with one team at each. Parts are being assembled on two main assembly lines. After the assembly line the truck is tested and delivered to the customer.

As mentioned earlier, the chassis are made from steel in the factory at Tuve. The frame members and cross members are later put together to the chassis. Later at the assembly line the chassis builds into a full-assembled truck. After the assembly line, where all components have been mounted, the truck has to be test-driven. This is carried out in their rolling-road facilities within the factory (Production Gothenburg, Volvo). When the truck is finished it leaves the assembly plant and the market department takes over in order to book transportations and to ensure that the truck gets to the dealer on the agreed day.

5 Empirical findings

This chapter will present the findings from the collected data. It will describe the current situation on what types of deviations that are occurring in the production process and how they are handled today. This chapter also describes the cost parameters that are included in the cost calculation model. In the end the findings from benchmark made in the factory in Umeå will be presented.

5.1 Current state

5.1.1 Production process

At the factory in Tuve the trucks final assembly are carried out. A comparison of the production process can be with a fishbone diagram, that is, sub-assemblies are connected to the final assembly process. The final assembly exists of two driven lines fed with chassis from two chassis lines, which also are defined as sub-assemblies. At other sub-assemblies parts are pre-assembled in order to be assembled on the final assembly line. After the final assembly trucks are tested in an inspections area and if the truck is correct without any deviations it will be delivered to the customer.

5.1.2 Handling of deviations

When an operator detects a deviation while working, he calls for support (Andon) to help him solve the deviation. If time isn't enough to solve it, the team leader will be contacted. The team leader will then inform the next stations about the defected truck to see if other operators downstream have the resources to solve the deviation. The occasion of stopping the line is very rare and is highly avoided. To stop the line permission from the production manager is necessary. Throughout the production process, there are inspection areas with controllers that detect and report possible deviations on the truck. The controllers write the deviations down on a control card that follows the truck through the whole production process. After the assembly line all the deviations on the control card, fixed or unfixed are documented in the quality information system.

Trucks with deviations at the end of the assembly line are transported to the adjustment station. The aim for the adjustment station is to repair deviations that occurred during the production process but couldn't be fixed before the truck left the line. Some deviations aren't detected until the final inspection area; also these are transported to the adjustment station to be repaired. The orders of repairing the trucks at the adjustment station are set due to the delivery date to customer. At the adjustment station there are several spaces for repairing operations. Trucks waiting to be repaired can also be placed outside at the yard. The adjustment station is supplied with all needed machines and equipment. There is also an inventory with base material and service parts.

Due to the size of the truck it can never leave the assembly line to go directly to the adjustment station if deviations occur. Therefore it has to go through the assembly line and all the belonging parts are being assembled on the truck. Sometimes parts can't be further assembled due to the deviation; these are then transported along with the truck throughout the line.

The continuous assembling on a defected truck on the assembly line can generate "built-in-deviations", which the operators in the adjustment station need to disassemble and reassemble again. The times of the operations in the adjustment station aren't documented but there are work instructions available at the station to repair different parts. The work hours in the adjustment station is adapted to how many trucks that needs to be repaired. Therefor they work several of shifts, both nights and weekends. If the ordinary operators at the station aren't enough to cover the demand of work, other operators from the assembly line covers up.

5.1.3 Report of deviations

Today deviations of the trucks are reported in a quality information system. During the assembly follows a control card where operators document all deviations they detect or are responsible for. The operators also sign the card with their personal number to easier follow up the occasion. At the end of the final assembly line the documented deviations are registered in the quality information system, where one person fills in the following regarding the deviations:

- Chassis number –*Specific article number to the truck*
- Problem part –*Which part that has a defect*
- Type of deviation –*What type of deviation it is*
- Problem owner –*Who (suppliers, final assembly, subassembly etc.) has caused the deviation.*
- Reporting –*W*here *the deviations were detected and reported*
- Personal code – *Who did the action (e.g solved or detected a deviation)*

According to the quality information system the source of the deviation is the same as the problem owner.

When a deviation has been solved somewhere along the assembly line or at the adjustment station, the operator reports the type of repair operation and his personal number in the quality information system. To work with prevention, a quality technician every week ranks the three most frequent deviations both. But due to the big variation of deviations many of them passes by the prevention work, as only the top three are investigated. The other deviations below the "top 3" on the ranking list will not be investigated. This information is a part of a weekly report that reaches production leaders at all stations throughout the factory. Thereafter the responsibility is theirs to set preventive actions and improvement work to make sure the deviations will not occur again.

5.1.4 Primary data

Data was collected through a questionnaire to both quality technicians and operators at the assembly line regarding their way of handling deviations. The questionnaires and the interview are presented in Appendix 1.

The quality technicians found that the problem area in the factory is the assembly line because it's driven and causes a lot of problems if it stops. Deviations that occur on the larger parts of the truck, such as the engine, frame or axle; leads to most secondary failures. The quality technicians also state that all deviations should be fixed directly when they are detected on the line, but due to lack of resources, knowledge and time, it is not always possible.

The operators on the assembly line agreed with the quality technicians regarding repair the deviations directly if possible. However, they sometimes have to send deviations they are aware of to the following stations due to lack of time, resources and knowledge. They did this against their "common sense" as they know the deviations could cause problems for the following stations downstream.

5.1.5 Secondary data

Through the collection of data from the quality information system it was possible to see how the handling of deviations was performed last year considering the share of using an offline repair strategy vs. online repair strategy. The number of deviations repaired at the adjustment station was divided by all reported deviation for one year. Likewise, the number of trucks repaired at the adjustment station was compared to the total production of trucks for the same time period. The reason to analyze both trucks and deviations was to get a wider picture of their way of using an offline repair strategy or an online repair strategy. The data was collected from one year (2012) and is confidential so therefore Figure 5.4 only visualizes an example of how the data could look like.

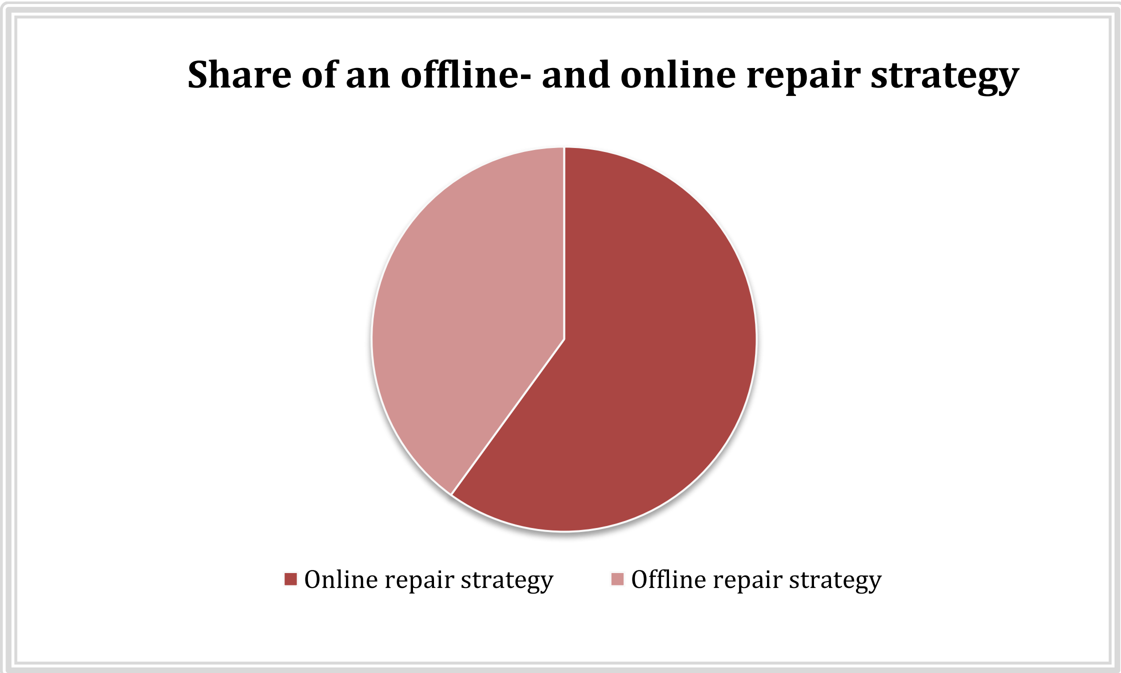


Figure 5.4 Portion of using an Offline repair strategy versus an Online repair strategy.

The collected data also made it possible to see where the deviations were originated. The deviations can be originated from many different areas within the factory but also from external sources. To easier handle the deviations, a categorization was made where the deviations were divided into three different categories:

- Internal, deviations that occurred in some areas within the factories four walls
- Suppliers, deviations that have their origin at any supplier to the factory
- Design, deviations that have their origins somewhere during the design process

5.2 Offline repair cost parameters

Costs were gathered in order to calculate the costs associated with using an offline repair strategy. The different cost parameters were categorized into fixed costs and variable costs. The fixed costs come with having an adjustment station, such as space, equipment, inventory etc. The variable cost parameters changes due to the volume of trucks repaired at the adjustment stations. In Table 5.3, the cost parameters are divided into fixed- and variable costs.

Table 5.3 Cost parameters

Fixed costs	*Variable costs*
- Spaces and supplies	-Personnel costs
- Equipments and machines > 20 000 SEK	-Personnel costs (overtime)
- Equipments and work materials < 20 000 SEK	-Late deliveries
- Inventory	-Tied-up capital for trucks waiting in queue
	-Tied-up capital for trucks extra days in production
	-Scrap
	-Renting clothes

In order to decrease the total cost of the offline repair strategy, the focus should be on the variable costs. If deviations are detected, solved and prevented earlier this parameters will decrease.

5.2.1 Fixed costs

The fixed costs are not dependent on the volume of trucks repaired at the adjustment station and would therefore not disappear or decrease until the whole adjustment station is eliminated.

Spaces and supplies

One of the fixed costs is spaces and supplies, which are costs for renting spaces where the repairing and storing of trucks takes place. This parameter also includes costs such as water, electricity and heat, see calculation in Equation 5.1.

$$Spaces\ and\ supplies\ (SEK) = area\ (m^2) * \ cost\ per\ square\ metre\ (SEK/m^2)$$
Equation 5.1

Equipments and machines > 20 000 SEK

The next fixed cost parameter are the costs for equipment and machines with a purchase price higher than 20 000 SEK. This cost includes equipment and machines at the adjustment station necessary to repair the different types of deviations. In order to calculate these costs, the purchase price and the average life length has been considered, see Equation 5.2.

$$Equipments\ and\ machines > 20\ 000\ (SEK)\ = \frac{purchase\ price\ (SEK)}{average\ life\ length\ (years)}$$
Equation 5.2

Equipments and work materials < 20 000 SEK

The following cost parameter covers the cost of equipments and work materials with a purchase price below 20 000 SEK. This type of equipment and work materials are consumable and therefore the calculation only covers the purchase price, see Equation 5.3. Work materials could be rulers, padlock, cables, pens etc.

$$Equipments\ and\ work\ materials < 20\ 000\ (SEK) = purchase\ price\ (SEK)$$
Equation 5.3

Inventory

The inventory cost parameter covers the cost of inventory only used in the adjustment station. This cost is calculated by consider the value of the inventory and the cost of tide-up capital, see Equation 5.4.

$$Inventory\ (SEK) = value\ of\ inventory\ (SEK) * cost\ of\ capital (\%)$$
Equation 5.4

5.2.2 Variable costs

The variable costs are dependent on the volume. One of the largest variable costs considered in this case study is the personnel costs.

Personnel cost

In order to calculate the total personnel cost the number of working hours at the adjustment station was multiplied with the cost per hour of an ordinary worker. The same has been done when calculating the personnel cost of working hours at overtime, see calculations in Equation 5.5 and 5.6.

$$Personnel\ cost\ (SEK) = operator\ cost\ (SEK/h) * working\ hours (h)$$
Equation5.5

$$Personnel\ cost\ (overtime)(SEK) =$$
$$operator\ cost\ (overtime)(SEK/h) * working\ hours\ overtime (h)$$
Equation 5.6

Late deliveries

Another variable cost that has been considered is the cost of late deliveries. If a lot of trucks need to be repaired at the adjustment station and they don't have enough capacity in order to reach the agreed production lead time, the truck will be late from the production to the market department. The calculation of late deliveries is shown in the Equation 5.7. In the calculation the total number of late trucks, due to been in the adjustment station, is multiplied with the current "fee" due to the delay.

$$Late\ deliveries\ (SEK) = late\ trucks\ (n) * fee(SEK)$$

Equation 5.7

Today there are no fees between the production and the market department at Volvo. If the truck is delivered late to the customer Volvo compensates this. However, some trucks are late from the adjustment station but the effect on the end customer could not be stated in this case study. In Figure 5.5 it is shown how the trucks that are delivered late from the adjustment station 2012 vary from week to week.

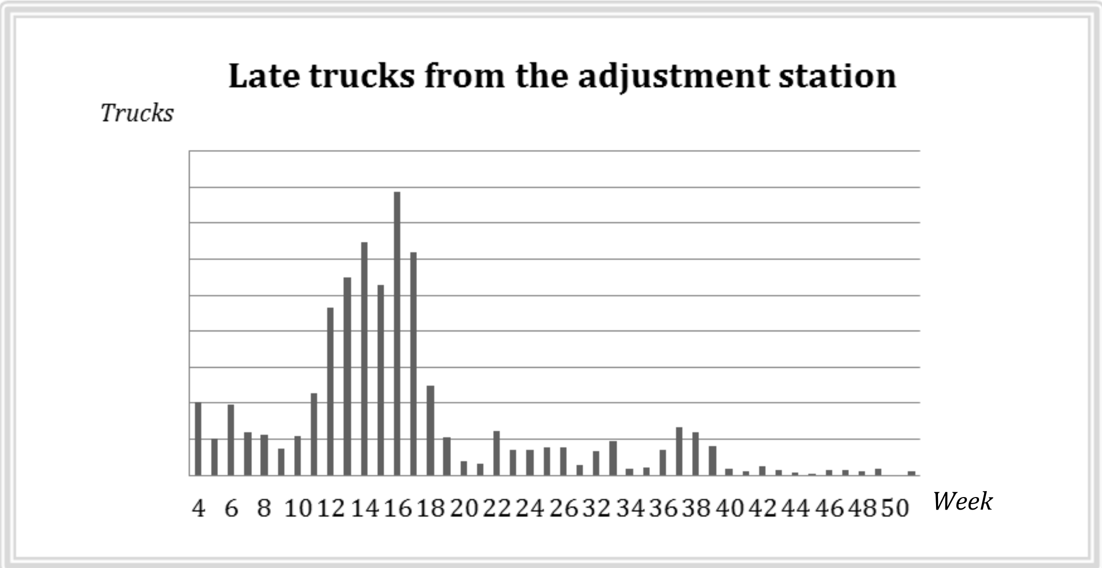


Figure 5.5 Number of late trucks from the adjustment

Tied-up capital for trucks waiting in queue

One important cost parameter for this case study is the cost of the queue of trucks into the adjustment station. This cost parameter includes the waiting time for the truck before it can be repaired in the station. If more trucks are delivered to the adjustment station than the number of trucks they can repair, a queue into the station is built up. As long as the trucks are waiting in the queue they cost money because of tied-up capital. This cost parameter can be seen as a hidden cost for the company. Figure 5.6 illustrates the variation in queue for 2012 and Equation 5.8 shows how the cost parameter has been calculated.

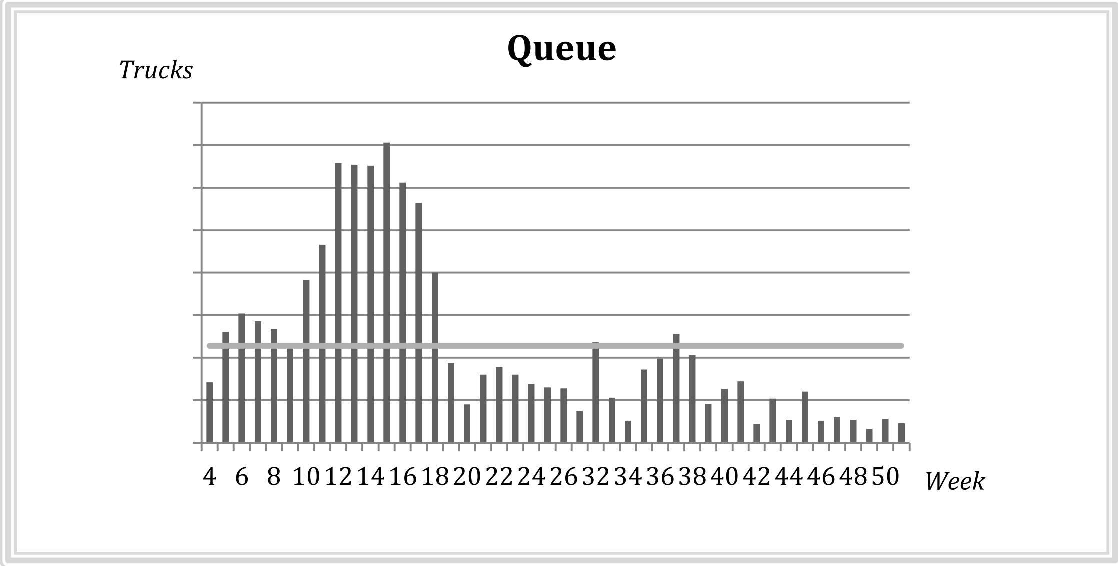


Figure 5.6 Numbers of trucks in queue waiting to be repaired in adjustment station.

$$\textit{Tied-up capital for trucks waiting in queue (SEK)} = average\ queue(n) * sale\ price\ (SEK) * cost\ of\ capital(\%)$$
Equation 5.8

Tied-up capital for extra days in production

Due to unstable processes, Volvo has planned two extra days in the production for each truck. For all trucks that pass the final inspection without any deviations, these two extra days are unnecessary. For the truck, it will only lead to two extra days of waiting to be delivered to customer. Like the cost of storing trucks in a queue to the adjustment station, this waiting time will also lead to a cost of tied-up capital. The tied-up capital for trucks extra days in the production is shown in the Equation 5.9.

$$\textit{Tied-up capital for trucks extra days in production (SEK)} = sale\ price\ (SEK) * trucks\ direct\ OK(n) * cost\ of\ capital(\%) * extra\ days(n)$$
Equation 5.9

Scrap

When handling trucks in the adjustment station, the risk of breaking any of the parts increases because of the extra handling work, like dis- and reassembling. This cost is calculated considering the purchase price of all material that needs to be scrapped, see Equation 5.10. At Volvo there could not be stated any cost related to scrap from the adjustment station.

$$\boldsymbol{Scrap\ (SEK) = purchasing\ price\ (SEK)}$$
Equation 5.10

Renting clothes

The operators at the adjustment station may use special clothes while working. The clothes are rented and all cost that comes with this service is calculated in the cost parameter of renting clothes, see Equation 5.11.

$$Renting\ clothes\ (SEK) = price\ of\ rent\ (SEK)$$
Equation 5.11

5.3 Online repair cost parameters

In order to compare the different repair strategies, the cost parameters considered an online repair strategy were interesting for this case study. As mentioned earlier, it is the Andon-persons that first try to solve the deviation on the assembly line when a deviation is detected. These operators have the same personnel cost as the operators at the adjustment station in this cost calculation.

Stop the line

Volvo already calculated the cost parameter of stopping the line. The calculation is based on that for each stop that lasts as long as their tact-time, they “lose” a truck. Therefore the parameter was calculated with the personnel cost of the current working hours that are needed to assemble a truck on the line. The overtime factor is to cover the additional cost if the truck instead needs to be assembled at overtime in order to not lose one truck in production rate. See Equation 5.12.

$$Line\ stop\ (min) = working\ hours\ per\ truck\ (h) * personnel\ cost\ (SEK/h) * overtime\ factor$$

Equation 5.12

5.4 Benchmark

A benchmark was carried out in order to compare the process of handling internal deviations. The benchmark was made between two Volvo factories, namely the Tuve factory and the factory in Umeå. Cabs to the trucks are produced from scratch at the Umeå factory and later delivered continuously to the final assembly at Tuve. A gathering of date and position of persons interviewed are stated in Appendix 2.

5.4.1 Umeå factory

The factory in Umeå is a cab producer that delivers cabs to Volvo factories. A final assembly of the cab is a part of the production process. In Umeå cabs are produced according to customers’ orders and not made to stock. The factory has an order stock of 19 days from order to delivery and the customers can choose between 4000 variants of cabs. The production of cabs takes 3-5 days. Umeå has a driven final assembly line and an adjustment station after the test and control area. The driven assembly line contains of seven different areas with a team leader at each one of them.

5.4.2 Handling of deviations

On the assembly line work three special operators called mobile adjusters, originally from the adjustment station, to continuously repair deviations. They work each on two areas of the assembly line and have the responsibility of controlling the cab before it continues to the next area. If an occasion of stopping the line would be necessary to get time to solve the deviation, the mobile adjuster has to ask the production manager for permission. However, stopping the line is very rare and if the mobile adjuster can’t solve the deviation within available time the cab continuous to be assembled throughout the line. The reason for further assembling even though a deviation is detected is that all belonging material has to follow the cab all the way. The mobile adjuster tries hardly to repair the deviation on the line but due to lack of time deviations passes through.

The mobile adjuster works in order to prevent deviations to reach the adjustment station. But if there isn't enough time to repair on the line, or the deviation isn't detected until the final inspection, the cab continues to the adjustment station. The work orders of the cabs are set due to date being delivered to customer. The times of the adjustment operations are documented after each handled cab. The operators at the adjustment station are planned to work at ordinary hours and one shift, not at nights and weekends. At the adjustment station, work instructions are available for each repair operation.

The load on the adjustment station at Umeå was very high when they didn't have any mobile adjusters so therefore the Umeå factory decided to reintroduce them recently. Previous there was more than double as many mobile adjusters on the assembly line but due to high personnel costs, all of these left their position under a three years period until a while ago.

In Umeå, there isn't as much space for waiting cabs in order to be repaired at the adjustment station as in Tuve. If the adjustment station is overloaded in Umeå, it leads to an interruption in the production flow and the assembly line needs to stop due to the bottleneck. Previous stoppages have led to a lot of bad feelings and therefore they try continuously to avoid this situation to happen by focus on their way of handling deviations.

5.4.3 Report deviations

Deviations occurring at the assembly line in Umeå are after the assembly line documented in the same quality information system as Tuve. If some deviations are corrected directly on the assembly line, they are never documented in the quality information system. Therefore, only those deviations that reach the adjustment station at Umeå are documented and followed up.

The operators on the assembly line need to confirm different assembly operations they have finished on a control card on the cab. Further on, another operator will control and confirm if the certain assembly operation really occurred previously. However, the operators also have the job to report deviations they detect or are responsible for while assembling. They are reporting these deviations on the control card that follows the cab until the end of the assembly line. At the card they have to assign with a personal number. It has being noticed that while the mobile adjusters are working parallel with the operators on the assembly line, a reduction of reported deviations has been occurred. But due to the increased pressure on the mobile adjusters, there is less time for them to both detect and solve all deviations.

Every production leader gets at regular intervals a list of all deviations that were originated at their responsible areas of the assembly line. Thereafter, the responsibilities of further preventive actions are given to them. Hence to the act of specifying the personal number when detecting a deviation, the leader can follow up the current deviation to the concerned operator. Likewise if an assembly operation wasn't performed correctly, the leader can tell the current operator responsible.

6 Analysis

This chapter analyses the collected data and the empirical findings in this project. The chapter includes what type of repair strategy that is applied at Tuve and how the information from the data collection has been used in order to answer the research questions.

6.1 Repair strategy at the Tuve factory

Based on the empirical findings at the Tuve factory, it can be confirmed that both an online and offline repair strategy is performed. An influence of the online repair strategy is shown with the performance of Andon-persons supporting and solving deviations on the assembly line and on the sub flows. When deviations cannot be solved, the truck is sent to the adjustment station for repair operations after the assembly. This also shows the occurrence of an offline repair strategy. The deviations that reach the station are those that couldn't be solved at the assembly line due to lack of time, or weren't even detected until the final inspection area.

When studying the data from 2012 of all deviations and trucks that was repaired in the adjustment station, it was important to analyze both factors to state the portion of an online versus an offline repair strategy. When only analyze the number of deviations might lead to one conclusions of which repair strategy that were mainly used at Tuve. However, when also studying the number of trucks repaired at the adjustment station, the conclusion did change. In order to answer the second research question "What are the costs for using and offline repair strategy?" the cost calculation was mainly focused on the influence of the offline repair strategy i.e. number of trucks repaired at the adjustment station.

6.2 Costs of an offline repair strategy

The costs of using an offline repair strategy were calculated for year 2012. The costs found were divided into fixed- and variable costs in order to see which costs that are dependent on the volume of trucks repaired at the adjustment station (see Figure 6.7).

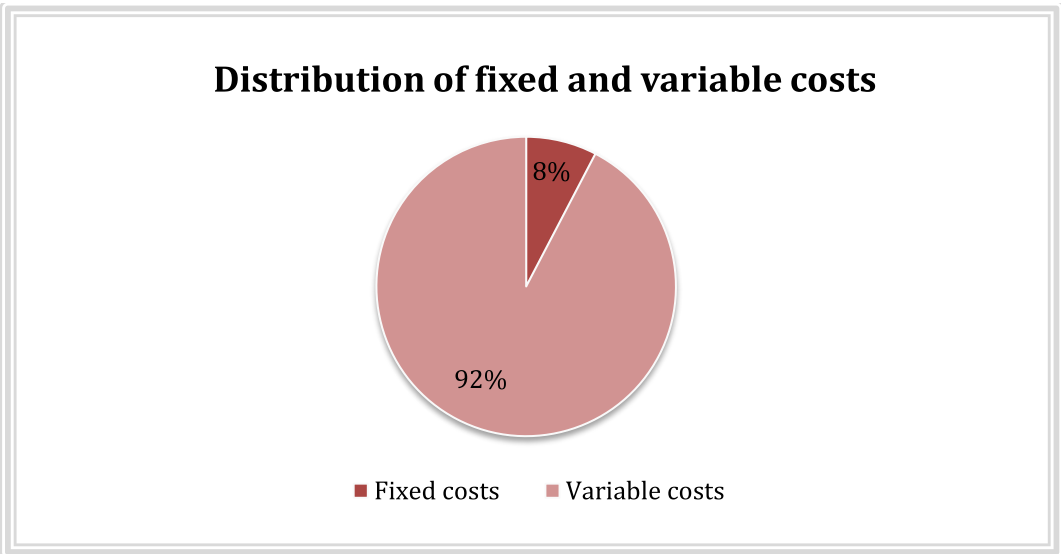


Figure 6.7 Share of fixed- and variable costs

The variable costs increase as the volume of trucks repaired at the adjustment station also increases. From the cost parameters seen in Figure 6.8 below the two largest costs for the offline repair are the personnel cost and the tied-up capital for trucks waiting to be repaired at the adjustment station. . The assembly plant in Tuve introduces new variants of trucks before they are manufactured at other factories. This of course generates new problem areas, as the production processes may not be adjusted to the new products. This needs to be considerate when looking at the result of the offline repair strategy.

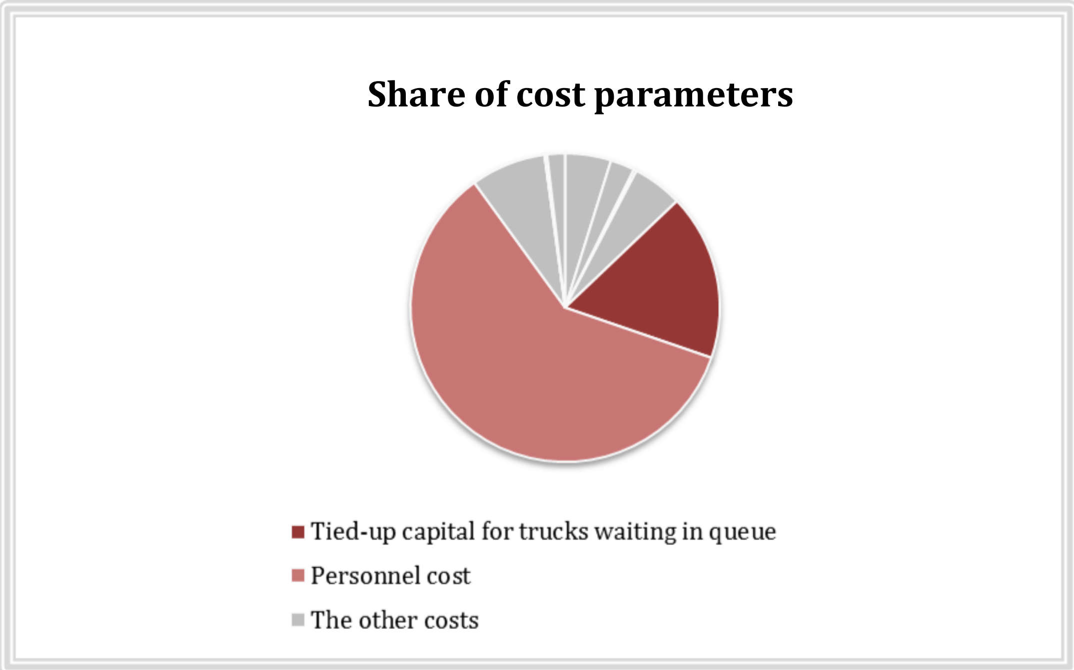


Figure 6.8 Share of cost parameters

As the personnel cost is the largest cost for the offline repair strategy at Tuve, it is of interest to know which factors affect this cost parameter. Two main factors are:

- Type of the deviation
- Numbers of trucks that needs to be repaired at the adjustment station.

6.2.1 Type of deviation

By calculating the cost of type of deviation gives a hint of the size of the consequences of it. But in order to pick out some deviations, the deviations need to be ranked, as there are a lot of different types of deviations. From the questionnaires and the interviews an indication was that the largest parts lead to most secondary failures and most work in the adjustment station. Therefore, deviations to these parts have been considered. The selected main parts are visualized in Appendix 3. In order to rank the parts and their deviations a FMEA was performed. The FMEA considers three factors while ranking the parts:

- Frequency
- Detection
- Severity

The first factor considers the frequency due to some deviations to a particular part occur more often than others. Data for this was found in the quality information system. The second factor considered was the probability of detection, that means if the deviations were detected before the assembly line or not. Deviations can go unnoticed during the whole production process until it reaches the final inspection.

The final factor was the severity describing the size of needed disassembly- and reassembly time in order to perform the repair operation in the adjustment station. Some deviations take longer time to repair than others. The disassembly- and reassembly time depends on which type of deviation it is and the position of the part. Often the first part with a deviation is built in by other parts through the assembling and creates secondary failures. If deviations to those parts that are built in are to be repaired at the adjustment station the operator needs to first disassemble parts to reach the deviations. Thereafter the operation of repair, replace or install the part with the deviation has to be considered. Finally the parts need to be reassembled again (see Figure 6.9). In order to calculate the cost of these different types of deviation the time for adjustment work (included the disassembly- and reassembly time) would be necessary. Unfortunate the actual repair operation times (install, replace, repair) were not available at Tuve and for the authors to make a time study of this size would be very time consuming. Estimations or simple time studies would also give a low reliability of the result. However, the reassembly- and disassembly times for the main parts were found in a document used for service stations.

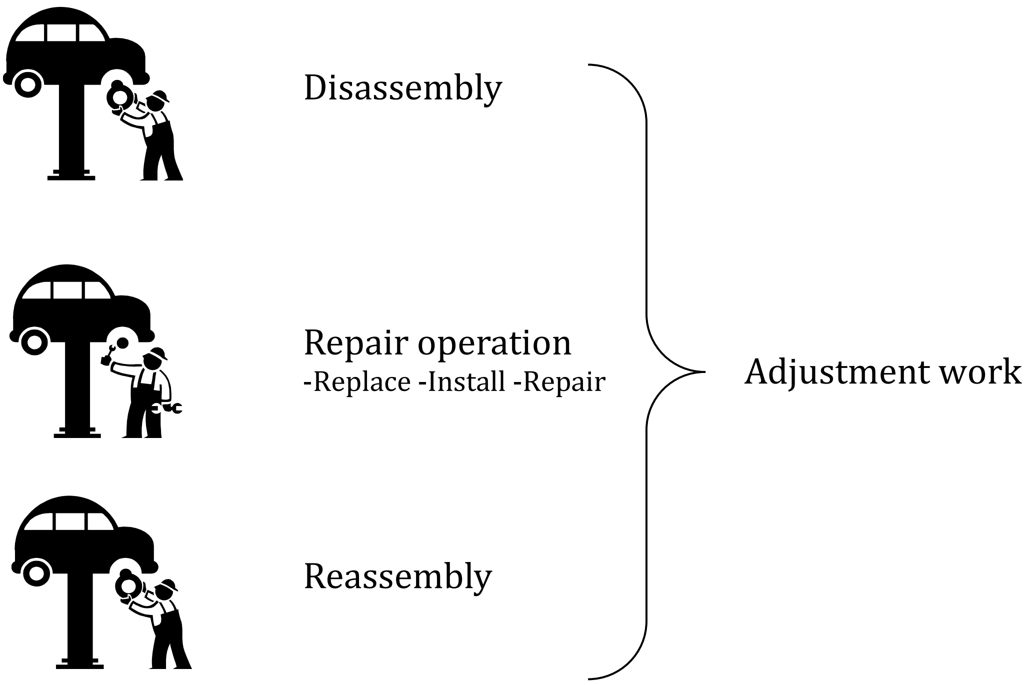


Figure 6.9 Illustration of disassemble, repair operation and reassemble.

Dis- and reassembly tree diagram

In order to state what parts that need to be disassemble in order to do a repair operation of a particular part, a construction of a disassembly- and reassembly tree diagram was made. The tree shows which parts that need to be disassembled in order to perform a repair operation of another particular part, see Appendix 4. The tree diagram flows from left to right. For instance, in order to make a repair operation of the engine the catwalk, exhaust pipe, crosses member cab, air filter, extra wheel and airflow reverser need to be disassembled and then reassembled again. This means that the time spent in the assembly line for assembling these parts not generated any value. The adjustment work for the engine therefore contains of disassembly these parts, make the repair operation of the deviation and then reassemble the parts again.

As mentioned in the previous chapter the repair operation times are not documented at Tuve. However the time of replacing, remove and install main parts was found in instructions for service stations. These times have therefore been used for calculating the disassembly- and reassembly times in the tree diagram.

FMEA

When all data was collected, a FMEA was used to rank the deviations and determine the worst deviations when it comes to frequency (probability), dis- and reassembly time (severity) and if it was detected before the final inspection area (detection).

Top 11 serious parts

In the Table 6.4 below, the “Top 11” parts are presented from the final FMEA. The whole process FMEA is visualized in Appendix 5, although the result of which parts are not presented as this is confidential. The highest risk level a part can get is 125 and the lowest is 1. The top 11 parts represent a score range from 25-100.

Table 6.4 Top 11 serious parts from total FMEA

Problem part	**Probability factor (P)**	**Severity factor (S)**	**Detection factor (D)**	**Risk level (P*S*D)**
Part A	4	5	5	**100**
Part B	4	4	5	**80**
Part C	4	4	5	**80**
Part D	4	4	5	**80**
Part E	4	4	5	**80**
Part F	4	5	4	**80**
Part G	2	5	4	**40**
Part H	2	3	5	**30**
Part I	5	1	5	**25**
Part J	5	1	5	**25**
Part K	5	1	5	**25**

6.2.2 Cost model of type of deviation

Based on the FMEA and the dis-and reassembly tree diagram the cost of a type of deviation was calculated. A cost model was constructed in order to calculate a type of deviation (see Appendix 6). The cost model can show the cost of a deviation repaired both offline and online. By comparing the two different costs it is possible to see how the resources could be used in the best efficient way. To the left in in the cost model is the calculation of repairing the type of deviation offline.

Offline repair cost in the model

All the cost parameters gathered, except the personnel cost, were divided with the number of trucks repaired at the adjustment station 2012. Then the cost of the repair operation is of course considered. Because of the high variation of repair times due to different deviations, a division of the deviations was made into three different categories; *replace*, *install* and *repair.* The part may need to be *"replaced"* because it is not functioning and cannot be repaired. If the deviation is that a part is missing the part only needs to be *"installed".* At last the category *"repair"* considers all various operations on the part to fix the deviations.

As mentioned earlier when sending a deviation to the adjustment station a lot of extra work is required to reach the certain part for repair. When calculating the cost of sending a deviation to the adjustment station, the cost of the work of dis- and reassembly for a particular part has been considered, the times are taken from the tree diagram. Figure 6.10 illustrates how the cost varies between different risk levels from the FMEA. Three parts were selected one from each risk level. *Green level:* Air filter, *Yellow level*: Cab anti-roll bar and *Red level*: Engine.

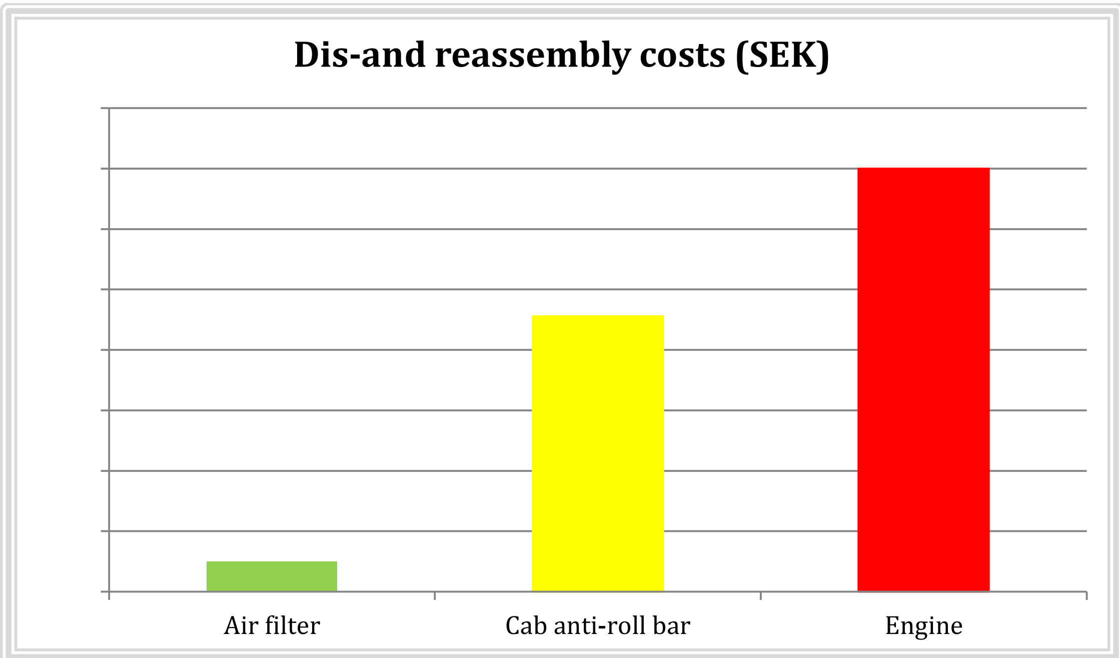


Figure 6.10 Dis- and reassembly costs from three parts

In order to quantify the cost of a particular deviation the frequency of the deviation is of high importance for the cost model. Some deviations may only happen a few times per year or not at all, as other deviations may occur more often. In the cost model it is possible to consider the number of affected trucks with deviations at the same part. Therefore, it is possible to calculate the total cost of all deviations at a part over a time. The main reason to consider the number of trucks with a certain part affected is to avoid double calculations if several deviations at a part occurs at the same truck.

The reasons of consider the frequency in the cost model is to estimate how much the company could save in costs by eliminate the same type of deviation. The cost for repairing trucks offline with the same engine deviation was calculated as an example. The reason for choosing Engine was because it was in the red level in the FMEA. This cost could instead be used for prevention actions in order to find the root cause and eliminate the deviations. After time more and more root causes can be eliminated and fewer trucks need to be repaired at the adjustment station.

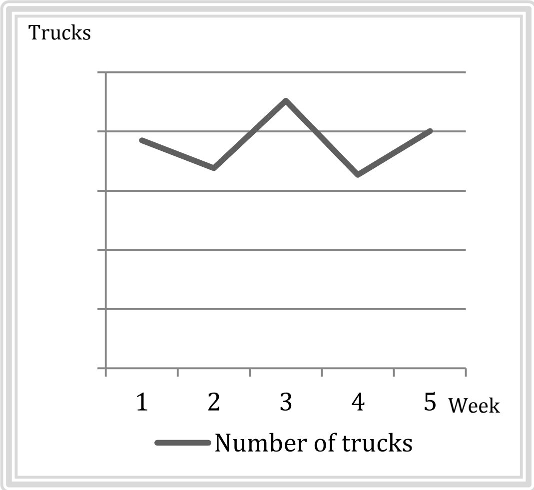
Online repair cost in the model

When the cost of the offline repair was calculated for a certain type of deviations, this cost was compared to repairing it online instead, that means to move the resources upstream. This was done to the right in the cost calculation model. In the example of the deviations on the engine, it turned out that for the same cost as repairing them offline, the line could have stopped and man-hours could have been spent on prevention actions. The aim for the prevention actions is to find the root cause and prevent it from happen again. Therefore, the frequency was not considered in this repair alternative, i.e. when solving it online includes working with preventive actions.

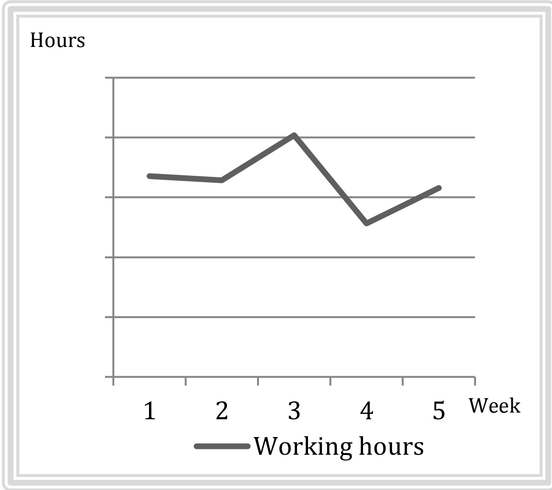
6.2.3 Number of trucks repaired at the adjustment station

As mentioned earlier the number of trucks being sent to the adjustment station is of interest as it affects the personnel cost parameter. Out of the collected data and interviews, it has been seen that the operators' work is planned according to the amount trucks sent to the adjustment station. As the station brings in more operators from the factory when needed there is no upper limit of how many trucks that can be repaired at the adjustment station. The number of trucks delivered is related to the amount of working hours at the station. Therefore also the personnel cost is affected due to the number of trucks sent to the adjustment station.

The number of trucks delivered to the adjustment station over a period of five weeks is showed in the Figure 6.11. A comparison has been done with the amount of working hours at the adjustment station during the same time period, illustrated in Figure 6.12. Out of that it can be seen that the actual working hours are quite adapted to the number of trucks delivered for repair.



6.11 Number of trucks delivered to adjustment station



6.12 Working hours in the adjustment station

Tied-up capital for trucks waiting in queue

The number of trucks sent to the adjustment station also affects the number of waiting trucks to be repaired. As more trucks are waiting the tied up capital increases, which was the second largest cost parameter in the cost calculation. At the adjustment station at Volvo Tuve, trucks are stored outside at a yard waiting to be repaired. It is therefore possible to store many trucks in a queue that tie up a lot of capital. The large number of trucks that are waiting results in an unstructured situation and makes it difficult to find a certain truck when it's time to repair it. The lack of control can also be shown as an unawareness of how many trucks that actually is waiting to be repaired. This can also lead to an unknowingness of the amount of deviations and quality issues that occurs in the factory.

6.3 Benchmark

When comparing the way of working handling deviations at Umeå and at Tuve, some similarities and differences were found. Both Tuve and Umeå have a driven assembly line and an adjustment station after a test and control area. Both the products (truck and cab) are too big to easily handle and take off the assembly line, which make things more complicated when deviations occur.

6.3.1 Online repair strategy

Both factories use an online repair strategy in the meaning that they have special operators (Andon-persons) available along the assembly line if need of assistance. Operators at both Umeå and Tuve have the responsibility to document a deviation if detecting while assembling. In Umeå the mobile adjusters have the responsibility of detecting and adjusting the deviations along the assembly line. At Tuve, special inspectors work at the end of each area of the assembly line. Their responsibilities are to inspect and detect deviations and call for assistance in need for adjustment. In Umeå a reduction of reporting deviations from the operators has been noticed since they introduced the mobile adjusters on the line. One reason could be that the operators trust the mobile adjuster to detect all deviations. However, this increased inspection work has led to less time to actually repair the detected deviations for the mobile adjusters.

Stopping the line to solve a deviation is very rare at both factories and needs special permission from the production manager to perform. Interviews resulted in an indication of that it exist thoughts at both factories that it is very expensive to stop the line. Also that it exist assumptions of losing a whole product when stopping the production flow a period as long as the tact time.

6.3.2 Offline repair strategy

Both factories also use an offline repair strategy when repairing deviations after the assembly line at the adjustment station. All adjustment operators have work instructions available but only at Umeå they document the time of the repair operation. It could be seen that in Umeå they had a more controlled situation over the adjustment station than in Tuve and this could be one reason. The documentation is beneficial when planning the adjustment work but also when controlling the workload at the station. Documentation of the repair times can also ease the quality work and decisions regarding a strategy to handle deviations.

At the Tuve factory, there is no limit of how many trucks that can be transported to the adjustment station. All trucks that can't be repaired online are stored in a queue outside at the yard. When the maximum capacity at the adjustment station in Umeå is reached, no cabs are transported to the yard. This could be another reason of the better control situation at the adjustment station in Umeå. When the maximum number of cabs is reached, the assembly line stops until the pressure of the adjustment station has declined. This action creates a lot of attention in the factory and contributes to really noticing the quality issues. The fact that trucks have wheels and more easily, than cabs, can be transported outside to the yard, might be a reason why this way of building up a queue is performed at Tuve.

The working hours in the adjustment stations also differs between Umeå and Tuve. If necessary the operators at Tuve are working nights and weekends to meet the demand of work. They also bring in more operators from the assembly line if needed. At Umeå the operators only work one shift and this is possible due to their upper limit of arriving cabs.

6.3.3 Report deviations

Deviations occurring at the final assembly line are documented in the same quality information system at both Umeå and Tuve. They have the same work structure by documenting detected deviations during the assembly line on a control card and later report it in the quality information system.

In Umeå, if a deviation is corrected directly on the assembly line it is never documented on the control card and later in the quality information system, as they are in Tuve. This means that the root cause analysis and preventive work will be hard to perform due to the lack of knowledge of the deviation's occurrence. The information is of high importance when working with reducing deviations and improving quality.

In Umeå every production leader gets regularly reports of the deviations that were originated at their responsibility area. At Tuve they have limit the information transfer to the three most common deviations that occurred every week. However, the high variation of deviations results in low frequency per variant and deviations pass by without root cause analysis and prevention work. To only consider the three most common deviations can result in missing out of other deviations that have similar severity of the consequences.

7 Guidelines for future work

Based on the cost calculations and the empirical findings some guidelines for future work have been summarized in this chapter. The guidelines in this chapter are suggestions and can work as a base for discussion at the company for how to handle deviations and if changes need to be made regarding the current repair strategy.

7.1 Raise attention immediately

Prevention costs are necessary to eliminate the root cause of deviations. To focus more on the preventive activities, a reduction in the total cost of all deviations will happen (Sörqvist, 2001, p. 35). When a deviation is detected something needs to be done in order to both correct the deviation and prevent it from happen again. The deviation needs to be paid attention to. Companies using an offline repair strategy put in an effort of correcting the deviation and find the root cause late in the process and it can take weeks before any attention is put on it. If efforts are put directly to the problem it can by some methods, as stopping the line, raise attention to the problem immediately (Liker J.K, 2009, p. 62). The example of stopping the line is an expensive solution in order to raise attention; even if can be very effective. The aim is to understand how serious it is and find the root cause to the problem to both save time and money downstream (Liker J.K, 2009, p. 165). By continuously rise problems to the surface and solve them at origin will eliminate waste and increase productivity. However, before the line stops, support help should be called to do their best to solve the deviation until it reaches the next section, if the deviation cannot be solved the line should automatically stop to raise the attention. Other ways of raising the attention could also be to introduce a signal or music when deviations occur. At Toyota for example the song “Fur Elise” by Beethoven is played to raise attention and signal out that something is wrong.

As mentioned earlier, line stops are expensive, but Toyotas line stop strategy or online repair strategy is a long term way of thinking. Quality will by time increase and costs will decrease eventually, even if larger costs will be necessary in the beginning, so called prevention costs. The long term thinking and the benefit from a cost perspective are illustrated in Figure 7.13. Because of the long term thinking, it is hard to say when the pay back will be, as there are lots of cost parameters that will be affected and some of them are very difficult to measure such as goodwill and badwill.

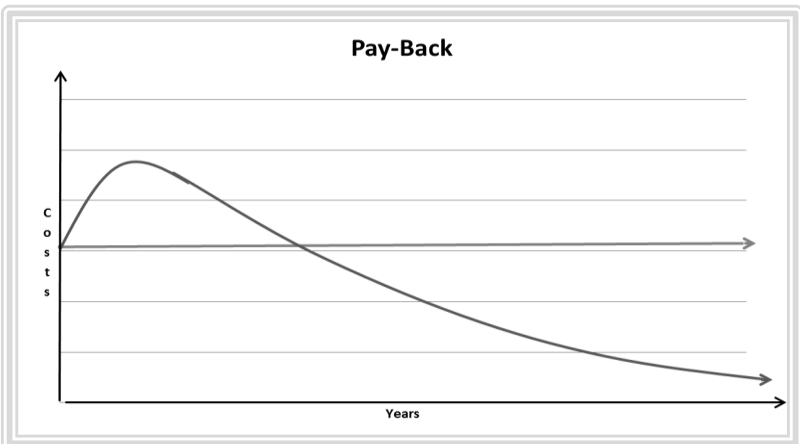


Figure 7.13 Payback of the change

7.2 Move resources upstream

Volvo Trucks in Tuve is on a good way of implementing a total online repair strategy and their ambition is there. Many deviations are solved directly by help of Andon-persons working besides the assembly line. However there is still a mindset of that it is cheaper to repair deviations at the adjustment station than on the assembly line or earlier in the production process. Out from the cost calculation model constructed for this case study, it was concluded that it is more expensive to repair deviations at the adjustment station. If it is possible to repair deviations earlier it is also easier to find the actual root cause in order to prevent it from happen again in the future. In the constructed cost calculation model of a certain type of deviation it is possible to experiment with how the same resources (money) for a repair offline could be used for a repair online instead. An example from the cost calculation model (confidential) showed that the same resources could have been moved up streams. The line could have been stopped in order to raise attention and man-hours been could have been spent on finding the root cause and put in prevention actions. One of the guidelines based on the cost calculation is therefor to move the resources upstream, as it is cheaper and easier to find the root cause so it never happens again. Moving the resources upstream is an effective way of working with continuous improvements and utilizes the knowledge of the operators working in the adjustment station.

7.2.1 Root cause analysis

As mentioned in the previous chapter it is easier to find the actual root cause if the deviation is detected early in the production process. The “Five why’s” is a technique to ensure that the root causes of problems are sought out (Bicheno, 2004). To do the root cause analysis, the main reason is to not send trucks with deviations to the adjustment station. It can also be that different deviations have the same root cause. The further downstream the deviation is detected and something is actually made to prevent it, the harder it is to put in the right prevention action to it. New deviation can occur and information of the deviation can disappear on the way. It is therefore important to raise attention to the deviation immediately and start the root cause analysis work right away.

7.3 Set limit of trucks in the adjustment station

Another guideline from this case study is to limit the number of trucks send to the adjustment station. Seen from the benchmark in Umeå, they had a limit of receiving cabs in the adjustment station. When the adjustment station was full, they did not store cabs on the yard by two reasons. First of all, it is harder to transport a cab without any wheels. Second, they will lose the control if too many cabs are stored at the yard. Instead the line gets stocked in the end and automatically stops at Umeå.

At Tuve, it is an easy solution to store trucks at a yard as they are moveable with wheels. Therefore, a start could be to set a limit of how many trucks that should be repaired at the adjustment station in order to not lose the control and to “force” more resources upstream. The limitation could be of the number of operation stations in the adjustment station, so no trucks need to be stored at the yard and contribute to the lack of control.

By introducing this limitation of trucks, another parameter will also be affected positively. Today at Tuve, the operators at the adjustment station work at nights and weekends due to the large demand of work. If the ordinary personnel aren't enough they also take in operators from the assembly line to cover up. As mentioned earlier, this lead to high personnel costs. As seen at the Umeå factory, due to their limit of trucks the adjustment operators only work at a daily basis and therefor the personnel cost doesn't increase as much as in Tuve.

7.4 Increase involvement of the operators

To discover deviations as early as possible can decrease a lot of costs that would arise later (Juran, 2010, p161). This means to also handle the deviations directly when they are detected to reduce the costs. Costs that would be avoided if doing so are among others; costs connected to repair work in the adjustment station, potential late deliveries and costs for lost sales due to a disappointed customers.

The type of activities such as inspecting and testing the trucks will eliminate the risk of deviations passing by. This is done today at Volvo Tuve as the operators along the line have the responsibility of reporting detected deviations. But continuously along the line there are also special inspectors that only control and inspect the trucks. This might increase the risk of trusting the inspectors to find all deviations themselves. This scenario has been seen at the Umeå factory. To successfully eliminate to miss detect deviations, all operators that continuously handle the truck along the assembly line should get more responsibility. Therefore, the responsibility of the operators at Tuve should increase and their work tasks should include properly inspection of the trucks while assembling. To bring the problems to the surface, it's important to have a culture of that it is okay to report your own mistakes. This acceptance is necessary to implement when increasing the responsibility to the operators. But it is not enough to just control and tests the trucks to find different deviations; the deviations should in a perfect world never even appear. Therefore, more focus should be put on attention as mentioned in Chapter 7.1.

According to the Lean philosophy and the online repair strategy, it's a prerequisite to involve the operators for a successful implementation (Shin & Min, 1993, p. 45). This will create a feeling of belongingness and conduciveness. But to accomplish this, it is necessary to create an overall understanding and acceptance of the way of handling deviations. Hence, the online repair strategy might at first lead to short-term losses and to avoid resistance the long-term perspective is important to apply (Shin & Min, 1993, p.44). Education and information is the main key and here play top management and leaders an important role. The operators that regularly handle the truck carry already a lot of knowledge but it is important they get to see the whole picture regarding handling deviations. To inform of the consequences of different ways of handling a deviation creates a wider understanding. Using this project's cost model to show the costs of solving a deviation online respectively offline could be one option. When informing of the consequences of different ways of handling deviations, the overall work will get easier with handling deviations in the best possible way.

8 Discussion

The following chapter is a discussion regarding the empirical findings and the results of the analysis. It also includes a discussion regarding the future scenario of a change in mind-set and how resistance may appear if stopping the line would be up to date.

8.1 Repair strategy

Previous research about the two different strategies applied to repair deviations either includes only the online repair strategy or the offline repair strategy. But seen from this case study it is common to use a combination of both strategies. In both cases, Tuve and Umeå there is an awareness of making repairs upstream in order to avoid unnecessary costs, but the online repair strategy is not totally accomplished. There is a strong mindset of worry at both factories to not go behind in productivity i.e. “loose” products by stopping the line. Even if Toyota is the most productive car manufacturer and stops the line at the same time the philosophy is not totally understood (Liker J.K, 2009, p. 165). So why is there still a caution to fulfill the online repair strategy completely? The main reason could be the mindset of quick and short solutions instead of a long term mindset. The online repair strategy is not a quick solution; it is a prevention strategy to avoid the same deviations to occur in the future. If the mindset is short term, putting expensive and large efforts as stopping the line for one deviation may seem confusing and unreasonable when it can be fixed later, downstream. But it is not only the repair that should be made when stopping the line. It is a tool for putting attention to the deviation and then the important work begins, finding the root cause. And the root cause is easier to find the earlier in the process the deviation is detected and reported. So why not do it immediately? The argument that it is cheaper downstream is from this analysis not true. The resources and money put downstream could be moved upstream and it does not have to become much more expensive, not even in the beginning.

8.2 Badwill

The cost of late deliveries from the production turned out to be hard to measure. It can be said that the overall consequences of a late delivery is hard to concretize, hence it can result in many different ways. According to Juran (2010, p. 162) the types of deviations that can result in a late delivery affects the customer directly and are therefore usually the most expensive ones. The goodwill-factor is here affected, which means the late delivery can occur a loss in the sales and a reduction of the customer trust (Sörqvist, 2001, p. 37). How much does it really cost when a customer gets disappointed? The bad reputation will probably be spread a lot faster than a good one, meaning that a disappointed customer will tell his story to a lot more people than if he was pleased. How do other people react to this story? This could also result in a loss of potential customers (Sörqvist, 2001, p. 40). As this cost is hard to measure it usually turns out as an estimation that might be incorrect and therefor hide the truth of the real consequences to the current company. When something is hard to measure it also becomes hard to control.

As mentioned previously there is no internally fee within Volvo when a truck is late delivered from the production to the market department. This might turn out in a lack of pressure and focus on delivering trucks on time from the factory. As this affects the customer directly it should have a high focus and understanding of the consequences. Seen from the empirical findings, the number of late delivered trucks from the adjustment station vary a lot. Therefor it's highly possible that this lack of pressure and focus really exist. Of course this is not the operators at the adjustment station to blame, but would Volvo invest in more resources to highlight the consequences of late deliveries and prevent them from occur, the goodwill-factor would probably be affected positively.

Another aspect of interest to discuss is if the customer would like to buy the product if he knew it had spent several hours in an adjustment station of repairing? Of course this information is highly classified and will probably never reach the customer. But does the quality differ between a product that has been error-free and one that has been repaired? If so, this will surely lead to more effects on the goodwill-factor.

8.3 Where to begin?

When a larger change is up to date it can be hard to know where to begin. From this case study the cost calculation can work as tool to pick out some deviations that can be of interest in order to start testing the new mindset of stopping the line and find the root causes directly. The process FMEA is also a good starting point. Some deviations may be very difficult to repair online, and maybe almost impossible. Therefore a good starting point could be to begin with some deviations that occur frequent, detected early and are possible to repair online concerning equipment and knowledge. But as mentioned earlier this is a long term mindset and everything will not happen over a night. By continuously working for the new mindset results will be shown in the future.

It is hard to say that the mind-set should work "for this, this and this" type of deviation especially when the deviations look very different. Also, some deviations cannot be repaired online but must be repaired at a separate adjustment station. When deviations such as missing parts from suppliers occur, the assembly line cannot be stopped for days until the part has arrived to Tuve. Also, the assembly line cannot be stopped for all types of deviations, as this would result in frequent line stops. So, the scenario of totally eliminate the adjustment station at Tuve is totally unrealistic, however the adjustment station can decrease in size over time. This could be done in form of decreasing the personnel costs and number of trucks repaired at the adjustment station.

8.4 Resistance to change

According to the project's final guidelines to the company, some changes would be necessary when it comes to their current way of handling deviations. If a change in the mindset would be up to date there is a big chance of resistance of stopping the assembly lines. At Volvo today there exist no cost calculations of how much it costs to repair deviations at the adjustment station. However, calculations of how much it costs to stop the line exists and this can be a source to the resistance. The base of the calculation is the mind-set of losing a truck for each line-stop that lasts as long as their tact-time. This way of thinking might scare a lot of operators to actually stop the line and this mind-set is probably settled pretty deeply. However, fear is usually a consequence of lack of information. If the proposed guidelines would be realized, it would be necessary to put a lot of effort in creating an overall understanding about the benefits with the current guidelines. The suggestion of stopping the line when deviations occur would probably be pretty hard at first due to the mindset of losing a truck.

As there doesn't exist any cost calculations of repairing deviations offline, operators at the assembly line aren't aware of the consequences when sending a deviation to the adjustment station. How would their work be affected if they got this information? They would probably be easier to convince if the suggested guidelines could be supported with costs and theory. Top management and leaders has an important role to play when it comes to this information flow and especially if a change is about to happen (Shin & Min, 1993).

8.5 The importance of documenting repair times

Throughout the project it was seen that the adjustment station at Tuve doesn't report their repair operation times. In the project's cost model, when comparing the different repair strategies, the repair operation time plays an important role in order to get the exact cost. Due to the lack of this information, an example of a repair operation time of a part was instead used in the cost model. What would the outcome be if the real repair operation times were available? The result of the cost calculation would be more credible. The project could provide several cost calculations of different repair operations and a wider result could be reached. Another aspect of not documenting the repair operation times can affect the work of the planner at the adjustment station. When planning the repair operations with the number of operators and working hours, this work would be easier if real repair times were available. Also, it is easier to tell the current capacity at the adjustment station. When receiving trucks, this leads to easier be able to tell when a truck could be delivered from the adjustment station. A reduction of the late deliveries could be seen. The risk of an uncontrolled situation at the adjustment station could increase when it is difficult to control the operations and the consequences of this might reach the customer at the end.

9 Conclusion

From this case study it was stated that both an offline and an online repair strategy exists at Tuve today. The reason for the use of the offline repair strategy is the mindset that it is cheaper to repair downstream, in the adjustment station. After calculating the costs of the offline repair strategy it could be seen that the two largest parameters for this repair strategy was the personnel cost and the cost for tied up capital for trucks waiting in queue. A cost model was constructed in order to compare costs for repairing deviations with an offline repair strategy versus an online repair strategy. From the cost model, it was stated that it is more expensive to repair deviations offline. The main factors are the additional amount of dis- and reassembly time and that the deviation occurs in the future. The deviation occurs again as it is hard to find the actual root cause downstream and to put in the right prevention action to eliminate it in the future. In order to compare the total costs for different deviations in the calculation model, the actual repair time needs to be documented at Tuve.

In order to increase the portion of the online repair strategy, guidelines for future work were formulated. The guidelines are based on the cost calculations in order to increase the awareness of putting more cost on prevention actions, which will decrease the total cost. One prevention action is to raise the problem to the surface. It is important to raise attention to deviations immediately when they are detected, one way is by stopping the line. To avoid that the deviation occurs again a root cause problem solving should be done directly to eliminate the risk for the same deviation to happen tomorrow, next week or next year. The resources used in the adjustment station should therefore be put upstream to work with prevention actions, such as root cause problem solving.

This thesis work has constructed a cost calculation model for the comparison of an offline repair strategy and online repair strategy in a real environment. The authors of this thesis did not find any previous research when a case study of the subject was carried out. Previous research has only discussed the use of either an offline repair strategy or an online repair strategy. But with the new trend of implement Lean in all industries it is the tools that are copied, such as Andon, this could be one of the reason for the mix of the repair strategies. This case study could work as a base for future research to include the importance of understanding the whole philosophy behind the tools in order to implement a total online repair strategy.

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Appendix 1 –Questionnaire and interview

Questionnaire to operators:

- What station do you work at?

- Have you experienced that you want to repair a deviation that occurred *at your station*, but can't due to lack of time or knowledge?
    - What type of deviations is it and how did it occur?
    - If the deviations can't be repaired, which stations does it influence?
    - How would you have solved the deviation? Andons, line-stop?

- Have you experienced that you want to repair a deviation that occurred *at a previous station*, but can't due to lack of time or knowledge?
    - What type of deviations is it and how did it occur?
    - If the deviations can't be repaired, which stations does it influence?
    - How would you have solved the deviation? Andons, line-stop?

Interview Quality technicians:

Deviations

- What type of deviations occurs in the factory and which do you find the most serious one?
    - Why do you find them most serious?
- Are there any deviations that you know leads to secondary failures?

Problem area

- Is there any special area in the factory where many deviations occur?
    - Where and why?

Repair

- Is there any type of deviations that could be repaired directly on the line instead of being send to the adjustment station?
    - Why so?

Appendix 2 -Benchmark at the Umeå factory

Date	Position	Reason of choice
1213-05-02	Quality coordinator	Responsible of the quality that reaches the customer.
1213-05-02	Document deviations	Responsible of informing the problem owner of the occurred deviations at their workstation.
1213-05-03	Manager final assembly	Responsible of the adjustment personnel.

Interview guide

Questions to Quality coordinator:

- How do you handle deviations that are detected on the assembly line?
  - Offline repair?
  - Andon-persons?
  - Other options?
- Are there deviations that could have been repaired directly but can't due to lack of knowledge, time or resources?
- Does it happen that the assembly line stops when deviations are detected?
- Does the cab continue to be assembled after a deviation is detected or are they special treated?
- How often do inspections occur?
- Do the operators on the assembly line have any responsibility according to the quality?
- Any root cause analysis?
- Is any attention put on the deviations when they occur?
- Do you have any Andon-persons? How many?

Questions to Manager final assembly:

- How many employees work at the adjustment station?

- Do you perform "first in and first out"?

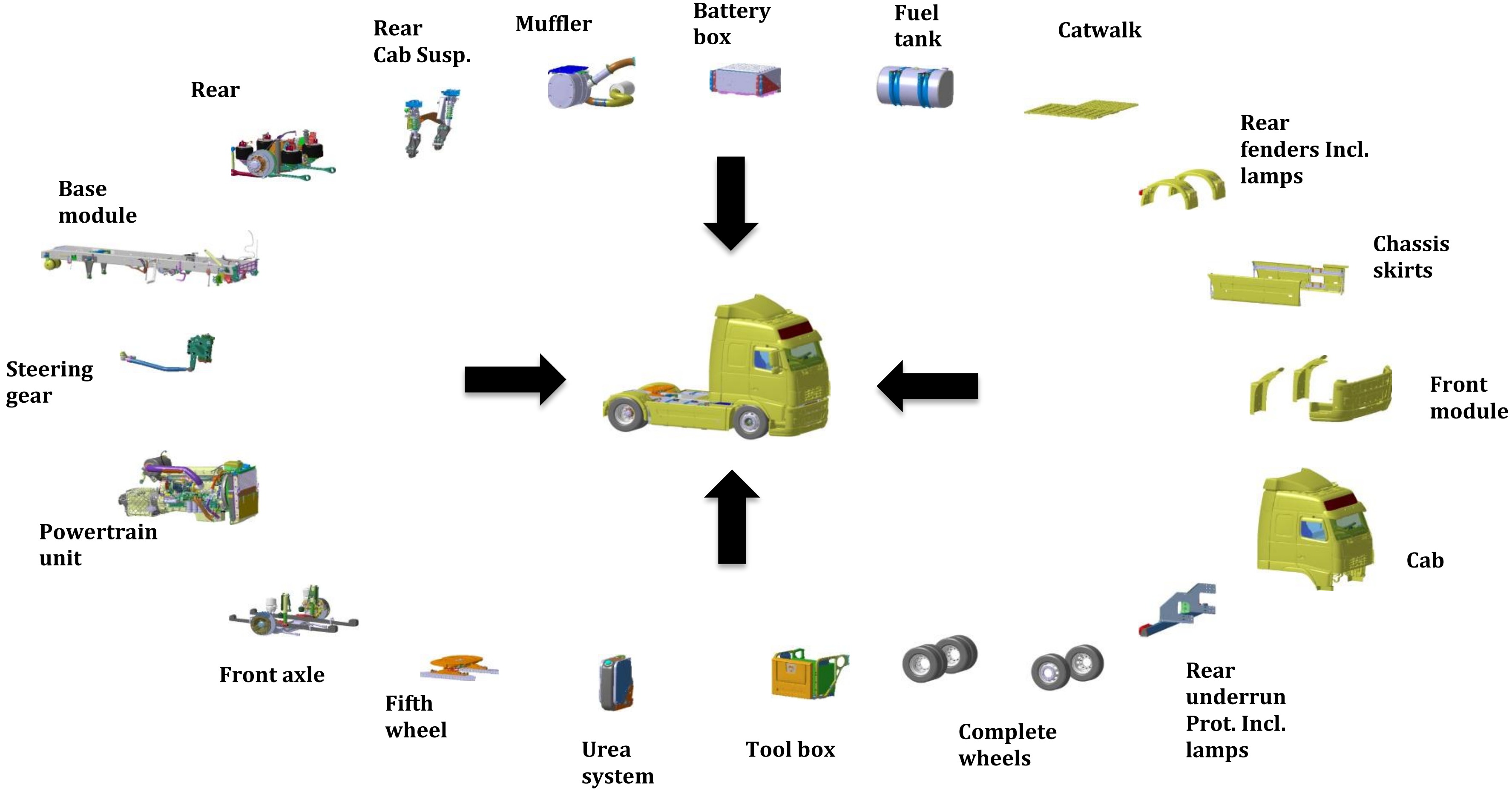
- Does any queue occur into the adjustment station?

- Do you document the adjustment times?
  -How?
  -Why?

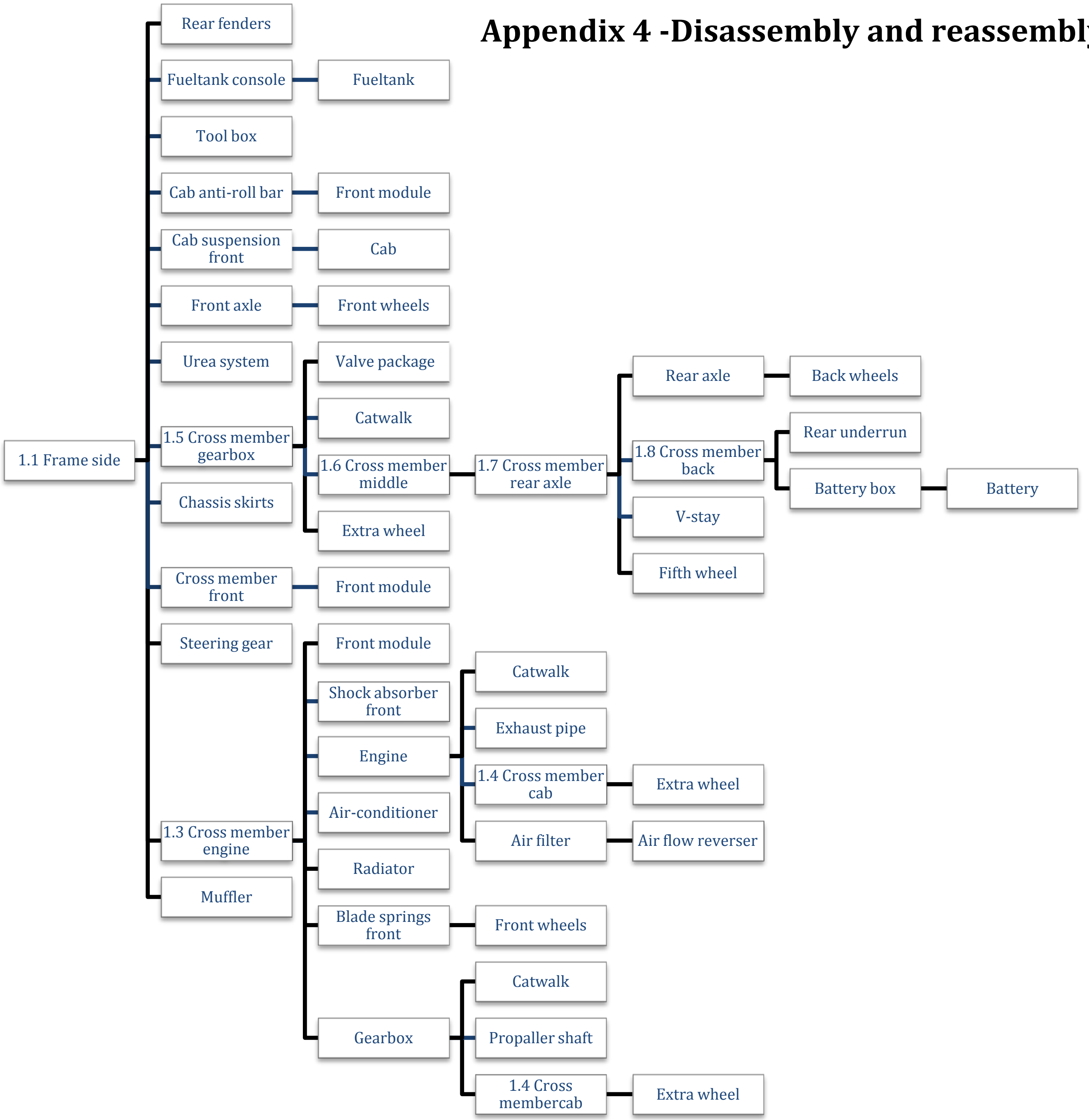
- How do you plan the work at the adjustment station?

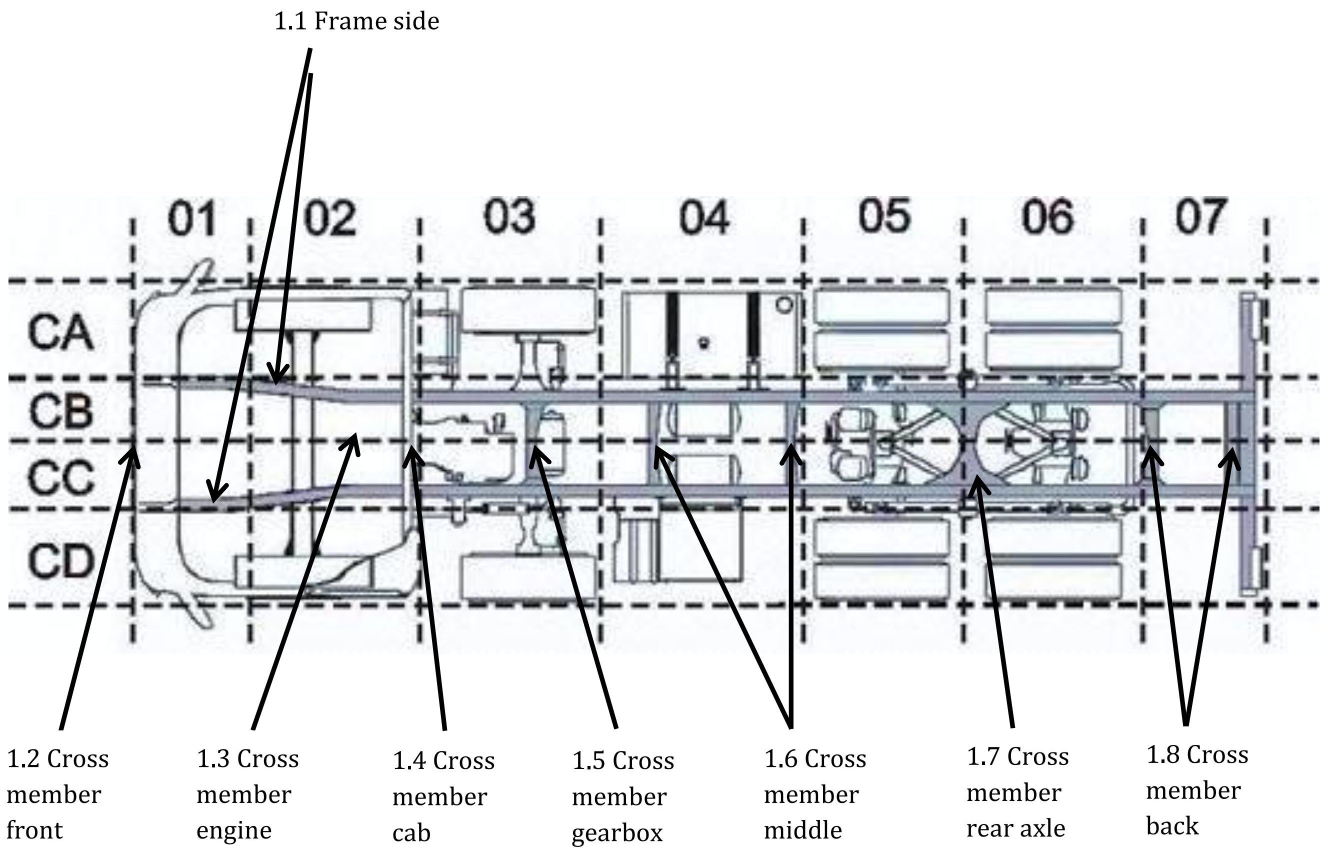
- Do the operators get any special education related to the adjustment operations? Do you have any work instructions?

Appendix 3 –Chosen main parts



Appendix 4 -Disassembly and reassembly tree diagram




1.1 Frame side
01
02
03
04
05
06
07
CA
CB
CC
CD
1.2 Cross member front
1.3 Cross member engine
1.4 Cross member cab
1.5 Cross member gearbox
1.6 Cross member middle
1.7 Cross member rear axle
1.8 Cross member back

Appendix 5 –FMEA

Probability	Frequency	Grade
Very high	1 of 10	5
	1 of 10-25	5
	1 of 25-50	5
High	1 of 50-100	5
	1 of 100-250	4
Medium	1 of 250-500	4
	1 of 500-1000	3
Low	1 of 1000-2500	2
	1 of 2500-5000	1
Very low	1 of 5000-10000	1

Severity	Consequence	Grade
Small	<10	1
	11-20	2
	21-40	3
Medium	41-80	3
	81-160	4
	161-320	4
Big	321-640	5
	641-1280	5
	1281-2560	5
Huge	>2561	5

Detection	Propability of detection	Grade
Very high	100-90%	5
	90-80%	5
	80-70%	5
High	70-60%	5
	60-50%	4
Medium	50-40%	4
	40-30%	3
Low	30-20%	2
	20-10%	2
Very low	10-0%	1

Problem part	Probability facor (P)	Severity factor (S)	Detection factor (D)	Risk level (P*S*D)
Part A	4	5	5	100
Part B	4	4	5	80
Part C	4	4	5	80
Part D	4	4	5	80
Part E	4	4	5	80
Part F	4	5	4	80
Part G	2	5	4	40
Part H	2	3	5	30
Part I	5	1	5	25
Part J	5	1	5	25
Part K	5	1	5	25
Part L	4	1	5	20
Part M	4	1	5	20
Part N	4	1	5	20
Part O	5	1	4	20
Part P	4	5	1	20
Part Q	1	4	4	16
Part R	4	1	3	12
Part S	4	1	3	12
Part T	4	1	3	12
Part U	3	4	1	12
Part V	2	1	5	10
Part W	2	1	5	10
Part X	1	5	2	10
Part Y	3	1	3	9
Part Z	3	1	3	9
Part 1	3	1	3	9
Part 2	3	3	1	9
Part 3	4	1	2	8
Part 4	4	1	2	8
Part 5	4	1	2	8
Part 6	4	1	2	8
Part 7	2	1	4	8
Part 8	1	1	5	5
Part 9	1	5	1	5
Part 10	1	1	5	5
Part 11	2	1	2	4
Part 12	2	1	2	4
Part 13	1	4	1	4
Part 14	1	4	1	4
Part 15	1	2	1	2
Part 16	1	1	1	1

Appendix 6 –Cost calculation model of a certain type of deviation