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Adjustment costs related to assembly complexity and ergonomics

A research project at Volvo Trucks, Göteborg, Sweden

Master of Science Thesis in the Master Degree Programme, Production Engineering

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Abstract

Strong relationships between production related ergonomics and quality outcome have been shown in a number of studies of assembly production. Poor ergonomic conditions cause more quality errors and thereby increased costs for adjusting assembly quality, but a relatively unexplored area of study in manual assembly production is quality cost related to assembly complexity.

This is a project considering the relationship between costs for quality losses to production related ergonomics and assembly complexity carried out at Volvo Trucks in Tuve, Sweden. It is a continuation and development of an earlier study at Volvo Trucks concerning the relationship between production related ergonomics and quality outcome. The study concluded there was a strong connection between ergonomics and quality outcome which also showed a positive relationship for the costs of correcting errors. The result showed that the number of quality errors and related costs for correcting the errors was multiplied for work tasks with poor ergonomic conditions.

This report will demonstrate the costs for correcting quality errors related to ergonomics and complexity and improve the conditions for improvement work. The current procedure for motivating improvement investments economically includes a calculation of saved expenses, which is performed by presenting costs for sick leave and social expenses. It is more preferable to present expenses in terms of quality and productivity losses as motivation for the investment. In the present situation at the company, the conditions for making such calculations need to be improved because the necessary data is not always measured or is complicated to obtain and to combine with other data.

In order to improve the situation and clarify the expenses a study was performed at Volvo Trucks on at a limited section of the assembly line. Measurements needed to improve the conditions for motivating improvements was elaborated. The result in this report confirmed the relationship between production-related ergonomics and complexity to costs for quality losses and showed an increase of the costs for assembly tasks with poor conditions related to ergonomics and complexity.

The purpose with the result of this report is to increase the awareness of the expenses affected by ergonomics and complexity and create knowledge in this field of expertise. Recommendations are given to Volvo Trucks regarding improvements of the situation in the field of ergonomics and complexity including future recommendations. The results and recommendations of this report will guide Volvo Trucks in their effort to improve work in the field of production related ergonomics and assembly complexity.

Keywords: Ergonomics, assembly complexity, quality, manual assembly, adjustment cost

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The group leaders, Andon and assembly personnel at section 2 of assembly line 21 at Volvo Trucks

Terminology

Assembly instruction - The assembly Instruction of an assembly task contains information regarding the assembly e.g. document, drawings, pictures and time studies of the work task. It also contains comments regarding how the assembly is to be performed.

Andon – A function originating from Toyota Production System working with assistance and adjustments at the assembly line.

Balance – The assembly tasks at the assembly line for one assembler.

Balance time study – The assembly time calculated according to standardized values of time consumption of the assembly tasks.

Blocked – If a truck is labeled *blocked* it indicates that an error of truck may cause severe consequences for a vital function and the truck is forbidden to be started.

Core instruction - The core instruction contains material information such as component number and variant combination.

Component – A truck is made out of components**.**

EMD – Ergonomics Mapping Device. The current system for storage of data related to ergonomics.

Green OK – The truck is ready to be delivered to customer.

Group leader – The team leader of a team at the assembly line.

Heavy adjustment department - Department for adjusting quality deficiencies in the after-line process.

K-zon – Quality Inspection Zone. At the end of each section of the assembly line there is a *k-zon* where a quality inspection of every truck is made.

Part section – A part of a section on the assembly line.

QULIS – Quality Information system. The system for managing quality deficiencies.

SARA – Samlad riskbedömning arbetsplatser. In this project only the ergonomics assessment tool will be used in SARA

Section – The assembly line at Volvo Truck is divided into different sections.

SPRINT – Integrated Production System. IT system containing information regarding all assembly tasks.

Station – A station consists of a group of assembly balances.

Team – Every section of the assembly line is divided into two teams.

Variant combination – The combination of functions the truck is composed of.

Table of contents

1. Introduction

This chapter will describe the background. Thereafter the problem definition, purpose and goals will be stated. Delimitations of the project will conclude the chapter.

1.1. Background

Production related ergonomics is often connected to consequences of work related injuries and social expenses. But the consequences are far more widespread as earlier studies have proven. A study at Volvo Trucks (Almgren J. & Schaurig C., 2012) shows the relationship between production conditions related to ergonomics and product quality. The result shows that poor conditions related to ergonomics affect the product quality in a negative way. This relationship puts production ergonomics in a new financial context.

In the present situation at Volvo Trucks the procedure for investing in more expensive improvements includes a calculation of saved expenses and payback time. Investments in the area of production related ergonomics presents expenses in terms of sick leave and social costs, but it would be preferable to show the importance of ergonomics by including quality and productivity as a motivation for the improvement investment.

1.2. Problem definition

The importance of production related ergonomics and assembly complexity in a financial context needs to be communicated. How these aspects affect the costs need to be formulated in new ways in order to be able to motivate investments for improvement.

Performing the calculations in the present situation is complicated. In order to be able to measure the total costs of the production ergonomics and assembly complexity related to quality losses the required information and the necessary data needs to be available and easily obtained.

In a previous study at Volvo Trucks the result shows a clear relationship between conditions related to ergonomics and the output of assembly quality has been shown. This means the adjustment costs for quality deficiencies will increase if the conditions related to ergonomics get worse. The total cost for correction of quality errors is in need of complementation and clarification.

The methods and tools used to measure the costs for adjustments are inadequate. In order to be able to measure the total costs the quality tracking system and tools must be developed in order to obtain the necessary calculation data.

1.3. Purpose and goals

The result of this study is expected to present a clarification of the costs related to production ergonomics and assembly complexity through quality losses. This clarification of costs related to production ergonomics and assembly complexity is essential for the formation of recommendations.

- Explain the economic aspects with focus on quality losses related to production related ergonomics and assembly complexity, with the help of existing databases and work templates.

- Find and show relevant measurements for the design and development of Volvo Trucks' data systems, in order to demonstrate deficiencies and to facilitate improvement suggestions in the field of production related ergonomics and assembly complexity.

- Make recommendations regarding Volvo Trucks' further research and plan of action in the field of production related ergonomics and assembly complexity.

1.4. Delimitations

Delimitations have been made to focus and clarify the boundaries of the project.

- No consideration will be taken to the after-market for finished and delivered products.

- This project will not provide improvement suggestion for the tools used in the study, for example the tools used for assessing the ergonomic and complexity conditions. Their effect on the result will only be discussed.

- No consideration will be taken to work-related injuries and social expenses.

1.5. Outline of the report

This report demands a certain amount of prerequisites and introductory information to fully understand the outcome of the project. Some chapters are of less importance if you, the reader possess deeper knowledge in areas of interest, such as the Volvo Trucks company, chapter 3 *Introduction to Volvo Trucks* and chapter 4 *Precondition for the project* is of less importance. If the reader has knowledge concerning production ergonomics and assembly complexity, chapter 2.4 *Assembly complexity* and chapter 2.5 *Ergonomics* can be skipped.

If the reader wants the essence of the report such as a Volvo truck employee, the focus should be on chapters 6 *Result*, 7 *Analysis*, 8 *Discussion* and 9 *Recommendations*.

2. Theory

The following section will present procedures and techniques used in the project along with the theoretical background for the project.

2.1. Process modelling

The process modelling process is a recognised method for structuring and organising work procedure. It focuses the efforts to strive in the right direction. As the model will be the overarching guide of the project it is important how the model is prepared and presented. Curtis et al. (1992) states that ``the perspectives that a process model is able to present are bounded by the constructs of the language used for modelling''. In a production oriented project the connection between technology and human is evident and the model needs to address these activities and visualise it in a consistent manner (Biazzo, 2002).

The presented model needs to be on a suitable information level for its purpose. This can be difficult for large projects which spans from general to detailed information. It also cannot be too complex in its interpretation as it can make the user to take incorrect decision. A well-balanced model will ensure the success of the project.

2.2. Sample study

Information from different sources has been collected in this project including through the use of interview as stated earlier. Skoogh & Johansson (2008) present methods to collect data manually. One is the use of interviews with selected people as stated earlier. Another is a recording process through a sample study which was conducted. A sample study is an empirical process. It enables collection relevant information which is processed to get a thorough understanding of the situation. Robson et al., (2001) describes sample study as the people, work groups or workplaces chosen from the area it intends to investigate. This helps to unveil complex connections and relations of the whole organisation.

Criteria and other demands presented later in the report have been of great use and a requirement when sorting data for the final analysis.

2.3. Interviews

A major part of the information gathering in this project was made through interviews. The interviewees range from production mangers to shop floor personnel at different departments. Zikmund (2000) states when the purpose of an interview is of exploratory nature, some formal questions can be prepared but most of the interview could be an informal discussion as it purpose is to investigate a problem area. It is important in a discovering phase not to direct the interview as this can result in important information being lost. Because of this unstructured and semi-structured interview techniques have been used in this project.

Thus, unstructured interviews can more be seen as a discussion where little or no planning in advance has been made more than the purpose of the meeting. This method was used mainly in the initial phase of the project to learn and understand all functions and processes.

Later on semi-structured interviews was carried out. Questions were prepared in advance which the interviewees were allowed to deviate from. The goal in this phase was initially to have open questions to make sure no important information was lost in the process. More specific questionnaires where later used. Question templates in this project can be found in appendix I.

2.4. Assembly complexity

High level of customization and product variety is today crucial for a company’s competitiveness. As an effect of this, assembly production systems must be designed to be adaptable to the variety of customer needs and at the same time achieve a high system performance in terms of quantity, quality and productivity (Falck et al. 2012a). This, in turn, results in a more complex manufacturing environment when the number of product variants is high, which may affect the system performance (ElMaraghy et al. 2010). Other aspects to be included in the concept of complexity are e.g. assembly instructions, direct feedback of the assembly, experience and competence of the assembler and accessibility and visibility of the assembly operation. The complexity of the assembly operation also considers the mounting position, fitting and self-evidence of the operation. (Falck et al. 2012a).

2.4.1. Assembly complexity: connection to quality and costs

In a study by Hu et al. (2008) it was found that assembly complexity may cause quality deficiencies and have effect on the performance of the manufacturing system. This relationship was confirmed in a study by Sarkis (1997) where the results showed that more efficient assembly systems had a lower level of assembly complexity. It also showed that with an increased level of assembly complexity the productivity indicators decrease.

Assessing the complexity of assembly processes supports assembly-oriented product design and guides product developers in designing low assembly complexity products. Assembly complexity taken into consideration supports production systems developers to rationalise the selection of the most suitable manufacturing processes (ElMaraghy et al. 2010).

For future research and for present assembly systems, complexity is a core challenge for manufacturing companies (ElMaraghy et al. 2010). Falck et al. (2012a) conclude that complex assembly tasks result in higher action costs than less complex assembly tasks. The financial significance of manufacturing processes often results in extensive efforts to increase the performance of assembly operations. A means to accomplish this is improving the situation of assembly complexity and its causes (ElMaraghy et al. 2010).

2.5. Ergonomics

The area of ergonomics concerns a broad span of disciplines. Physical ergonomics considers the physical work environment and work load. It is about how postures, movements, physical stress and other conditions affect the human body thorough muscles and joints. This includes the design of work premises, workplaces, work items, and tools (Arbetsmiljöverket, 2007:6).

Ergonomisällskapet i Sverige (The Ergonomics association in Sweden), ESS, defines ergonomics as:

"Ergonomics is an interdisciplinary research and application area, which treats the interaction between man-technology-organization with a holistic approach in order to optimize health, well-being and performance in the design of products and systems." (Arbetsmiljöverket)

Arbetsmiljöverket (Swedish National Board of Occupational Safety and Health) provides guidelines for the design of the work place and the work environment. It is stated definitions for the time, weight and postures for body work, repetitive work, and the responsibility of the employer and the employee for example. Guidelines for heavy and repetitive work are stated below.

Physically heavy work is often characterized by manual lifting, but can also mean other work that is physically demanding and where the whole body is involved during a longer period of time. This may imply work tasks that bring the employee to apply considerable physical force, such as using hand-held machines or other heavy equipment. Physically heavy and exhausting work tasks are affected by factors such as prolonged strenuous postures (Arbetsmiljöverket, 2005:1).

To constantly repeat the same movements result in a constant and uniform load on the human body. Characteristic of repetitive work is to perform one or a few work tasks with similar movements that are repeated over and over again for a substantial part of the working day. The endurance of a work task is usually very short and often represents only a small and limited portion of an entire workflow. Moreover, it is often performed at a high tempo (Arbetsmiljöverket, 2003:4).

2.5.1. Ergonomics: connection to quality and costs

A number of studies confirm the relationship between product quality and physical ergonomics, for example a study by Lin et al. (2001) at a camera producing company with line-based manual assembly. It was shown that quality could be directly related to two variables related to ergonomics: time-pressure and postural stress.

Another study that confirmed this relationship is a study by Falck et al. (2010) where the relationship is further extended to also include the connection of ergonomics and quality to action costs. The study was conducted at a car manufacturer and the result showed significantly fewer errors related to ergonomics with low load assemblies than medium or high load assemblies. This, in turn, affected the costs for correction of quality errors, the costs were multiplied several times for high and medium load assemblies respectively compared to low load assemblies.

3. Introduction to Volvo Trucks

The following chapter is an introduction the company of Volvo Trucks in Tuve, Sweden. The presented information is relevant for the comprehension of the project and its goals.

Volvo Trucks is one of the world leading manufacturers of heavy duty trucks. Already in 1928 the first Volvo truck rolled of the production line, but not until 1982 the production started in Tuve (Volvo Trucks, 2013). It is a company with a retail strategy of high customisation which puts high demands on the production lines. The product variety causes big time variations in production and balancing the production is therefore difficult, which has resulted in a long tact time.

The three core values of Volvo Group express the commitment of the company to quality environmental care and safety. Together they are part of forming the common base for the company culture. Customer focus is of great importance to Volvo Group and the needs and expectations of the customer make the core values an important aspect of the products and services. Volvo Group describes that the ambition for high quality, safety and environmental care is present throughout the entire chain of operations, from product development to production and delivery of the finished product. The aim of Volvo Group is to improve energy efficiency and safety, reduce the risk of accidents and produce reliable products and services with a high level of customer satisfaction (Volvo Group, 2009).

3.1. The assembly lines

At the factory in Tuve there are two parallel assembly lines. Each assembly line is divided in different sections which in turn are divided in workstations where the assembly takes place. There are many similarities between the two lines in regards of work procedures and work organisation. For this project a section part was chosen to make the scope of this study temporally manageable. A detailed description of the chosen area of study is presented in chapter 4 *Precondition for the project.*

3.1.1. Line set-up

The line where the study was performed is divided into six sections and at each section different assembly work is done starting with the two steel frames which make up the base for the chassi of the truck and at section six wheels are mounted before the truck gets to end of line. Each section is divided in different stations which in turn consist of one to six workstations that form balances.

Volvo Trucks can produce a great number of truck variations and offers their costumers a high level of customization. But this also causes difficulties in balancing production. For these reasons the tact time has been chosen to deal with these variations. It is long enough to allow the workers to have recover time when a truck with a short assembly time is produced.

Every section is divided between two work teams and within these teams work rotation is applied to further vary the work situation. Each team has a group leader. This role consists of leading the group, informing about changes and giving feedback on past work. The group leader also reliefs assemblers or helps out when needed.

3.1.2. Work instructions and SPRINT system

At every balance there is a binder containing the instructions of the assembly work tasks. The work tasks are sorted according to the production schedule and each day new instructions are printed and delivered to the balances.

The IT system called SPRINT (Integrated Production System) contains information regarding all assembly tasks. It is built-up as a tree structure where the branches represent the process. The factory is branched to the lines, which is further divided into stations and balances. Under each balance heading are all core instructions and assembly Instructions found. Core instruction contains information about the material needed for the assembly. The assembly Instruction has information regarding the assembly e.g. document, drawings, pictures and time studies of the work task. It also contains comments regarding how the assembly is supposed to be performed.

3.1.3. Product variation

Every truck is composed according to a variant combination where each variant of a function of the truck is specified. In other words the variant combination is what makes a specific truck in terms of component variant, for example there are many different air tanks to choose from, the customer need to choose one based on what they need. This means almost every truck is unique which makes it really hard to categorize the trucks into variants or models.

When a customer buys a truck it can be specified to a great extent to the customers' needs. There are many options of the variant combination and the options are often connected through construction rules for the truck. This means the customer makes choices based upon what is important for the application of the truck and the rest of the variant combination follows with that decision.

In case the customer has special needs that violate the construction rules the truck gets customer adaptation where all the needs of the customer fit the construction. These trucks are an important income to the company but are not desirable since it is something additional to the usual production. This increases the risk of production disruptions.

3.1.4. Scrapped material

Along the assembly line there are boxes placed for scrapped material. When an item is discarded as scrap an assembler puts it in one of the boxes along with a small note card which describes the item and why it was discarded. The boxes are handled by the scrapped material department. When the scrapped material has been collected by the department it is registered in the quality system and an order for a new component is made if it is not in stock.

3.2. Quality functions

One of Volvo Trucks core values and maybe the most important is quality, which puts high demands on the company's end products. With such a focus, quality issues are always current at the company.

Volvo Trucks has a system called QULIS (Quality Information System) which is global system for registering quality errors during the production. With every truck follows a protocol through the entire production process. It is an adjustment protocol where all discovered quality errors are noted by assemblers and other accredited persons.

At the end of every section of the assembly lines there is a *k-zon* (Quality inspection zone) where a routine control of every truck is preformed according to a predefined protocol. Errors noted on the adjustment protocol following the truck, both adjusted and not yet adjusted are registered in QULIS along with errors discovered during the routine control. This means errors are discovered and corrected as the truck moves along the assembly line and the goal is to have no errors left at the end of the line.

When an error is registered into QULIS the information and circumstances regarding the error is logged as well. QULIS has been one of the main sources for this project when searching for errors. The information which can be found in QULIS is extensive and many different search options are available.

3.3. Procedures to adjust quality losses after end of line

The general procedure is to build the truck and correct as many errors as possible before the truck leaves the production line. If there was no time to correct the error or if there was a shortage of material, the truck will still continue to the end of line with the error built-in. At the end of line the trucks run by own power to the next processes.

3.3.1. Section 7 and 8

After end of line the trucks continue to section 7 and later to section 8 where a series of after line processes will be performed. Since all trucks pass these sections they can be considered as an extension of the existing line. Here adjustments workers have the opportunity to make further adjustments.

At section 8 axle control, minor defects correction, minor painting jobs and drying is done. A final inspection is made to ensure the function of the truck and it is labelled green OK, which means the truck is ready for delivery to the customer. But if a truck still has errors, it will continue to the heavy adjustment department.

3.3.2. Heavy adjustments

As mentioned, if there still are errors after section 8 which could not be corrected the truck is taken to the heavy adjustment department. At truck can also be taken directly to the heavy adjustment department if a serious error is discovered on the production line. If the error causes severe consequences for a vital function of the truck, the truck will be labelled *blocked*, which means the truck is forbidden to drive by own power and a forklift will tow the truck to the heavy adjustment department. The truck will still be fully assembled with the serious error built in and not until the end of the line at section 6 it will be towed away.

When the truck is taken to the heavy adjustment department it is parked outside the department due to the high number of trucks in need of adjustment. The order in which the trucks are to be adjusted are arranged and sorted by their delivery date. The heavy adjustment department keeps basically no record of performed adjustments or how long they took to correct. Hence, finding data and trace errors back to its origin has been proven difficult.

3.3.3. Andon

Andon is a function which comes from the Toyota production system which Volvo Trucks has adopted and incorporated into their production. This function is an assembler working fluently over the stations and balances. There is at least one Andon on every section on the line. The main work tasks are; to replace assembly workers working on a balance when this is required and assist an assembly worker who has problems or time shortage. Andon is also responsible for adjusting errors discovered in the own section and errors which has been discovered in sections further ahead on the assembly line which originate from the own section.

When an error is discovered by an assembler in another section later on the line, the assembler adjusts the error if it is possible and registers the error in QULIS. If the error is not possible to adjust, for example there is no time or there are not the correct tools and material available, the group leader of the section is alerted. He will note the error and contact the Andon of the section where the error first occurred to adjust the error. If it is not possible for Andon to adjust the error, the line is stopped until the error is corrected or the truck will continue on the line and the error will be adjusted in the after line processes. Occasionally the truck is taken off the production line, this decision is based on the nature of the error.

3.4. Work-related ergonomics at Volvo Trucks

Volvo Trucks has developed a storage called EMD (Ergonomics Mapping Device) to visualize the situation related to ergonomics in the factory. EMD is a compiled list of evaluated balances. The actual ergonomics evaluations are based on recommendations from The Swedish Work Environment Authority and Volvo Trucks own standards (Volvo Standard, 2009). The ergonomics evaluation are supposed to be performed by engineers, educated assemblers and group leaders on the line but the evaluations are perceived as inconvenient, subjective and ambiguous and therefore has so far mainly an ergonomist performed the evaluations.

In later time a work environment evaluation tool has been developed called SARA (Samlad Riskbedömning Arbetsplatser) which consists of and addresses many different parts such as ergonomics and work environment issues. In this project only the part of SARA related to ergonomics will be considered. SARA has been adapted to Volvo's standards and hence only considers physical ergonomics.

As for now the ergonomics assessment tool is used only at a limited extent in terms of a pilot project. Since the assessment tool will be used this project, the resulting work has become a part of the pilot project. Later on, a decision will be made if the tool is going to be implemented in the entire production plant as one of Volvo Trucks tools. SARA is meant to be a tool for performing the ergonomics evaluations. With education in the area the group leaders and assembly line workers are intended to be able to do the evaluations, which will bring a greater understanding of the work with ergonomics, what the source of poor conditions related to ergonomics are and how to improve the situation. Hopefully this will result in an increased initiative from the production and that the work with ergonomics improvement is eased to be made continuously and constitute a part of the daily work.

A development of the pilot project will eventually result in an extensive mapping of the conditions related to ergonomics of the assembly tasks (or balances) in the production plant. A mapping of the conditions related to ergonomics in the production plant will help to know where the problem areas are and direct the improvement work to where it is most needed.

3.4.1. Improvement investments

For investments with goals related to ergonomics, the company ergonomist performs a calculation of absence due to illness expectancy after the eventual investment, which is compared to a calculation of absence due to illness expectancy in the current state. No calculations are currently performed regarding quality and productivity losses caused by poor production conditions when applying for resources for investments with an aim related to ergonomics.

Changes to the product, redesign of a component or changing the way of assembly to make it better takes a long time to implement. The production engineers use a feedback system to the product development department to report necessary changes in the product design. Changes to the product design are expensive due to redrawing of the product drawings and required change of the production by the supplier. This results in a difficulty to economically motivate investments in the product design area.

4. Precondition for the project

A prerequisite for this project was to make it manageable and focused. A part of the production line was chosen to be examined as a case study. This was considered essential to be able to perform the stated goals to find adjustment costs and relate these to the ergonomics perspectives and to find relevant measurements of importance. The information gathered from this section part constitutes the base for the project and its result. Thus, station 7, 8 and 9 at section 2 was chosen for analysis.

Section 2 was carefully chosen in consensus with all involved people. It needed to be a part of the line where the assembly personnel were willing and interested in issues related to ergonomics and were able to dispense time and recourses. This section part was also chosen because there were no major process changes during this time period which could interfere or disturb the project.

Another important condition was the registration procedure in the quality system QULIS. At this section errors logged in QULIS are logged on specific balance level compared to other sections of the assembly line where the errors are logged to the section. This was very important since sorting thousands of errors by hand and connecting them to the corresponding balance would be very time consuming. Still, large amounts of errors needed to be sorted but through this choice the sorting was reduced. Finally the choice was approved by the production manager and the study could be carried out.

Altogether. section 2 is made up by station 7 to 13 and at station 13 is also the quality control, *K-zon* which is described in chapter 3.2 *Quality functions*. The section is divided into two work teams, team 1 which includes station 7, 8 and 9 and team 2 which includes station 10, 11, 12 and 13. In figure 1 the balances at this section part are shown in detail and underneath follows a description of the stations and the balances.

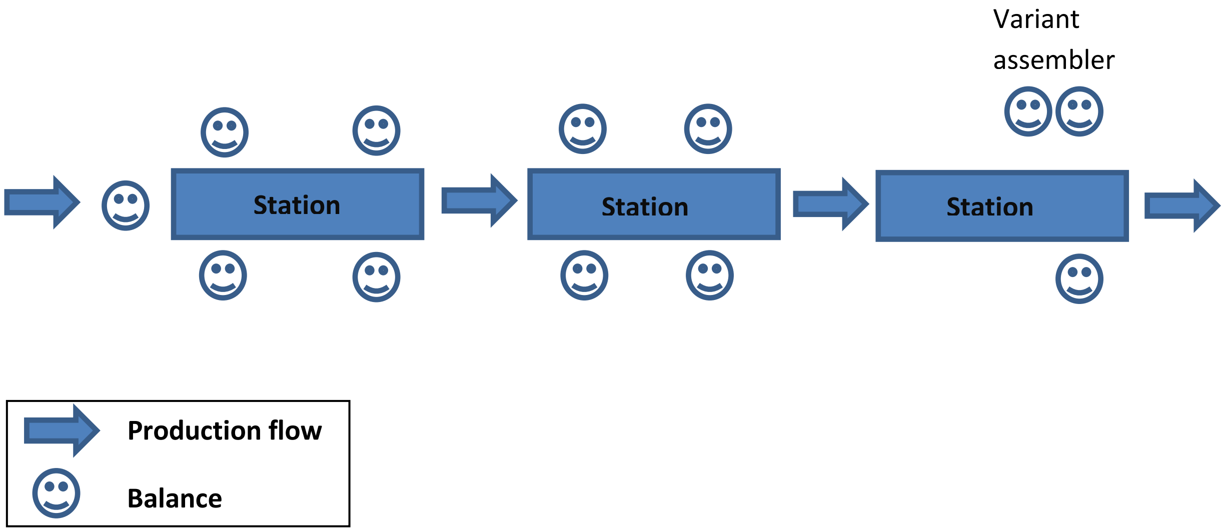


Figure 1: Visualisation of the chosen section part

Station 7:

This station consists of five balances. The mounting includes components such as shock absorbing brackets, air tanks and rods.

For the air tanks there is a lifting tool to aid the assemblers. This is however rarely used because the assemblers need to change the tool adapter to fit to the correct tank variant. There are six different tool adapters for the air tank variants some of which are quite heavy. The usual procedure is to lift the air tank by hand and mount it. This is not good from ergonomics point of view.

Station 8:

Station 8 has four balances and the work consists of mounting different nipples and valve brackets, mounting profiles and tightening the screws.

In this line section there is a lot of screw-related work compared to other sections. This will be brought up later on in chapter 6 *Result* as it will represent a category of error types.

Station 9:

Station 9 consists of one balance and two variant assemblers. The assembler at the one balance mounts among other things engine brackets, pumps and bracket for cable protection. The two variant assemblers work includes mounting pipes and pipe coupling for the cooling system. Their work is usually time-consuming. This means when a truck requires their work they start mounting already at station 8 or even station 7.

Half way into the project it became clear the two variant assemblers had to be excluded from the study mainly because there was almost no registered error entries in QULIS but also since they do not work in the same continuous way as the other assemblers. The variant assemblers have a very uneven workload which is very changeable on a daily basis. Their work besides includes a great deal of preparatory work, which is usually not the case for the other assemblers.

5. Method

In order to reach the stated goals in this project a methodology had to be worked out. Below follows a short description of the procedure which was developed in collaboration with the supervisors, Volvo Trucks' managers and engineers. Later, by the aid of a visualisation of the methodology in figure 2 each function is further described in detail step by step.

5.1. Description of procedure

As mentioned in chapter 4 *Precondition for the project*, an area was chosen for a detailed study to accomplish the purpose of this project. The procedure was to collect all errors related to the chosen section part, then interviewing the assembly personnel about how long time it takes to adjust the each unique error. Finally, by using the generalised cost for one assembler in time units calculate the cost to adjust the unique error.

The cost was then connected to production ergonomics and assembly complexity using two assessment tools to see if there was any connection between these factors and the cost of adjusting errors.

This procedure was supposed to clarify the costs related to ergonomics and complexity, and show an example of how the calculations can be performed. This would hopefully provide the possibility to confirm the connection between costs and ergonomics at Volvo Trucks and create a connection between costs and the complexity of the work task. This information can then be used when making investment calculations concerning conditions related to ergonomics and complexity in the plant. This method will make it apparent how easily accessible stored data and information is. In addition, it is likely to reveal what information which is barely or not at all measured or accessible.

This data analysis part together with interviews with different personnel and departments will be used to conduct future recommendations for Volvo Trucks.

5.2. Visualisation of methodology

Figure 2 shows the representation of the project procedure which has its base from the information in chapter 2.1 *Process modelling*. The project starts with creating a knowledge base that together with the gathered data forms the information foundation for the continuation of the project. Here the base for the economic aspects is gathered along with the basic conditions for improvement work. All data and information is then processed and analysed and the assessments of the work tasks are made to form the result and conclusions of the study. In the following sections, the different parts of the project procedure will be described more in detail.

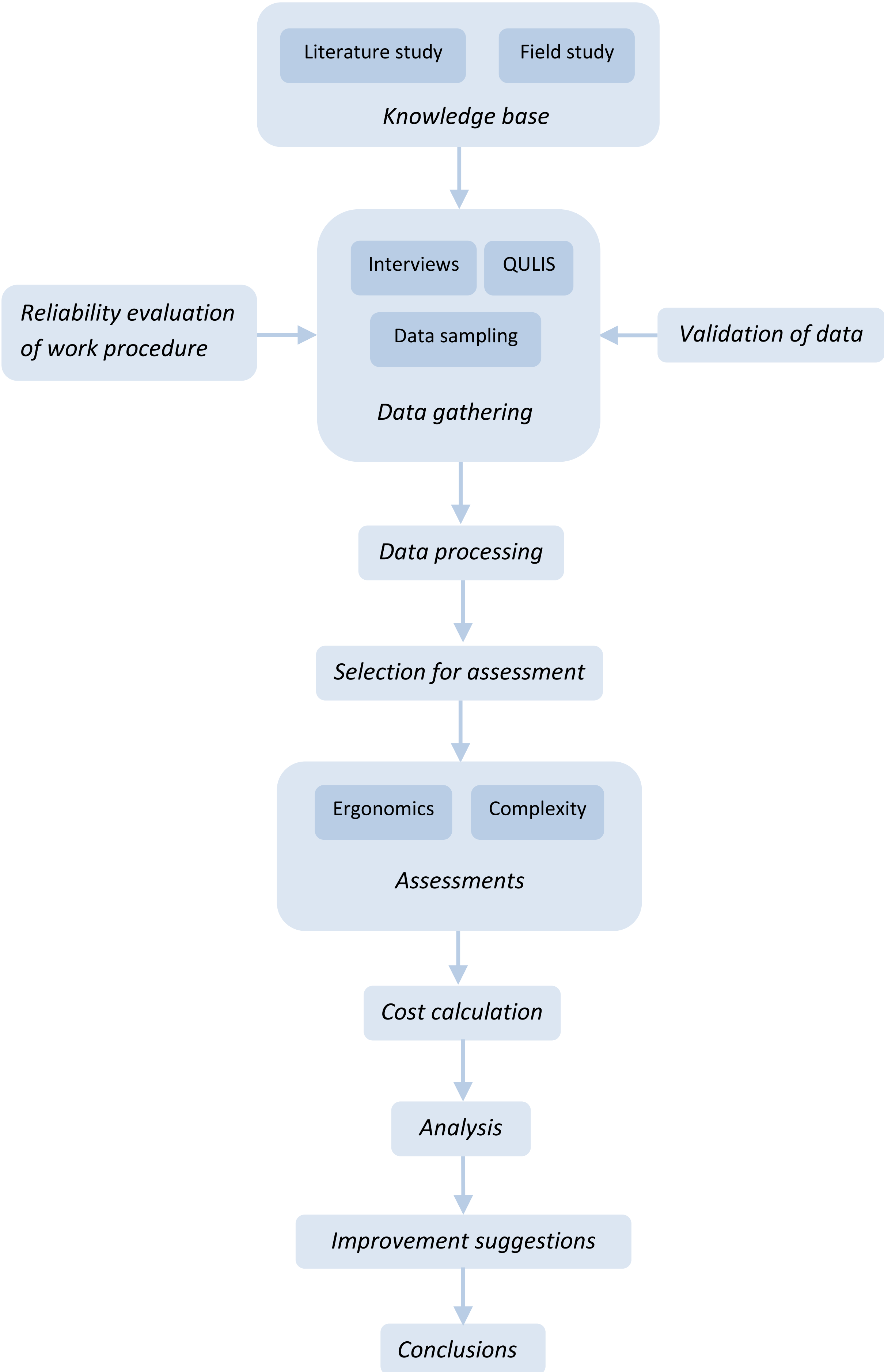


Figure 2: Visualisation of project work procedure

5.3. Knowledge base

The field study at Volvo Trucks and together with the literature study makes up the base of knowledge for this project. The field study was an extensive information gathering regarding the chosen section part of the assembly line. The two most important data variables to collect for this study were specific errors and the time consumption for adjusting them. This study was made during one cohesive week. The hourly cost for an assembler is a fixed number which was collected during interviews with the economic department. For reasons of confidentiality, the exact cost is not disclosed.

The literature study concerned topics of importance to the study such as process modelling and previous studies in the area. Especially the previous masters' thesis examining the area at Volvo Trucks (Almgren J. & Schaurig C., 2012) was considered.

5.4. Data gathering

The parts concerning the data gathering will be described more in detail in the following chapter.

5.4.1. Collecting errors

A data sampling was performed to find the amount and frequency of errors discovered at the section. This was done in order to find the relative amount of errors which does not get registered in QULIS. The amount and frequency of errors discovered *at other parts of the line* but not registered in QULIS was found through interviews with Andon at the section part.

When all errors related to the chosen section part were collected, they were categorized according to error type as follows:

- **Screw related error** – Screws related to the work task has been assembled in an incorrect manner
- **Not performed** – The designated work task as not been performed
- **Wrong component** – The wrong component has been assembled
- **Placed incorrectly** – The component has been assembled in the wrong place
- **Performed incorrectly** – The designated work task as not been performed the correct way

At the studied section screws are frequently used and screw related errors are common, thus a category regarding this error type was created. The category includes errors such as too long or too short screw and undrafted screws. In the case of error type *not performed* the assembler has forgotten to or was not able to perform the work task. It can also be the designated component for assembly was not in stock.

5.4.1.1. Data sampling

To complement the error data registered in QULIS a data sampling was carried out. Through the sampling collection of additional information regarding error frequency and error types were not registered in QULIS could be obtained.

The sampling was carried out at each balance at the studied section of the line during a consecutive period of one week. The number of assembly errors in each group of assembly tasks was counted among with error type and cause of error.

5.4.1.2. Searching for quality data

To specify the search in the quality system, a few parameters and options had to be defined. There parameters were defined as follows:

- *Factory* – Tuve, Gothenburg
- *Assembly line* – Line 21
- *Problem owner* - Section 2 (The studied section of the assembly line)
- *Time period* – 2012 03 12 until 2013 03 11

The options chosen to specify the search are stated below:

- *Fault description* – The fault description normally holds a more precise description of the error.
- *Scrapped material* – In order to see if the error caused any scrapped material.
- *Component number* – A way of connecting errors to a certain work task, but the number was not available in most cases. In case of scrapped material the component number was frequently registered, which is necessary information when finding out the cost for the components trough the economic system.

The time period of the search was foremost set by the time period available in QULIS to find data sorted into balances. This sorting was available for more than one year back in time, but at the beginning of the sorted data period the data was incompletely sorted. This short period of incomplete sorting was removed and the chosen time period was established. The chosen time period seemed as a good choice because it would distinguish periods when occasional errors occurred.

5.4.2. Interviews

One of the most important information which was collected was how long time specific adjustment took and the generalised hourly cost for one assembler. A list of the interviewed functions at Volvo Trucks and the intent of the interviews is stated below:

- **Production engineers and the head of the production engineers**
  These interviews were held to gain knowledge regarding specific information about the production and the systems such as production schedule of specific trucks which was needed for the assessment basis. Information regarding specific work tasks was also collected to some extent.

More general questions were asked regarding how improvement work is done and what the problems when proposing improvement suggestions are. Besides, the interviews were carried out in order to gain an overview of the current ergonomics and complexity situation.

- **The department handling scrapped material**
  When gathering information concerning the handling of scrapped material interviews were conducted. Both information regarding the registration of scrapped material in QULIS and the amount of scrapped material handled was questioned.

  Small object such as screws, washers and bolts are not considered and are instead thrown away in the metal waste bin. Sometimes materials are wrongly put in the waste bin. This is done by accident or because the assembler is not bothered to fill in the scrap note. However the department estimates this loss to be small.

- **The heavy adjustment department**
  The heavy adjustment department takes care of the remaining errors when trucks have left section 8. However, after interviews with this department it was found they are not using the same system for registering adjusted errors as the assembly line. This made it practically impossible to connect specific errors to specific adjustments.

- **Assembly personnel**
  To get an overview of the production assembly personnel was interviewed. Information regarding assembly instructions, registration in QULIS, error types and adjustment procedures was gathered. An overview of the current situation in terms of ergonomics and complexity was gathered. The most important questions asked was however the time consumption for adjusting errors of different types. This information was essential to be able to calculate adjustment costs.

- **Ergonomists**
  Interviews with ergonomists was especially important before and during the performance of the ergonomics and complexity assessment, but also the current situation related to ergonomics in the production plant as a whole.

- **The economy department**
  An overview of the economic systems was asked for. More specific information regarding cost for scrapped material was wanted. The generalised hourly cost for one assembler was collected which is needed to calculate the error costs.

- **The quality department**
  Questions especially regarding QULIS was asked, such as which information is accessible in the system and how to improve the search to reach specific adjustments including the work procedure for registrations and how the system should develop in the future.

5.5. Data processing

Data from the chosen time period was collected from QULIS for both errors registered at the studied section and errors registered at another part of the assembly line. Microsoft Excel was used as the software for processing the data. In the sheet with errors registered at the studied section the data was checked so that it was registered correctly on the right balance where the assembly task is performed. The data registered in QULIS from other parts of the assembly line had to be sorted and registrations not belonging to the studied section were removed.

It was not possible to include all errors in the study due to inconsistencies. The list below describes the rules used to distinguish the errors not to include in the study.

- Errors not possible to connect to a certain assembly task were excluded.
- Errors registered incorrectly.
- Errors not belonging to the assembly task at the studied section part of the line.

Questions were asked frequently regarding different ways of registering errors in the system, in order to sort identical errors together and distinguish non identical errors registered in the same way. All data was sorted in an Excel sheet and when completed it was made up by 79 unique work tasks in total. From these work tasks a further selection for the assessment was made. This process is described in the next chapter.

5.6. Assessing the ergonomics and complexity conditions

The assessments can be performed directly on sight by persons educated in the field of ergonomics and assembly complexity. The work task for assessment can also be filmed and later be evaluated. For this study it was decided to film the work tasks to get most equal conditions for the assessments. The filming and the ergonomics assessment of the work tasks was performed by a certified ergonomist. The complexity assessment was performed by the developer of the method (Falck, 2012) using the same films as assessment documentation. Filming the assembly tasks for assessment has benefits in form of:

- The assembly procedure of the task can be viewed infinite times so that no details are overlooked.
- Filming the work tasks enables a calculation the total amount of time a working position is held or repeated e.g. static posture.
- It is possible to show what has been evaluated.
- The film can be stored for future examination.

When the line section was chosen all work tasks were sorted to their corresponding balance and all error data and adjustment times were collected. Due to the time scope it was not possible to film all the work tasks. This had been more beneficial as it would give a more comprehensive result. Instead a number of criteria were created to sort out the most suitable work tasks for the assessments.

- **Not too few reported errors in QULIS over a year**

To get a consistence in the sample, the errors needed to be fairly in number and be dispersed over the period of time to insure the errors were not temporary occurrences for that time.

- **Avoid misreported errors in QULIS associated with old work instructions**

When new work routines are created articles may be mounted by another assembler. However, this is not always or badly communicated to other units such as the *k-zon* at the end of each section. This means when an error is detected it will be logged to the old assembly balance.

- **A clear connection between SPRINT and errors in QULIS**

The errors in QULIS must be easily traced to the work task in SPRINT to make sure there are no uncertainties which article it is referring to.

- **A good spread of different kind of errors for the work task**

This was done in order to not select any one-sided errors. For example it can be many reports for the same error for an article during a short time period. This implies there was probably a failure by the supplier.

- **The information in SPRINT must be clear to understand and updated**

Some core instruction in SPRINT has been moved or does not longer exist or is badly written. For filming it was vital to know how the work task was supposed to be performed since this was not always known by the assemblers.

- **Choose at least one work task from every balance**

This was done to secure the spread of errors over the section.

When this selection had been made 40 of the original 79 work tasks were chosen. These 40 work tasks will make up the final base for the assessments and the related adjustment cost presented in chapter 6 *Result*.

5.6.1. Ergonomics assessment

The SARA assessment is divided into four sections and consists of work posture, lifting, hand and arm movement and muscle usage. Variables to consider are time, the weight of the relevant component and tool and the number of repetition per hour. Every section is then graded and summed up with the rest of the sections to get the final score. The final score represent a colour which is the ergonomics evaluation. However if one or more of the subsections gets a red sub score, the final outcome will be red regardless of the final total score. The colours represent as follows:

Green: No further analysis is required - low hazards related to ergonomics

Yellow: Begin with improvement work to reduce the number of yellow markings, begin where highest score is reported. More thorough (secondary) analysis may be required by an expert.

Red: Prioritized improvement work
More thorough (secondary) analysis may be required by an expert.

Evaluating the chosen assembly tasks related to ergonomics was made in cooperation with the company ergonomist.

5.6.2. Assembly complexity assessment

To get a more comprehensive result it was decided to also examine the influence of manual assembly complexity. At Volvo Trucks the focus has mainly been on physical ergonomics and not so much on cognitive ergonomics. A study made by Falck, A (2012) indicated the degree of complexity highly affects the assembly quality. This study uses a number of criteria to measure assembly complexity in a convenient way.

The assessment is based on 16 criteria, which have to be answered for every work tasks included in the study. It is a closed questionnaire which has to be answered true or false. The number of fulfilled criteria is summarized and the total score gets a colour grade according to the scale in table 1 which corresponds to the level of complexity. The assessment can also be done in the opposite way where the aim is to measure how low assembly complexity there is.

Criteria for high assembly complexity tasks considered as "tricky and demanding" operations:

1. Many different ways of doing the task
2. Many individual details and part operations
3. Time demanding operations
4. No clear mounting position of components
5. Poor accessibility
6. Hidden operations
7. Poor ergonomics conditions implying risk of harmful impact on operators
8. Operator dependent operations requiring experience/knowledge to be properly done
9. Operations must be done in a certain order
10. Visual inspection of fitting and tolerances, i.e. subjective assessment of the quality results
11. Accuracy/precision demanding
12. Need of adjustment
13. Geometric environment has a lot of variation (tolerances), i.e. level of fitting and adjustment vary between the products
14. Need of clear work instructions
15. Soft and flexible material
16. Lack of (immediate) feedback of properly done work, e.g. a click sound and/or compliance with reference points

Table 1: The complexity levels

Fulfilment of criteria	Degree of complexity	Complexity level
0-3 (0-19%)	Low	Green
4-7 (44-25%)	Rather low	Yellow-green
8-11 (50-69%)	Moderate	Yellow
12-14 (75-88%)	Rather high	Yellow-red
15-16 (94-100%)	High	Red

Some assumptions should to be made to adapt the assessment to the company's processes. These adaptations are a necessity for the performance of the assessments and are formulated to have as small influence of the result as possible.

Conditions for assessment of assembly complexity:

- The assessment should be performed during normal work circumstances and rely on the premade assemble time studies which contains information on how the work task carried out.
- To get a justified and correct result during filming the work tasks should be performed by an experienced assembler.
- It is assumed after an introductory education a newly employed assembler is able to perform the work task.
- If there are any uncertainties when answering the criteria, for example when it is very even between true and false the safest choice should be selected.
- The assessments in this project only consider the individual work task and do not consider the total work cycle at the balance.
- Each work task is treated in the assessment as repetitive work, in other words no work variation or rotation.

5.6.3. The most frequent and most demanding variant of the work task

To give the study an extension aspect the assessment of the assembly tasks was performed on two variants of the task, the most frequent and the most demanding. This was mainly done for Volvo Trucks' behalf as it provides ergonomics foundation both for the pilot project and for the future to improve the ergonomic situation at the factory. In chapter 6 *Result*, only the most frequent variant of the work task was used in the study.

In many cases the most frequent variant was also the most demanding, which gave the two variants the same evaluation. Since Volvo Trucks keep no track of the frequency of performed work task or how common a specific component is mounted it was not possible to obtain this information in an acceptable time frame of the project. The most demanding work tasks can be decided through ergonomics assessment but since there are very few ergonomics assessments performed on specific component variants and by that specific work task variants it was not possible to know this in advance and it would have been impossible to perform the ergonomics assessments of all work task variants within the time frame of the project. The solution was to interview several production engineers, group leaders and assembly line workers and in consensus with them decide which work tasks to examine.

This was done in order to notice the difference in terms of ergonomics and complexity of an assembly task. Currently there is no way of connecting the costs to a specific component that belongs to a core instruction, which implies there could be errors in the result. For a further discussion regarding the influence of the result of this, see chapter 8.3.3 *Most common and most demanding.*

5.7. Required calculations for the result

In this chapter the detailed procedure to calculate the adjustment cost for work tasks in the study will be presented. This is the procedure which makes up the base of the 40 selected work tasks for the result in chapter 6 *Result*.

Each adjusted error was sorted to its specific work task where it was further sorted into the five error types as stated earlier:

- **Screw related errors**
- **Not performed**
- **Wrong component**
- **Placed incorrectly**
- **Performed incorrectly**

Each error type on each of work task was assigned a generalised adjustment time for one error which was gathered through interviews with assembly personnel.

$$total\ number\ of\ errors * adjustment\ time\ (minutes) * \left(\frac{the\ hourly\ cost}{60\ minutes}\right)$$
$$= total\ cost\ for\ screw\ related\ errors\ for\ that\ work\ task$$

This is made as well for the remaining four error types for that specific work task. When this has been done, all adjustment cost for each error type is summarised including any reported scrapped components to get the total adjustment cost for the work task.

This procedure is done for all 40 work tasks which are included in the study. The result can be seen in table 2 in chapter 6 *Result.*

6. Result

The result consists of 40 studied work tasks which were selected with the criteria stated in chapter 5.6 *The assessments*. The work tasks have been evaluated through the complexity and ergonomics assessment and then sorted after the number of errors in descending order. All cost figures are in Swedish crowns (SEK) and the error data corresponds to one year's production in the assessed assembly section. How to perform assessments and how to interpret the colours and score scales is presented in chapter 5.6.1 *Ergonomics assessment* and 5.6.2 *Assembly complexity assessment.*

For the statistical calculations of the correlation and coefficients of determination the program pack from SPSS Statistics were used. The correlation is a measurement to show how well the linear relationship between two variables is. The coefficient of determination (R^2 in the figures) is a measurement to determine how well the model equation explains and predicts future outcomes. The correlation is based on ordinal scales and the analysis of the coefficients of determination has a bivariate base. The definition of significance level is the probability of rejecting the null hypothesis in a statistical test when it is true.

The following table is an abbreviated summary, for the complete list with all error details can be found in appendix II. Pleas view chapter 5.7 *Required calculations for the result* for the calculations used to acquire the resulting table 2.

Table 2: List of studied work tasks

Work task number	Total number of errors for the work task	Total cost for correcting the errors for the work task (SEK)	Complexity outcome	Ergonomics outcome
1	137	3730	9	
2	135	2098	0	
3	122	1725	5	
4	116	2103	6	
5	107	1946	0	
6	106	3319	5	
7	86	4150	11	
8	82	481	3	
9	80	603	4	
10	73	1647	9	
11	73	2052	8	
12	67	621	1	
13	64	1226	3	
14	63	1844	5	
15	62	1277	6	
16	59	522	5	
17	50	157	5	
18	35	5056	9	
19	33	613	4	
20	33	99	3	
21	29	479	7	
22	29	453	1	
23	28	889	3	
24	28	471	1	
25	27	337	4	
26	26	712	3	
27	24	71	5	
28	24	266	3	
29	22	162	4	
30	21	256	4	
31	21	383	1	
32	21	537	1	
33	20	139	4	
34	20	377	3	
35	17	269	7	
36	17	185	0	
37	15	155	1	
38	11	134	4	
39	9	66	5	
40	7	33	4	
Total	**1999**	**41640**		

6.1. Result of the ergonomics assessment

To obtain a comparison the total cost and total number of errors for every colour level was summarized and then divided which results in the cost per error which can be seen in table 3 and 5:

$$\frac{total\ cost\ for\ green\ complexity\ level}{total\ number\ of\ errors\ for\ green\ complexity\ level} = cost\ per\ error\ at\ a\ green\ colour\ level$$

The costs per error for the ergonomics levels are displayed below. These costs have then been compared to the green level by dividing the yellow cost per error with the green cost per error and the same with the red costs.

It shows that errors at the yellow level are on average 1,26 times per year more expensive to adjust compared to errors at a green level. For red errors the costs are on average 1,42 times higher per year.

Table 3: Ergonomics calculations

Ergonomic level	Total cost (SEK)	Number of errors	Cost per error	Comparison to green
Green	22029	1194	18,45	1,00
Yellow	12183	522	23,34	1,26
Red	7428	283	26,25	1,42

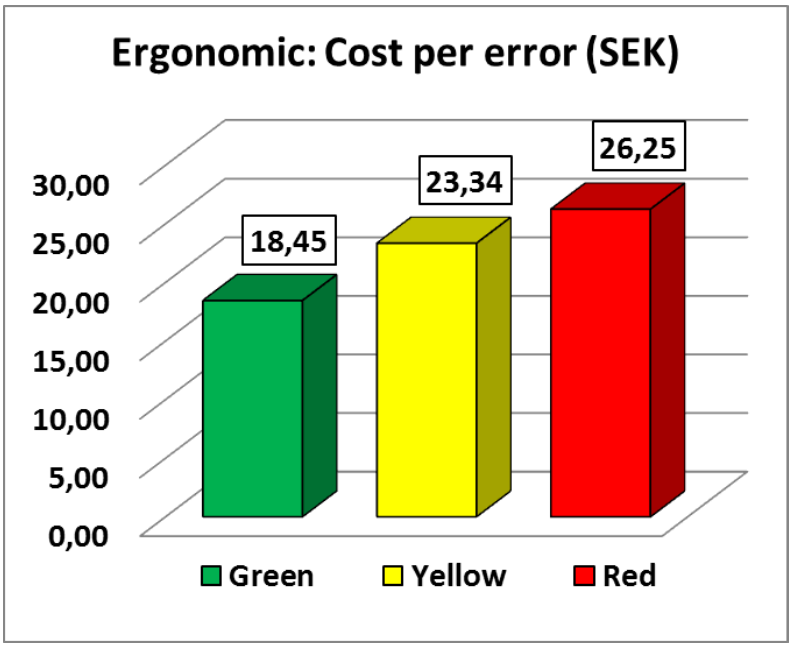


Figure 3: Ergonomics comparison

The ergonomics evaluation can also be displayed as a scatter plot, see figure 4. It shows the individual relationship between costs and ergonomics level for all 40 work tasks. The trend line in the diagram shows a positive direction between the two variables with a correlation of 42 %. The trend line, in other words the linear equation and the coefficient of determination (R^2) is stated in the diagram box. It shows an increase of 826 SEK to correct errors per increased ergonomics load level and year and the coefficient at a level of 18 %. The correlation and the coefficient of determination are statistically reliable with a significance level of less than 1 %.

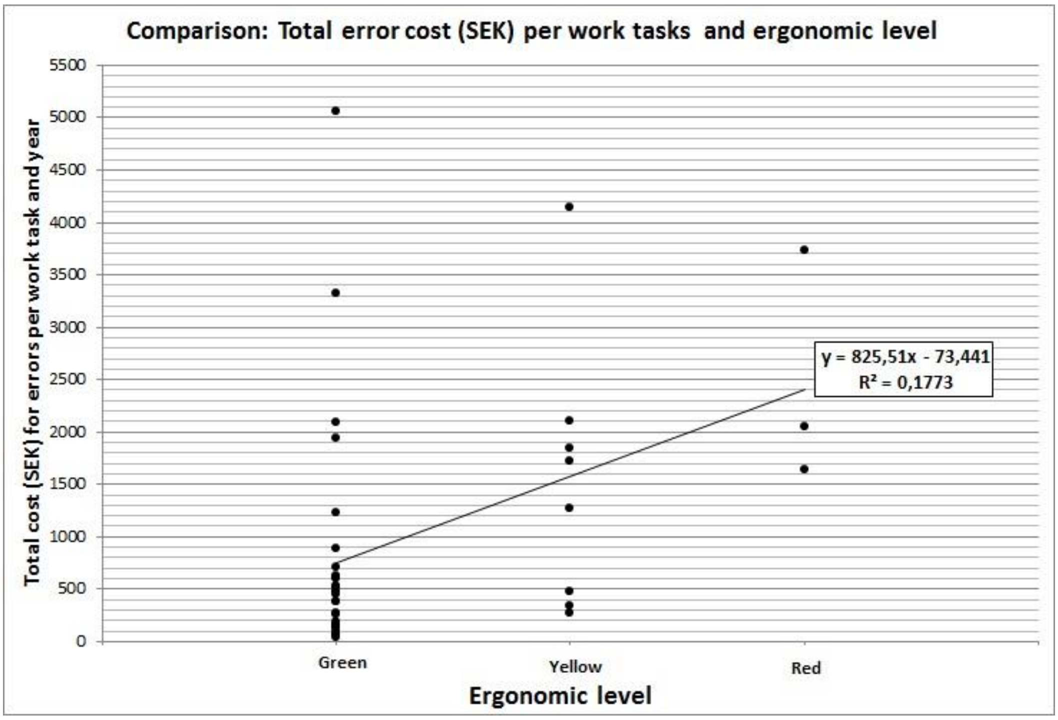
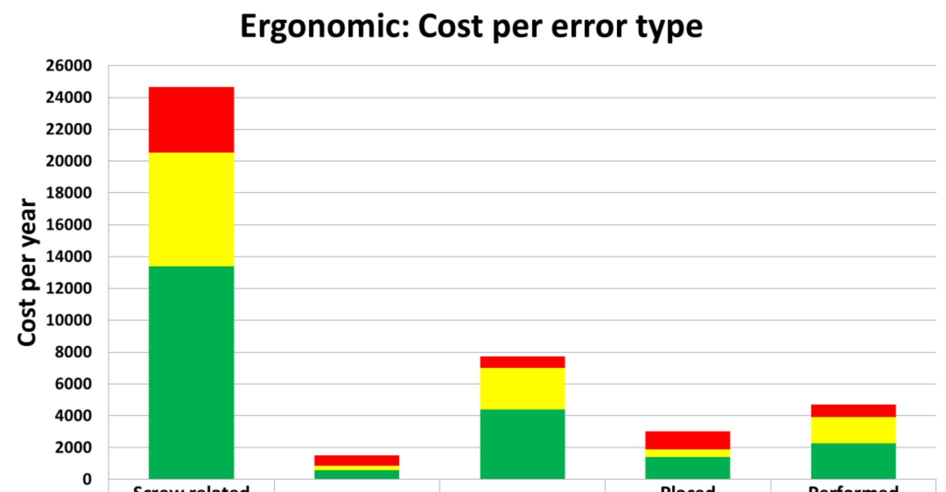


Figure 4: Ergonomics comparison

The following diagram shows the inbound costs distributed on the different error types. It also displays the cost for every ergonomics level. To see the complete list with all errors view Appendix II and for detailed information of the different error types see chapter 5.4.1 *Collecting errors.*



	Screw related errors	Wrong part	Not performed	Placed incorrectly	Performed incorrectly
Red	4125	664	699	1135	806
Yellow	7154	266	2625	502	1637
Green	13383	593	4393	1393	2267

Figure 5: Cost (SEK) per error type

6.2. Result of the complexity assessment

The same procedure for calculating the cost per error as used for ergonomics has been applied to the complexity assessment. Important to note is that the colours and scales are different from those belonging to the ergonomics assessment. Therefore no direct comparison can be done more than the correlation between the assessments which is presented in the next chapter.

The result shows that the highest noted score in the complexity assessment was 11 on the 16 point scale. Hence the highest complexity levels of yellow-red and red are not displayed in the diagrams. As mentioned before the colour levels are:

Table 4: The complexity levels

Fulfilment of criteria	Degree of complexity	Complexity level
0-3 (0-19%)	Low	Green
4-7 (44-25%)	Rather low	Yellow-green
8-11 (50-69%)	Moderate	Yellow
12-14 (75-88%)	Rather high	Yellow-red
15-16 (94-100%)	High	Red

As for the ergonomics assessment to obtain a comparison the total cost and total number of errors for every colour (complexity) level is summarized and divided, e.g.:

$$\frac{total\ cost\ for\ green\ complexity\ level}{total\ number\ of\ errors\ for\ green\ complexity\ level} = cost\ per\ error\ at\ a\ green\ colour\ level$$

The costs per error are displayed below as well as the comparison to green level of complexity. It shows that errors at the green-yellow level are on average 1,06 times more expensive to adjust per year and the yellow level is 2,71 times higher per year compared to the green level.

Table 5: Complexity calculations

Complexity level	Total cost (SEK)	Number of errors	Cost per error	Comparison to green
Green	10898	717	15,20	1
Greenyellow	14108	878	16,07	1,06
Yellow	16633	404	41,17	2,71

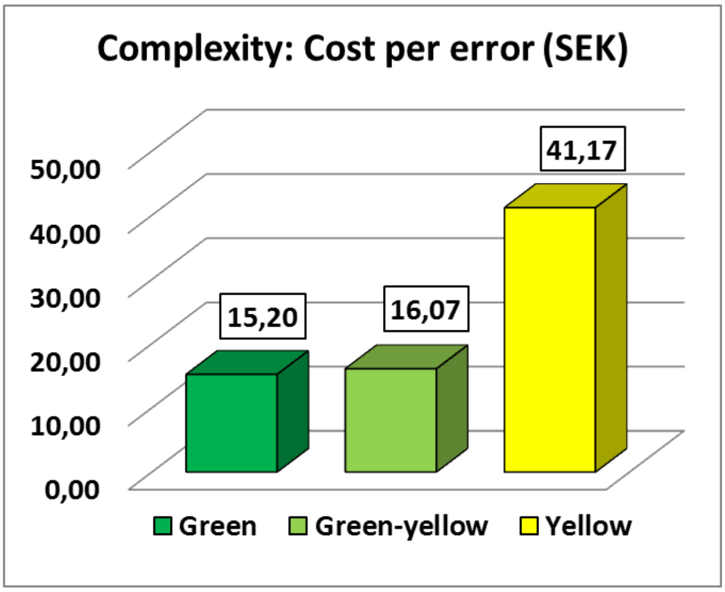


Figure 6: Complexity comparison

The scatter plot for the complexity comparison is shown in figure 7. Here, the x axis shows the complexity level in numeric values according to the 16 complexity criteria. It reveals as well as the ergonomics assessment a positive connection between the costs for adjusting the errors and complexity level.

The trend line shows an increase of 253 SEK to correct errors per increased complexity level per year. The correlation and the coefficient of determination are at a level of 56 and 31 % respectively with a significance level of less than 1 %.

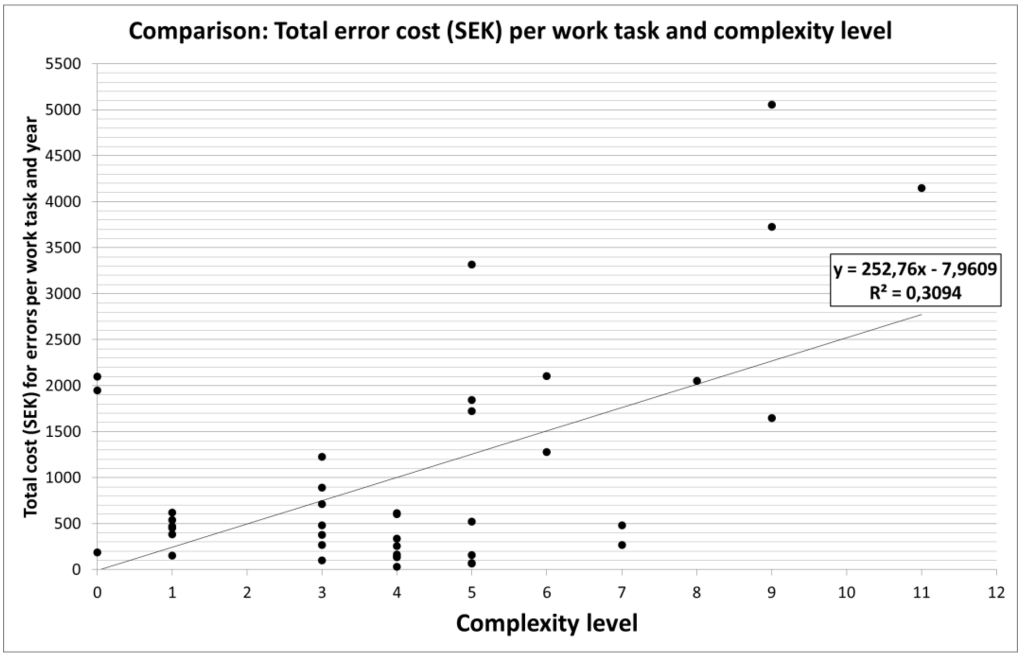
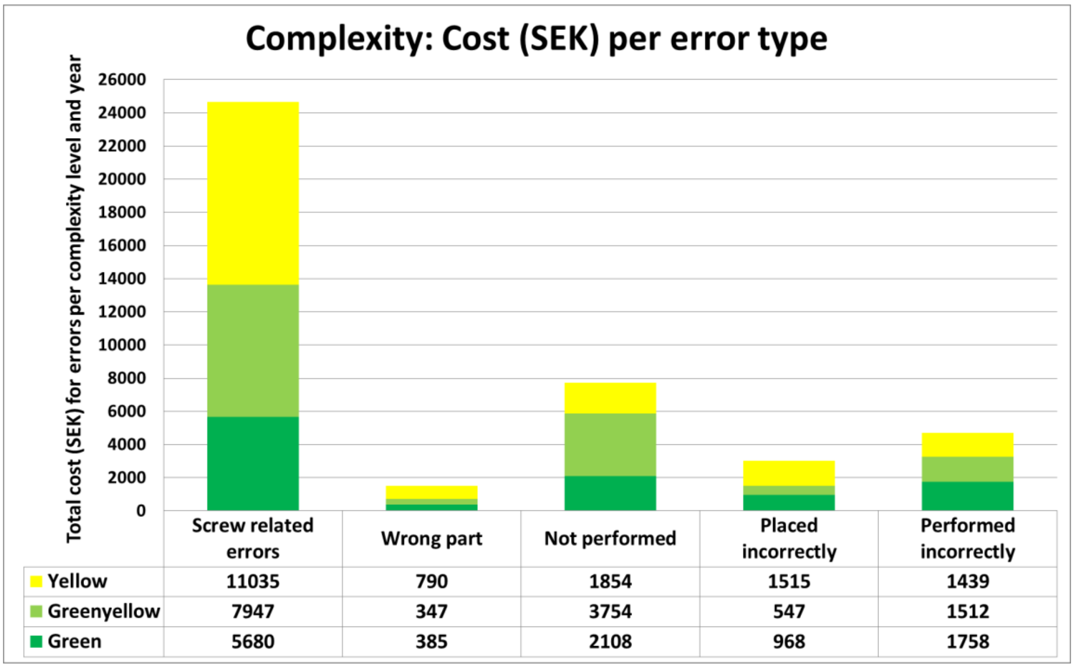


Figure 7: Complexity comparison

As for the ergonomics result, the following diagram shows the total costs distributed on the error types along with the complexity colour levels.



	Screw related errors	Wrong part	Not performed	Placed incorrectly	Performed incorrectly
Yellow	11035	790	1854	1515	1439
Greenyellow	7947	347	3754	547	1512
Green	5680	385	2108	968	1758

Figure 8: Cost (SEK) per error type

6.3. Result comparison of ergonomics and complexity assessment

Finally the correlation (R) and coefficient of determination (R^2) between the two assessments are displayed in figure 9. It reveals a correlation of 69 % and a coefficient of 48 %. The correlation and the coefficient of determination are statistically reliable with a significance level of less than 1 %.

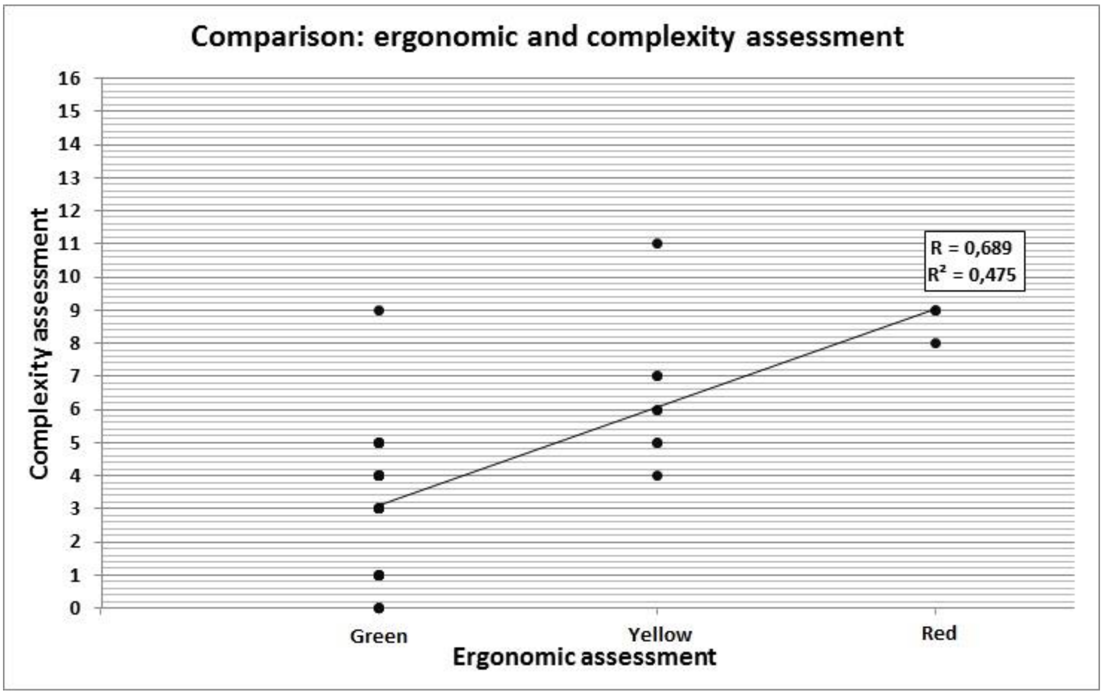


Figure 9: Comparison of assessments

7. Analysis

The purpose to study a limited section part of the production line was to get a detailed mapping of all the possible errors and see how they are connected to ergonomics and assembly complexity.

The study reveals what kind of information is possible to obtain and to what extent. It tells about the difficulties there are with these kinds of studies if they were to be performed again. These subjects will be further analysed and what kind of conclusions that can be drawn from it are brought up in the discussion chapter 8.

7.1. Analysis of the ergonomics assessment

As the result in chapter 6, table 6 shows the costs for correcting the errors are 26 % more expensive for yellow work tasks and 42 % more expensive for red work task compared to green ones.

Table 6: Ergonomics calculations from the result chapter

Ergonomic level	Total cost (SEK)	Number of errors	Cost per error	Comparison to green
Green	22029	1194	18,45	1,00
Yellow	12183	522	23,34	1,26
Red	7428	283	26,25	1,42

Here it is interesting to point out the distribution of colour levels for the 40 studied work tasks, see table 2 in chapter 6 *Result*. There are only 3 red work tasks and 8 yellow ones. But these 11 work tasks stand for almost half the total error cost in the study.

If the red and yellow work tasks were to be improved to a green level, the equation to calculate the savings each year is the linear relationship, see chapter 6.1 *Result of ergonomics assessment, table 4*:

$$825{,}51 * x - 73{,}441 = y$$

Where x is the ergonomics level starting with green = 1, yellow = 2 and red = 3. Y is the cost to correct all errors in a work task at the ergonomics x level.

First the corresponding green cost is calculated:

$$(825{,}51 * green\ level - 73{,}441) * the\ number\ of\ work\ tasks = Cost\ for\ 11\ green\ work\ tasks$$

$$(825{,}51 * 1 - 73{,}441) * 11 = 8\ 272{,}8\ SEK$$

Then the cost for 8 yellow and 3 red work tasks is calculated:

$$(825{,}51 * 2 - 73{,}441) * 8 = 12\ 621\ SEK$$

$$(825{,}51 * 3 - 73{,}441) * 3 = 7\ 209{,}8\ SEK$$

Finally summarising all the error costs:

$$red + yellow - green = yearly\ savings$$

$$12621 + 7209{,}8 - 8272{,}8 = 11\ 557\ SEK$$

This means 11 557 SEK will be saved in reduced error costs each year if these actions were made. This might sound little for such a big company but one should take into consideration that a work task is only a part of a whole balance and there are hundreds of balances on the lines consequently a huge number of work tasks. This implies that efforts should be put on the balances with the most red work tasks and improving them because there are substantial savings to be made.

When looking at the costs per error type it is obvious that screw related errors stand for most of the costs, namely 59 % of the total cost for all errors in the study. As mentioned earlier, the chosen section part proved to have a lot of screw-related problems. The colours indicate the costs for every inbound ergonomics level.

If one study the complete list in appendix II it is revealed there are screw-related errors in all the studied work tasks. The distribution in screw-related errors is: 29 green, 8 yellow and 3 red respectively. This means red and yellow work tasks make up 28 % of the total number of work tasks but stand for 46 % of the total error costs for that error type.

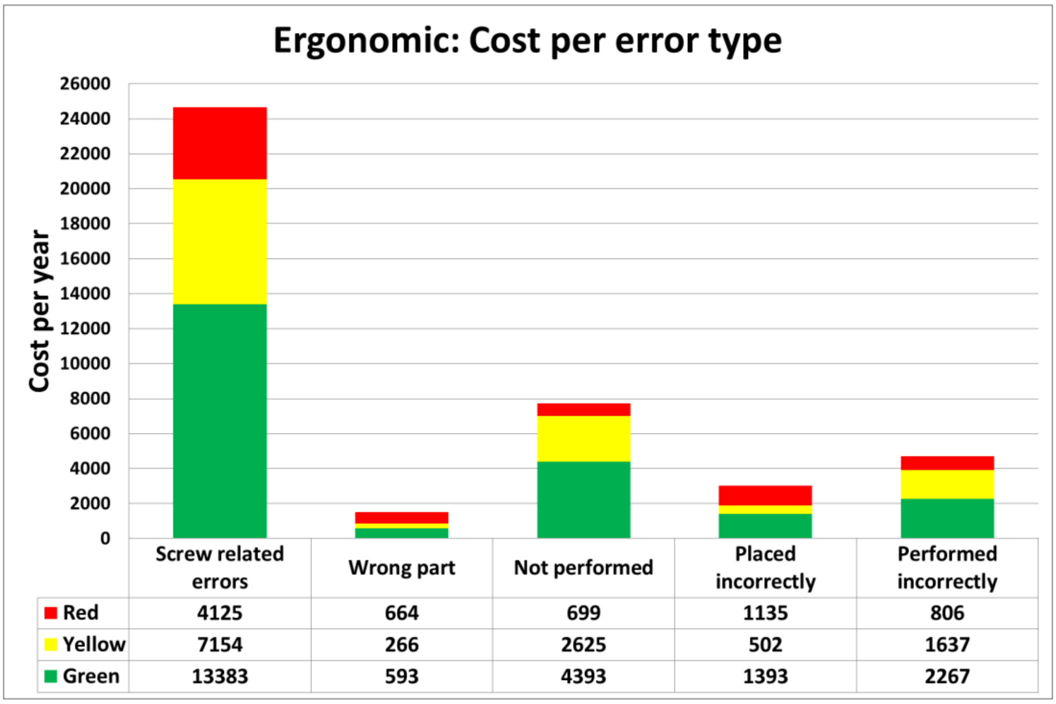


Figure 10: Cost (SEK) per error type

7.2. Analysis of the complexity assessment

For the complexity analysis the same reasoning is used as in the ergonomics analysis. Looking at the comparison diagram in figure 11 the yellow complexity level work tasks costs more than twice as much as the green errors.

But when looking at the green-yellow level there is almost no difference to the green level. This means there is no big difference in error costs for low and rather low complexity work tasks.

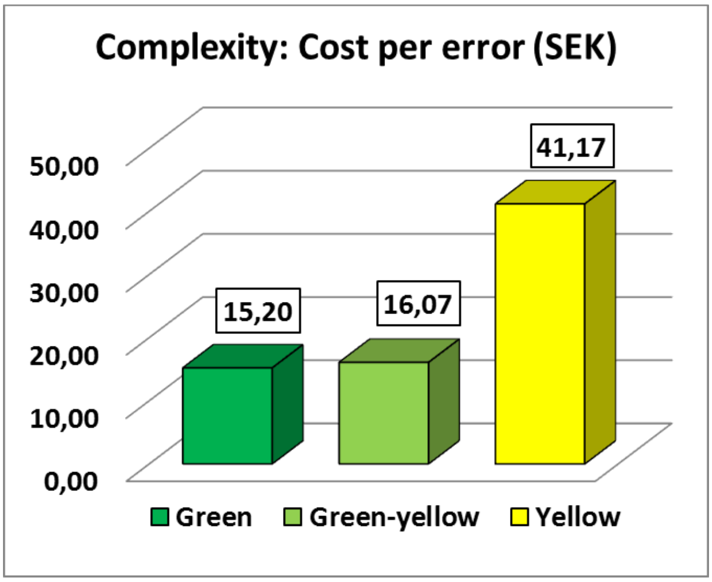


Figure 11: Complexity comparison

Compared to the ergonomics calculations the resulting complexity level spans from 0 to 11 and the colouring level is according to table 4. This makes the calculations a bit different.

Since there is almost no difference between green-yellow and green, only the yellow level will be calculated to be improved to a green level.

The linear equation for the complexity assessment is as follow (see chapter 6.2 *Result of complexity assessment, table 7*):

$$252{,}76 * x - 7{,}9609 = y$$

There are five yellow work tasks with complexity levels at 8, 9, 9, 9 and 11, see table 2. These will be improved to a complexity level of 3 since it is the maximum value in the green interval. Hence the calculations are as follows using the same reasoning as for the ergonomics calculations:

$$five\ green\ at\ a\ level\ of\ 3\text{: } (252{,}76 * 3 - 7{,}9609) * 5 = 3\ 751{,}6\ SEK$$

$$one\ level\ on\ 8\text{: } 252{,}76 * 8 - 7{,}9609 = 2\ 014{,}1\ SEK$$

$$three\ levels\ on\ 9\text{: } (252{,}76 * 9 - 7{,}9609) * 3 = 6\ 800{,}6\ SEK$$

$$one\ level\ on\ 11\text{: } 252{,}76 * 11 - 7{,}9609 = 2\ 772{,}4\ SEK$$

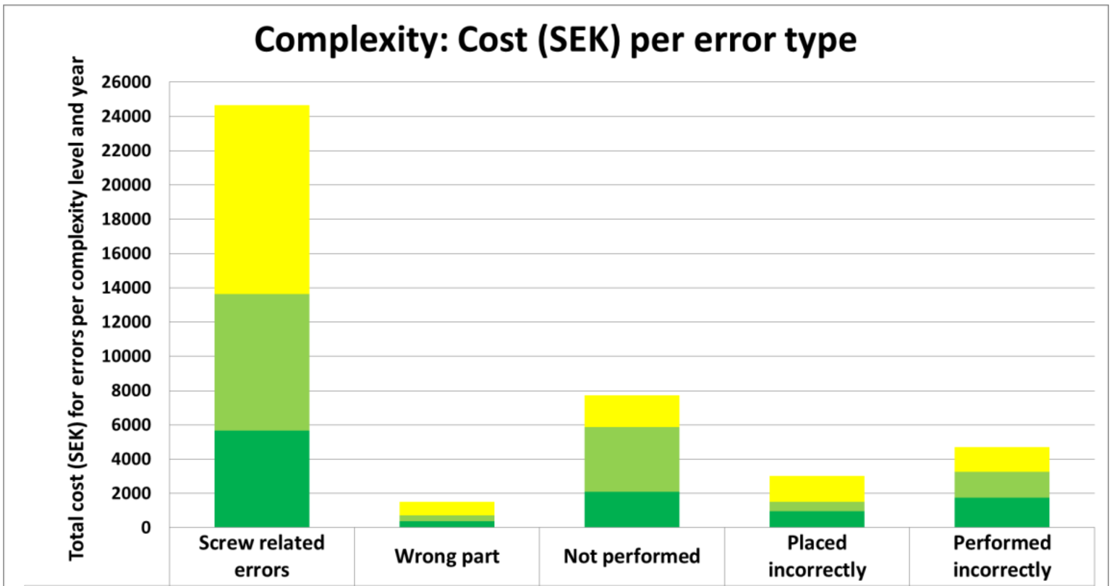
Finally summarising all error costs:

$$2\,772{,}4 + 6\,800{,}6 + 2\,014{,}1 - 3\,751{,}6 = \ 7\,836\ SEK$$

7 836 SEK on average will be saved each year if these five work tasks at a yellow complexity level is improved to an acceptable green complexity level.

When looking at the costs per error type for the complexity diagram (figure 12) it has the same total cost for every error type since it is based on the same 40 work tasks. The inbound distribution between the colours is different.

Here when looking at the screw-related error type the five yellow work tasks only stand for 13 % of the total number of work tasks but is responsible for 45 % of the error cost for that error type.



	Screw related errors	Wrong part	Not performed	Placed incorrectly	Performed incorrectly
Yellow	11035	790	1854	1515	1439
Greenyellow	7947	347	3754	547	1512
Green	5680	385	2108	968	1758

Figure 12: Cost (SEK) per error type

7.3. The comparison between the assessments

The diagram (figure 9) in chapter 6.3 *Result comparison of ergonomics and complexity assessment* is a way to show the consistency between the assessments and how well they correspond with each other. Both the correlation and the coefficient of determination indicate a strong connection between the assessments. The interrelation between the both assessments is difficult to decide, but it can be assumed that there is an interrelation.

8. Discussion

The purpose with the study of a limited section part of the production line was to get a detailed overview of all the possible errors and see how they are connected to ergonomics and complexity assembly and reveal the extent of associated costs.

The project did reveal what kind of information is possible to obtain. It tells about the difficulties with these kinds of studies if they were to be performed again. The following chapters will attend these questions. Important to note is the project only studies a small section part of the production line, which means no firm conclusions can be drawn but rather indications of the situation.

8.1. Discussion regarding the result

The following sections will address and discuss the result from a wider perspective with further aspects.

8.1.1. The assessments

The most obvious result to be drawn from the assessments is that there are positive connections between the cost of quality losses and physical ergonomics and also with assembly complexity. This result has been indicated in other studies (Falck, A. 2012a) and (Almgren, J & Schaurig, C. 2012). In both assessments the comparison is made to the green level. The green ergonomics assessment level is to be treated as a good and harmless level but one must remember that this is only a relation comparison and does not necessarily tell if a work task is harmful or not for other reasons.

As the result of ergonomics and complexity follow each other quite well, it is difficult to draw conclusions in which extent one of them affects the result. The result indicate the higher the complexity level, the greater is the ergonomic level as well. As stated in the analysis, it is difficult to say if the assessment has any interrelation, but it can be assumed that they have. Further studies in the area of assembly complexity is motivated by the statistically reliable connections between the complexity level and adjustment costs.

8.1.2. Adjustments off line

The heavy adjustment department was unfortunately difficult to get specific information from. At first this department was considered to be a significant part of the project but was later on shown to be very difficult to include in the study with the current method.

Only the existence of this department is a fact that indicates that much money can be saved. As earlier studies have shown (Almgren, J & Schaurig, C. 2012) adjustments made by the after line processes on average take multiple times longer to make than adjustments on the production line, which means the longer it takes to adjust the more it costs.

With this statement, a further investigation in this area would be to look at the costs of errors found in the aftermarket. As another study has shown (Falck, A et al. 2012b) the cost for correcting errors in the aftermarket can cost up to twelve times more. Hence this will be a suggestion for a recommendation of a further study.

8.2. The connection between functions

The systems at Volvo Trucks are mostly used separately. It is of course an advantage when designing a new system to configure it in a sense which is most beneficial for the cause of the system. The results in this study are obtained from systems which are structured in different ways and with different level of detail concerning the information handled by the systems. This results in difficulties when transferring information between systems or when using information from different systems.

When performing a study or an investigation like this which includes different areas or functions in the company it is necessary to convert the information and constantly make compromises in order to combine the data. The following text chapter will describe how the structure of the systems and especially the quality system QULIS, has influenced the result of this project.

8.2.1. QULIS

In this project QULIS has been used in a way which is not consistent to how Volvo Trucks uses it on a daily basis. This has been inconvenient when processing the data, sorting and connecting the errors to the correct work task. These problems have also occurred during the use of the system by the production personnel. QULIS cannot store any information regarding work task in the registration of errors. This makes it difficult to connect the information to other systems such as SPRINT.

The registrations in the system have affected the result by bringing difficulties such as:

- Not being able to connect errors to a certain work task.
- The same error can be registered in different ways.
- Errors being registered incorrectly.
- When an error is found at another section which has its origin at an earlier section, it is sometimes difficult for the personnel at that section to log the error on the correct section and even harder to know which station and balance it belongs to.
- Even if the error is correctly registered with enough information to connect it to the correct assembly task, it is in some cases difficult to get an understanding regarding the circumstances of the error. More information is needed in order to know what may have caused the error.

There are inconsistencies in the procedure regarding where the error was made when it is registered in QULIS. An error may be reported to where the assembler stood in relation to the truck when he or she mounted it or it could be reported on the balance that mounted it. For example, one of the balances at station 7 has work tasks around the whole truck and an error made by this assembler can turn up in QULIS reported to have been made by an another assembler at his or hers balance. In other words whoever reported the error logged it on the balance position where the component was mounted on the truck and not on the balance whose task it was to mount it.

One solution to improve the information connection in QULIS would be to have predefined choices where work task or component number already is included so the error is connected to a specific variant or component. The process of logging errors on its correct balance origin is vital to be able to improve areas of deficiencies in an effective manner.

8.2.2. Ergonomics and complexity information

The assessments in this study have been performed by using single work tasks as a starting point and not entire balances, which consist of many work tasks. If the assessments in this study were performed on balances this would provide a more realistic result for the ergonomic and complexity working conditions the assembly line personnel is exposed to during the work and for the assembly line as a whole. To make the connection work possible at a detailed level and hence obtain a more in depth view of what aspects influencing the quality and costs every work tasks needs to be assessed separately and be connected to the corresponding quality losses and costs. This can be done by performing assessments of the work tasks instead of the balances.

One problem when performing the connection at a detailed level is to relate unique costs for quality losses to the total assessment evaluation of the balance. In QULIS the registration of errors is done on a general level, more specific to the general name of the component. For example an air tank, but it does not specify which air tank variant the error concerns. This means the component variant cannot be related to the correct work task. However, this is possible to do if the component number is registered, and with some effort it can be related to the correct work task.

In order to make the work process when performing the assessments more effective the assessment evaluations from a work tasks can be "copied" to another work task with similar arrangement. The adverse with this method is the generalization of work tasks, which might result in information losses of ergonomics and complexity aspects.

Storage of the ergonomics assessments data is currently done in a separate system. When a work task or balance is improved it is difficult to update the information concerning the ergonomics evaluation in the system and there exist no standardised routines for these procedures. Keeping the data in the system updated and using it in the daily work is prevented by the extra effort it takes to look for the data in the system, which not all personnel currently have access to. The effort needed to obtain the information would be decreased if a connection between the systems was created and the information was transferred automatically.

If the data regarding the assessments were stored in a system that is used on a daily basis it would gain a greater focus when it is presented, for example when rebalancing a whole balance at a station. It would be easier to see if the balance contains a lot of work tasks with poor conditions related to ergonomics or complexity.

8.2.3. The economic connection

The economic system concerns component number and material cost of the logistics system in the production plant. Information regarding costs of scrapped material for a specific component during a specific period is stored in the system. But it does not store information regarding a specific component at a specific place of assembly in the plant. The information in QULIS regarding scrapped material and the information in the economic system was corresponding but the connection between the location of a component and QULIS was not good.

8.2.4. The heavy adjustment department

The system for registering information regarding errors is not the same for the assembly line and the heavy adjustment department. The department have the possibility to register adjusted errors in QULIS but usually do not do this. This made it very difficult to connect specific errors to the heavy adjustment department. This would have affected the result since the department was not possible to include in the calculation for the cost of the errors. This is a big drawback since the after processes hides a lot of costs.

8.2.5. The connection

The poor accessibility of required data at Volvo Trucks has had an unbeneficial effect on the result. It can be said the connection problems between systems at Volvo Trucks has been of great influence of the study and the time it consumed. Especially errors registered in QULIS which cannot directly be connected to a specific work task in SPRINT which in turn affects the work process of the ergonomics and complexity assessments. Being able to easily connect errors to a certain work task is of great importance when performing cost calculations. For future work in this area, system development must strive to a more uniform state.

8.3. How methods and functions influenced the result

The choice of work procedure of this project has affected the result which is discussed further in this section.

8.3.1. The study procedure

When this study was performed, all errors were examined and sorted on their corresponding work task. Then a selection of these was made to be included in the assessments. A better way would have been to first perform the assessments on all work tasks in the chosen section, and then make a selection of which work tasks that should be included for error cost calculations. This was not possible due to the time scope of the project and the few resources at hand to do all the assessments and it was not possible to know in advance what the result of the assessments could be.

8.3.2. The selected section part

The chosen section had advantages in form of a developed system for registering quality data and good access to historical quality data. It was also had advantages in form of resources in form of production personnel offering time to help us.

The assembly tasks performed at the chosen line section was regarded as mostly not harmful in terms of ergonomics and complexity as can be seen in chapter 6 *Result, Table 2*, the evaluations are to a great extent on a green level. The yellow and red work tasks bring multiple costs when adjusting the errors. This implies that other parts of the assembly line where conditions related to ergonomics and complexity are worse might have a more distinct result.

Assembly conditions related to ergonomics and complexity differs a lot at the sections of the assembly line and hence would a study at another part of the line have provided a different result. The achieved result implies that it cannot be applied directly on to other sections of the assembly line and is only valid for the concerned section part. It can be assumed sections with worse ergonomics and more complex conditions will bring higher expenses for adjusting errors.

8.3.3. Most common and most demanding

Many of the work tasks include the assembly of a component family, in other words, there are variants of the component assembled and therefore also variants in the performance of the work task. When searching for quality information in QULIS there is basically no way to see which component in the component family the registered information refers to since the component number is rarely noted. A way of broadening the study was to include variants of the work task, which means the most common component in the component family assembled and also the most demanding component of the work task to mount. Important to note are that these components correspond to the same dataset so there is no telling which errors belongs to what component. This was done to see if there were any big differences to the result of the assessments for the most common component variant and the most demanding component variant of a work task.

This was made for Volvo Trucks to use in the pilot project and in the future for the improvements in the field of ergonomics and complexity. The differences in the variants of the work tasks are important to consider when performing ergonomics and complexity assessments. If this difference is taken into consideration, it will help to prevent the assessments of the work tasks from being misleading and ergonomics and complexity problems from being built-in in the work task structure in the case of significant differences between the variants of a work task.

In appendix 2 the research list of the study is shown with both assessments for the most common and most demanding variant of the work task. The left column for both the ergonomics and the complexity assessments are the results of the most common variant of the wok task and the right column is the result for the most demanding variant of the work task. The results of both the ergonomics and complexity assessments for the variants are stated with colour level and assessment points. As can be seen in the table, most of the variants of the work tasks were very similar and the result of the assessment was considered equal. Many of the assessed work tasks are only performed in one variant and then the result of the assessment was considered the same.

If this difference was considered significant it would have considerable effect on the result of the study. What was recognized was that in most cases the most frequent variant and the most demanding variant did not differ significantly. This implies that this had no great influence on the result of the study.

8.3.4. Scrapped material

The number of scrapped components at the studied section part was during the chosen time period very low compared to other sections. One explanation to this can be that most of the components mounted at the studied area are made of different metals and hard plastic, which is not so easily damaged.

8.3.5. The work tasks for the assessments

When the study was conducted a total of 79 different work tasks were initially examined. After the selection for the assessment, see chapter 5.6 *The assessments,* 40 tasks were chosen to be included in the assessments. The most justified result would have been accomplished if all work tasks had been included in the assessment, but due to inconsistencies in the logged errors and time limits of this project a selection had to be made. If a complete assessment mapping of the section part was made a number of work tasks from these should have been picked out for analysis. This might have given a more equitable result.

8.3.6. The complexity assessment as a tool

The complexity assessment is still under some development. It is a relatively new and ground-breaking method. The boundaries for the five colour levels are not exactly established. As can be seen in chapter 6 *Result: Table 2*, there are only green, green-yellow and yellow work tasks at the studied section part. What these colours tell is subjective and can only be put in relational perspective. It can be presumed the trend line of the results is continuing in the same manner in the presence of work tasks with a higher level of complexity.

8.3.7. Relationship between the assessments

When examining the 16 criteria of the complexity assessment, see chapter 5.6.2 *Assembly complexity assessment* the assessment includes criteria which are strongly related to the field of physical ergonomics. This implies the conditions related to ergonomics can affect the result during both assessments, which in turn can result in a larger influence of ergonomics aspects on the study than what really is the case.

8.4. Information considerations for Volvo Trucks

This chapter will discuss a series of aspect to be considered for Volvo Trucks and their continuing effort to improve.

8.4.1. Standardised work

Currently there is no standardised way to perform the work tasks at Volvo Trucks which means the assemblers on the line can perform the work tasks in any way they preferred. This is an aggravating condition for all improvement processes. At Volvo Trucks this complicates the learning process for new employees and the procedure of performing the work task. This also influences the assembly time, the quality, assembly complexity and the production ergonomics. This difference in performance of the work task makes the performance of ergonomics and the complexity assessment difficult to be equitable. If a standardized way of working was introduced in the production plant the improvement procedures would be easier to facilitate which means the production quality would be improved as well.

When an assembler can perform the work task in a preferred manner it will results in an ever changing work performance of the work task, which the ergonomics assessment does not take into consideration. This is an issue Volvo Trucks will be dealing with in future projects for implementing standardised ways of working at the assembly line. Through this it will be possible to get everyone to work in the same way, which will improve the improvement processes of ergonomics and clarify the situation. It will also bring benefits in form of improved productivity, quality and simplify the learning and instructing new personnel.

8.4.2. Communication

An opinion of the assemblers is when an ergonomics assessment is made, not much more happens. If the ergonomic condition was apparent or visualized for all concerned personnel in the daily production it would drive the ergonomics improvement work forward more effective.

An extended dialog with the assembly personnel whom are greatly affected by the conditions related to ergonomics regarding the work in the field is to be preferred. Involving assembler in production ergonomics and designing their workplace will work as a motivator to change their work situation. Usually the connection between ergonomics and complexity to making a mistake is not always clear for the assemblers. This dialog can help assemblers to further develop their understanding of their work and communicate issues in a consistent manner.

8.4.3. Design-phase cooperation

A future goal for Volvo Trucks is to work out a better cooperation between the product development department and the production in order to improve the ergonomic assembly conditions. If the aspects related to ergonomics to assemble a new product could be incorporated already in the design phase it would be a huge success in both ergonomics and monetary aspects. This can also solve the problems where the accuracy of the fitting of components is poor which can cause poor ergonomic conditions in terms of inadequate working postures. Besides, extra force and tools may have to be used.

8.4.4. Procedure and requirements to perform the study

The following branch diagram (figure 14) shows the information connections and paths used to conduct the study. It is an overview of the required data for calculating the cost of quality losses related to ergonomics and assembly complexity. It is also an overview of the systems used for gathering data and the connection between the systems.

If a similar study is to be performed, this diagram can function as inspiration and guide for the procedure and data gathering of the study. In order to obtain a complete visualisation of quality losses and costs the influence of the department for heavy adjustments and the aftermarket needs to be included in the calculation.

To interpret the figure below, start with the result box and move down the branches to discover what information is required. In some boxes the system which is required to obtain the correct information is stated in italic. Information stated without a system requires interviews to be obtained. Further information concerning the procedure of this study and data gathering is stated in chapter 5 *Method.*

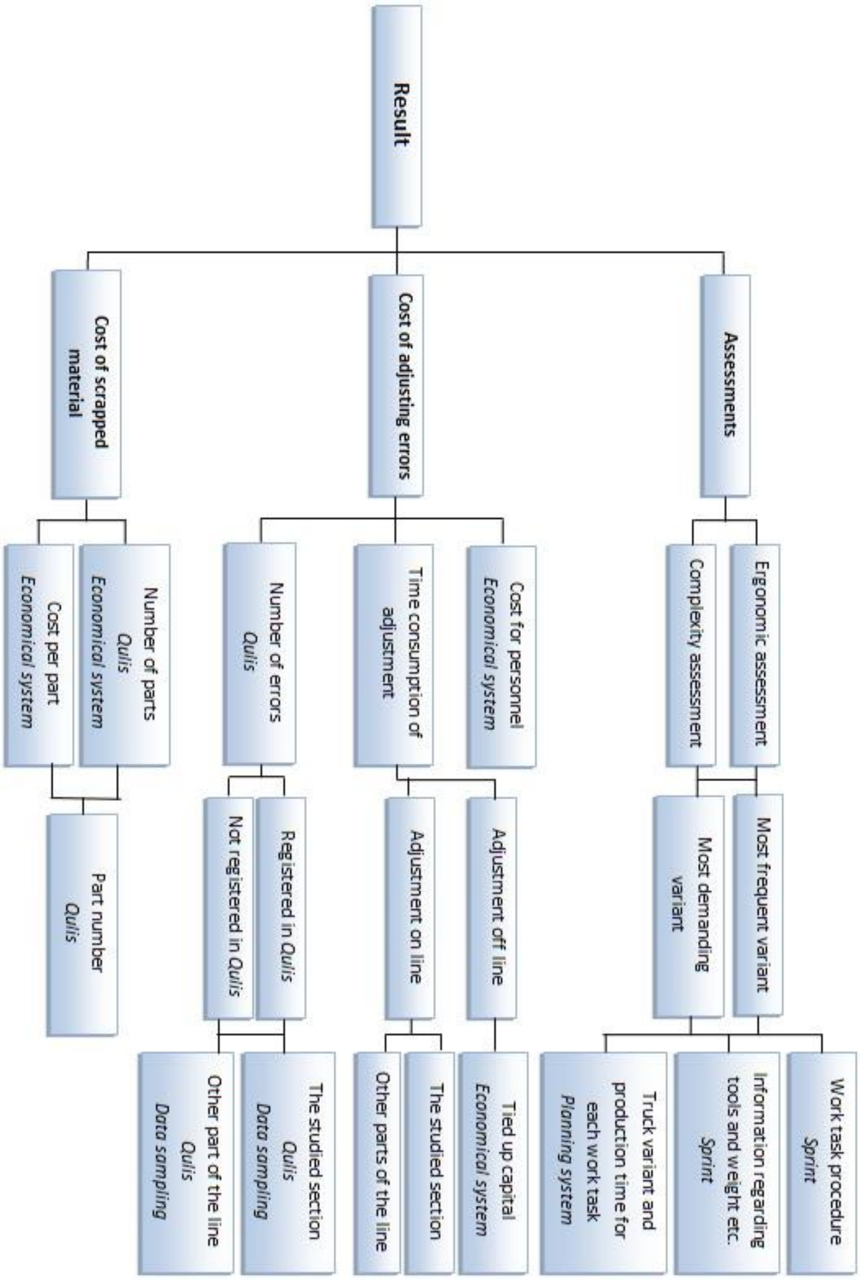


Figure 14: Required data and information paths

8.5. Reliability and validity

The idea with reliability and validity is to secure the accomplished study is correct in its statements and is carried out in a proper way (Bryman & Bell, 2011). Ejvegård (2003) explains validity as; to really measure what is intended to measure. Reliability is the ability to measure the accuracy of a study. Reliability can be achieved by comparing the result with other studies repeating the study using the same methods (Yin, 1994). In this project, several stages of different information levels have undergone processing, from interviews to data gathering.

The process model used in this project is a well tried and tested implementation methodology which ensures the progress of the study. It has a structured order to make sure all vital information details are gathered. By observing production processes and procedures combined with trying out yourself to assemble ensures an accurate perception of the current situation.

Interviews with different departments have been conducted using unstructured and semi-structured interview methods, allowing the interviewee to deviate from the question and evolve the interview. This ensures vital information to be collected. These interview methods have proven to be most suitable for the project due to big and complex processes at the company.

QULIS was been the main source for historical adjustment information. The registered data in this system can be considered to be accurate as when an error is discovered it does not take long before it is registered in QULIS. The error which has not been registered in the system has instead been collected through sampling and interviews with assemblers at the production line. These have afterwards been verified by several engineers, quality operators and assembly personnel. The sorting processes to screen out deviating and incorrect data makes sure the studied data is a good representation of the real situation.

The extensive data in QULIS also ensures the credibility and minimises the risk of incorrect interpretations of datasets. All these actions contribute to a positive reliability for the gathered data.

Several other studies regarding condition related to ergonomics and assembly complexity connected to adjustment costs has been made. As the study will show, similar result was obtained. This makes the reliability to be considered as high.

A final verification of the report has also been made to definitively make sure the stated information and details are correct.

8.6. Fulfilment of purpose

This section considers the fulfilment of the purpose and goals of the project, for a refreshment of the purpose and goals of the project, see chapter 1.3 *Purpose and goals*. Below is presented how the three different parts of the purpose and goals were fulfilled and if they are considered to be fulfilled.

Clarification of the economic aspects

The first part of the purpose, clarification of the economic aspects, was fulfilled by performing the study of calculating the costs for adjusting errors and connecting it to the conditions related to ergonomics and complexity of the studied section part of the assembly line. The costs and its connection to production ergonomics and complexity have been further clarified by visualizing the costs differences of correcting an error related to the level of ergonomics and complexity.

Relevant measurements

The fulfilment of the second part of the purpose of the study was achieved by the preformed study, which provided knowledge regarding measurements missing in the systems and simplifying the access to and the combination of already existing measures in the systems. Recommendations for improvement in this area are given.

Future recommendations

The direction for further work and research in the area of ergonomics and complexity is discussed and recommendations regarding Volvos Trucks' future work in the area are presented in order to improve performance. A list of recommendations is stated in the next chapter. This provides a fulfilment of the third part of the purpose.

9. Recommendations

The following chapter will uncover the recommendations concerning different areas. Recommendations for Volvo Trucks are presented and further discussed along with recommendations for future projects.

9.1. Recommendations for Volvo Trucks

The work with ergonomics and assembly complexity needs to become a natural part of the daily work and also the improvement work. When ergonomics and assembly complexity is not seen as an extra burden but integrated in the improvement and development work procedures, the situation will be much easier to improve. It is necessary to clarify the responsibilities of the work in the ergonomics field with a strong leadership to clarify the direction and the continuation of the work.

To make it possible to find all the information and data required for motivating improvement suggestions, it is necessary that information stored in different systems is possible to combine and the information is registered and stored in a coherent way. This is important if it is to be used as historical statistics for quality deficiencies.

In the following sections recommendations concerning measurements and work procedures are presented.

9.1.1. Recommendations concerning required measurements

To simplify the cost calculations for improvement suggestions in the field of production related ergonomics and assembly complexity, some data variables have to be observed or how data is registered has to be revised.

- **Adjustments made by the heavy adjustment department must be logged in QULIS**
  The adjustment work made the adjustment department must be registered in a way that makes it possible to connect it to the information in QULIS to be able to follow the quality history of a specific truck. The time consumption of adjusting every error in the adjustment department also needs to be registered because it is likely to be very high.

- **Register time consumption for adjusted errors**
  The time consumption of adjusting every error at the assembly line must to be registered. There is already a checkbox for this information when registering an error in QULIS, but it is very seldom written down.
  - This can be improved by introducing checkboxes with time consumption intervals.

- **Information concerning where the error occurred must be registered**
  The place of occurrence of all errors must be registered down to station and balance. This will simplify the sorting of errors and hence presenting statistics of historical quality data.

9.1.2. Recommendations concerning work procedures

In the following sections further recommendations concerning work procedures for the systems, improvement processes and the areas of ergonomics and assembly complexity are stated and discussed.

9.1.2.1. Recommendations concerning work with systems and improvements processes

The information stored in the systems are important parts for the work of simplifying improvement suggestions. A holistic approach needs to be adopted in the work with improvements, in order to cover all aspects of the situation, including aspects such as ergonomics and assembly complexity. Creating beneficial conditions for this is made by having a good cooperation with the product development department and making the information stored data systems easily accessible. Recommendations concerning work with systems and improvement processes will be presented and further discussed in this section.

- **Implement standardized work**
  Proceed implementing standardized work at the assembly line in order to improve quality and facilitating improvement work procedures. With a standardized way of working the ergonomics and assembly complexity assessments will be more accurate with only one way to perform an assembly task.

- **The registrations in QULIS must be consistent**
  The same error can be registered in QULIS in different ways. This results in difficulties when sorting the errors. If errors were registered in the same way it would be possible to find statistics of historical quality data.
  - Reduce the number of combinations describing the same error.

- **Increase the cooperation with the product development department**
  Early in the product development process the implementation of changes to the product or the process cost less. A greater cooperation with the product development department will make it possible to implement changes to the product and the assembly work earlier in the development chain. This will provide a better base for developing the conditions related to ergonomics and assembly conditions in general in the plant.
  - Educate the personnel working with product design in the field of ergonomics and complexity.
  - Develop a tool considering ergonomics and complexity to be used in the product and process design phase.

9.1.2.2. Recommendations concerning the work in the areas of ergonomics and complexity

Recommendations concerning work in the areas of ergonomics and assembly complexity will be presented and further discussed in this section.

- **Ensure the production equipment used for ergonomics purposes is functional**
  The function of production equipment needs to be adapted to the production environment and the conditions of use. Safe, fast and well suited for the variations in the product, otherwise it will be too time consuming for the assembler to use. For example the lifting equipment for air tanks at the studied section part must be changed so assembler chose to use it.
  - A suggestion is to make a one-fit-all lifting tool for all air tanks.
  - Involve the operators in this work.

- **The information concerning ergonomics assessments needs to be stored in SPRINT and be up to date**
  The ergonomics classification of the work tasks needs to be easily accessed and up to date in order to be truly useful. The follow up of the improvements done in the ergonomics area should be improved. For example the assessment information should be stored in SPRINT to ease the use of it in the daily work with balancing of work tasks.

- **Perform a complete mapping of the conditions related to ergonomics in the plant**.
  This will serve as an indicator of ergonomic problem areas in the plant that must be prioritized. Such major decisions can only be done if managers recognise it as a serious matter. A change of attitude is requested.

- **Engage a group with responsibility for ergonomics on full time**
  A group of personnel with authorisation to use big resources should be engaged on full time. The team should be cross-functional and the leader of group should be a manager already high up in the company hierarchy.

9.2. Recommendations for future projects

Recommendations of interest for further research are presented in this section.

- **Investigate other financial factors influencing the costs**
  When improving conditions related to ergonomics and complexity, savings in terms of increased productivity and less line stoppages are expected and the following cost savings must be examined. This will further contribute to the economical motivation of investments.

- **Investigate costs for adjusting errors discovered in the after-market**
  Further research for adjustment costs discovered after the delivery of the finished truck is of interest. Also the indirect costs for decrease of customer trust when errors on the finished truck are discovered should be investigated.

- **Further research in the area of cognitive production ergonomics**
  The effect of cognitive ergonomics on quality losses and adjustment costs is not included in this project, but needs to further examined to see if it has any effect on productivity.

9.3. Summary of recommendations

Ergonomics and assembly complexity related to adjustment costs need to be further investigated. In order to accomplish this, the responsibility and leadership of the work need to be obvious. *The costs of adjusting errors in the heavy adjustment department along with the after-market need to be examined and be connected to the costs for adjusting errors occurring on the assembly line, in order to visualise a total overview of all the costs.*

Improving the economic base in terms of adjustment costs when motivating improvement suggestions has been proven to be very useful and convincing and can be applied in the future processes. The registration of quality deficiencies must be coherent to easily display historical quality statistics.

The condition of ergonomics and assembly complexity of work tasks needs to be mapped. A condition for this is the implementation of standardised work which is recommended to be implemented in the entire plant.

An increased cooperation with the product development department during the development of products and processes will provide the work with ergonomics and assembly complexity at the assembly line better fundamental conditions.

The realisation of the above presented recommendations will provide a substantial development of the work with ergonomics and assembly complexity. The procedure for improvement suggestions will be better supported and much facilitated through cost-benefit calculations on behalf of reactive adjustment costs. The significance of ergonomics and assembly complexity will be put in a new financial context where closely related aspects such as productivity and quality are considered.

10. Conclusion

To conclude this report the following is stated:

- The relationship between production ergonomics and costs for quality losses previously studied and shown at Volvo Trucks has been strengthened.

- There is a relationship between assembly complexity and costs for quality losses at Volvo Trucks.

- It is possible to perform detailed cost calculations of quality losses at Volvo Trucks but it is complicated. There are large potential to improve the conditions for motivating improvement investments by considering the recommendations given in this report.

- In order to be more competitive and profitable Volvo Trucks needs to continue to prevent reactive action costs for quality losses related to ergonomics. *The heavy adjustment department and the after-market are of special importance.*

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Appendix I: Questionnaire template for the interviews

- **Production engineers and the head of the production engineers**

  Improvement work

  What do you think could be improved in the procedure of making improvement suggestions?

  Which problem do you see in the procedure?

  How does the procedure of making improvement suggestions work?

  Give an example of an implemented improvement suggestion, how did you perform it?

  The data systems

  How does SPRINT work?

  What information can be found in SPRINT?

  The production

  What do you think of the conditions related to ergonomics of the section?

  What do you think of the assembly complexity conditions of the section?

- **The department handling scrapped material**

  How does the procedure of handling scrapped material work?

  What is the proportion of registered scrapped material?

  Where does the scrapped material occur?

- **The heavy adjustment department**

  How frequent do you find errors originating from section 2 of the assembly line?

  How long is the adjustment time for errors?

  How does the procedure of the heavy adjustment department work?

  How does the registration of error work?

- **Assembly personnel**

How long is the adjustment time for errors?

How frequent do the errors occur?

How do the instructions for assembly work?

What is the registration procedure when an error occurs?

What is the adjustment procedure when an error occur

What types of errors occur?

What do you think of the conditions related to ergonomics of the section?

What do you think of the assembly complexity conditions of the section?

- **Ergonomists**

How does the classification of the conditions related to ergonomics of an assembly task work?

What is the difference between SARA and EMD?

What is stated in the Volvo Trucks standard regarding ergonomics and complexity?

What do you think of the conditions related to ergonomics of the section?

What do you think of the conditions related to ergonomics of the plant in general?

How do you think the conditions related to ergonomics in the plant could be improved?

What are the prerequisites for assessing the conditions related to ergonomics?

- **The economy department**

What is the standard cost for production personnel per time unit?

How does the economic system work?

How do we find out the cost for scrapped material?

How can tied up capital be calculated?

- **Quality department**

  How does the registration procedure work?

  How does QULIS work?

  What information can be found in QULIS?

  Which are the possible search paths regarding errors in QULIS?

  How can we specify our search?

  What are the future plans for the development of QULIS?

Appendix II: Complete research list of the study

The most common and most demanding work task variant is based on interviews with technicians and assemblers. Sometimes, the most common and demanding is the same work task.

Adjustments

													Complexity assessment			Ergonomic assessment		
Work task number	Type of error	Number of registered errors	Number of not registered errors	Number of errors registered from other parts	Number of errors not registered from other parts	Total numbers of errors	Adjustment time [min]	Adjustment time from other parts [minutes]	Total adjustment cost	Number of scrapped components	Total cost for scrapped component	Total adjustment cost	The most common work task variant	The most demanding work task variant	Intervals for the complexity assessment: 0-3 Green 4-7 yellow-green 8-11 Yellow 12-14 Yellow-Red 15-16 Red	The most common work task variant	The most demanding work task variant	Belastningsergonomiskbedömnimg: If any part of assessments A - D turns red, the overall evaluation red. Otherwise, the colour is determined by the sum total of the part assessments A - D with the intervals: 0-16 Grön 17-32 Gul >32 Röd
1	Screw related error	23	29	20	20	92	2	10	2554	1	279,12	2833	9	9		32	32	
												0						
	Not performed	9	11	1	1	22	3	10	405			405						
												0						
	Wrong component	3	4			7	3	10	106			106						
												0						
	Placed incorrectly	3	4	1	1	9	3	10	208			208						
												0						
	Performed incorrectly	2	3	1	1	7	3	10	177			177						
												0						
	Total					137						3730						
2	Screw related error	59	73			132	3	10	2006			2006	0	0		2	2	
												0						
	Not performed					0						0						
												0						
	Wrong component					0						0						
												0						
	Placed incorrectly					0						0						
												0						
	Performed incorrectly	1	2			3	6	10	91			91						
												0						
	Total					135						2098						
3	Screw related error	8	10	5	5	28	0,5	10	552			552	5	5		18	26	
												0						
	Not performed	3	4			7	1,5	10	53			53						
												0						
	Wrong component	10	13	2	2	27	1	10	319			319						
												0						
	Placed incorrectly	6	8	1	1	16	1,5	10	208			208						
												0						
	Performed incorrectly	17	21	3	3	44	1,5	10	593			593						
												0						
	Total					122						1725						
4	Screw related error	8	10	31	31	80	0,5	5	1616			1616	6	6		19	19	
												0						
	Not performed					0						0						
												0						
	Wrong component	9	11	4	4	28	2	5	405			405						
												0						
	Placed incorrectly		1			1	2	5	10			10						
												0						
	Performed incorrectly	3	4			7	2	5	71			71						
												0						
	Total					116						2103						
5	Screw related error	42	52	3	3	100	3	10	1733			1733	0	0		2	2	
												0						
	Not performed					0						0						
												0						
	Wrong component					0						0						
												0						
	Placed incorrectly					0						0						
												0						
	Performed incorrectly	3	4			7	6	10	213			213						
												0						
	Total					107						1946						
6	Screw related error	11	14	20	20	65	2,5	10	2343			2343	5	5		10	11	
												0						
	Not performed					0						0						
												0						
	Wrong component	10	13	4	4	31	3	10	755			755						
												0						
	Placed incorrectly	3	4			7	3	10	106			106						
												0						
	Performed incorrect		1	1	1	3	2,5	10	114			114						
												0						
	Total					106						3319						
7	Screw related error	14	18	6	6	44	10	15	2533			2533	11	8		21	17	
												0						
	Not performed		1			1	10	15	51			51						
												0						
	Wrong component	10	13	3	3	29	3	15	806			806						
												0						
	Placed incorrectly	1	2			3	10	15	152			152						
												0						
	Performed incorrectly	1	2	3	3	9	10	15	608			608						
												0						
	Total					86						4150						

8	Screw related error	17	21			38	0,5	5	96			96	3	3			7	7
												0						
	Not performed					0						0						
												0						
	Wrong component	14	18	3	3	38	1	5	314			314						
												0						
	Placed incorrectly		1			1	1	5	5			5						
												0						
	Performed incorrectly	1	2	1	1	5	1	5	66			66						
												0						
	Total					82						481						
9	Screw related error	15	19	3	3	40	0,5	5	238			238	4	4			5	5
												0						
	Not performed		1			1	1	5	5			5						
												0						
	Wrong component	8	10	4	4	26	1	5	294			294						
												0						
	Placed incorrectly		1			1	1	5	5			5						
												0						
	Performed incorrectly	5	7			12	1	5	61			61						
												0						
	Total					80						603						
10	Screw related error	15	19	9	9	52	2	10	1257			1257	9	9			32	32
												0						
	Not performed	5	7			12	3	10	182			182						
												0						
	Wrong component	1	2	1	1	5	3	10	147			147						
												0						
	Placed incorrectly		1			1	3	10	15			15						
												0						
	Performed incorrectly	1	2			3	3	10	46			46						
												0						
	Total					73						1647						
11	Screw related error	3	4			7	1	5	35			35	8	8			14	14
												0						
	Not performed	1	2			3	5	10	76			76						
												0						
	Wrong component	7	9	2	2	20	3	10	446			446						
												0						
	Placed incorrectly	9	11	4	4	28	5	10	912			912						
												0						
	Performed incorrectly	3	4	4	4	15	5	10	583			583						
												0						
	Total					73						2052						
12	Screw related error	19	24	3	3	49	0,5	6,5	307			307	1	1			7	7
												0						
	Not performed		1			1	1	6,5	5			5						
												0						
	Wrong component	3	4	1	1	9	1	6,5	101			101						
												0						
	Placed incorrectly		1	1	1	3	1	6,5	71			71						
												0						
	Performed incorrect		1	2	2	5	1	6,5	137			137						
												0						
	Total					67						621						
13	Screw related error	5	7	3	3	18	2	5	274			274	3	3			8	8
												0						
	Not performed	5	7			12	5	5	304			304						
												0						
	Wrong component	6	8	2	2	18	2	5	243			243						
												0						
	Placed incorrectly		1			1	5	5	25			25						
												0						
	Performed incorrect		1	7	7	15	5	5	380			380						
												0						
	Total					64						1226						
14	Screw related error	9	11			20	10	15	1013			1013	5	5			24	24
												0						
	Not performed		1			1	10	15	51			51						
												0						
	Wrong component	17	21			38	3	15	578			578						
												0						
	Placed incorrectly		1			1	10	15	51			51						
												0						
	Performed incorrectly	1	2			3	10	15	152			152						
												0						
	Total					63						1844						
15	Screw related error	21	25	8	8	62	2	10	1277			1277	6	6			21	21
												0						
	Not performed											0						
												0						
	Wrong component											0						
												0						
	Placed incorrectly											0						
												0						
	Performed incorrect											0						
												0						
	Total					62						1277						
16	Screw related error	14	18	1	1	34	0,5	6	142			142	5	5			12	12
												0						
	Not performed					0						0						
												0						
	Wrong component	3	4	5	5	17	1	6	339			339						
												0						
	Placed incorrectly		1			1	1	6	5			5						
												0						
	Performed incorrectly	3	4			7	1	6	35			35						
												0						
	Total					59						522						
17	Screw related error	17	21			38	0,5	5	96			96	5	5			15	15
												0						
	Not performed		1			1	1	5	5			5						
												0						
	Wrong component	3	4			7	1	5	35			35						
												0						
	Placed incorrectly		1			1	1	5	5			5						
												0						
	Performed incorrectly	1	2			3	1	5	15			15						
												0						
	Total					50						157						

18	Screw related error		1	9	9	19	2	10	922	4 (3 konsc	3454,52	4377	9	9			13	13
												0						
	Not performed	1	2			3	5	20	76			76						
												0						
	Wrong component	1	2	3	3	9	3	10	350			350						
												0						
	Placed incorrectly		1	1	1	3	5	20	228			228						
												0						
	Performed incorrect		1			1	5	20	25			25						
												0						
	Total					35						5056						
19	Screw related error	4	5	1	1	11	1	10	147			147	4	4			16	16
												0						
	Not performed		1			1	2	10	10			10						
												0						
	Wrong component	4	5	3	3	15	2	10	395			395						
												0						
	Placed incorrectly	1	2			3	2	10	30			30						
												0						
	Performed incorrectly	1	2			3	2	10	30			30						
												0						
	Total					33						613						
20	Screw related error	12	15			27	0,5		68			68	3	3			7	7
												0						
	Not performed		1			1	1		5			5						
												0						
	Wrong component	1	2			3	1		15			15						
												0						
	Placed incorrectly		1			1	1		5			5						
												0						
	Performed incorrect		1			1	1		5			5						
												0						
	Total					33						99						
21	Screw related error	1	2			3	0,5	3	8			8	7	7			22	22
												0						
	Not performed		1	2	2	5	2	5	111			111						
												0						
	Wrong component		1	4	4	9	1	5	208			208						
												0						
	Placed incorrectly	2	3			5	2	5	51			51						
												0						
	Performed incorrectly	2	3	1	1	7	2	5	101			101						
												0						
	Total					29						479						
22	Screw related error	3	4	2	2	11	0,5	5	119			119	1	1			5	5
												0						
	Not performed		1			1	1	5	5			5						
												0						
	Wrong component		1	1	1	3	1	5	56			56						
												0						
	Placed incorrectly		1			1	1	5	5			5						
												0						
	Performed incorrectly	1	2	5	5	13	1	5	269			269						
												0						
	Total					29						453						
23	Screw related error		1			1	0,5	9	3			3	3	3			8	8
												0						
	Not performed					0						0						
												0						
	Wrong component		2	2	2	6	5	9	233			233						
												0						
	Placed incorrectly	1	2	3	3	9	5	9	350			350						
												0						
	Performed incorrectly	5	7			12	5	9	304			304						
												0						
	Total					28						889						
24	Screw related error	11	14			25	3	10	380			380	1	1			2	2
												0						
	Not performed					0						0						
												0						
	Wrong component					0						0						
												0						
	Placed incorrectly					0						0						
												0						
	Performed incorrectly	1	2			3	6	10	91			91						
												0						
	Total					28						471						
25	Screw related error		1			1	0,5	5	3			3	4	4			17	17
												0						
	Not performed					0						0						
												0						
	Wrong component	5	7	4	4	20	1	5	263			263						
												0						
	Placed incorrectly		1			1	1	5	5			5						
												0						
	Performed incorrectly	1	2	1	1	5	1	5	66			66						
												0						
	Total					27						337						
26	Screw related error	1	2			3	0,5	5	8			8	3	3			8	8
	Not performed					0						0						
												0						
	Wrong component	5	8	1	1	15	5	9	421			421						
												0						
	Placed incorrectly	1	2	2	2	7	5	9	258			258						
												0						
	Performed incorrect		1			1	5	9	25			25						
												0						
	Total					26						712						

27	Screw related error	9	11			20	0,5	5	51			51	5	5		15	15
												0					
	Not performed		1			1	1	5	5			5					
												0					
	Wrong component		1			1	1	5	5			5					
												0					
	Placed incorrectly		1			1	1	5	5			5					
												0					
	Performed incorrect		1			1	1	5	5			5					
												0					
	Total					24						71					
28	Screw related error	3	4			7	0,5	5	18			18	3	3		7	7
												0					
	Not performed					0						0					
												0					
	Wrong component	2	3	3	3	11	1	5	177			177					
												0					
	Placed incorrectly		1			1	1	5	5			5					
												0					
	Performed incorrectly	1	2	1	1	5	1	5	66			66					
												0					
	Total					24						266					
29	Screw related error	5	7			12	1	10	61			61	4	4		16	16
												0					
	Not performed		1			1	2	10	10			10					
												0					
	Wrong component	3	4			7	2	10	71			71					
												0					
	Placed incorrectly		1			1	2	10	10			10					
												0					
	Performed incorrect		1			1	2	10	10			10					
												0					
	Total					22						162					
30	Screw related error	2	3	4	4	13	0,5	5	215			215	4	4		14	14
												0					
	Not performed		1			1	1	5	5			5					
												0					
	Wrong component		1			1	1	5	5			5					
												0					
	Placed incorrectly		1			1	1	5	5			5					
												0					
	Performed incorrectly	2	3			5	1	5	25			25					
												0					
	Total					21						256					
31	Screw related error	1	2	3	3	9	0,5	5	160			160	1	1		5	5
												0					
	Not performed		1	1	1	3	1	5	56			56					
												0					
	Wrong component		1	3	3	7	1	5	157			157					
												0					
	Placed incorrectly		1			1	1	5	5			5					
												0					
	Performed incorrect		1			1	1	5	5			5					
												0					
	Total					21						383					
32	Screw related error	5	7	2	2	16	3	10	385			385	1	1		2	2
												0					
	Not performed					0						0					
												0					
	Wrong component					0						0					
												0					
	Placed incorrectly	2	3			5	6	10	152			152					
												0					
	Performed incorrect					0						0					
												0					
	Total					21						537					
33	Screw related error		1			1	0,5	5	3			3	4	4		14	14
												0					
	Not performed	5	7			12	1	5	61			61					
												0					
	Wrong component	1	2			3	1	5	15			15					
												0					
	Placed incorrectly		1			1	1	5	5			5					
												0					
	Performed incorrect		1	1	1	3	1	5	56			56					
												0					
	Total					20						139					
34	Screw related error	1	2	1	1	5	0,5	5	58			58	3	3		11	11
												0					
	Not performed					0	1	5				0					
												0					
	Wrong component	1	2	6	6	15	1	5	319			319					
												0					
	Placed incorrectly					0	1	5				0					
												0					
	Performed incorrect					0	1	5				0					
												0					
	Total					20						377					
35	Screw related error	4	6			10	3		152			152	7	7		23	23
												0					
	Not performed					0						0					
												0					
	Wrong component	1	2			3	3		46			46					
												0					
	Placed incorrectly		1			1	5		25			25					
												0					
	Performed incorrectly	1	2			3	3		46			46					
												0					
	Total					17						269					
36	Screw related error	2	3			5	0,5	6,5	13			13	0	0		6	6
												0					
	Not performed		1			1	1	6,5	5			5					
												0					
	Wrong component	1	2			3	1	6,5	15			15					
												0					
	Placed incorrectly		1	1	1	3	1	6,5	71			71					
												0					
	Performed incorrectly	1	2	1	1	5	1	6,5	81			81					
												0					
	Total					17						185					

37	Screw related error		1	1	1	3	0,5	5	53			53	1	1			5	5
												0						
	Not performed		1			1	1	5	5			5						
												0						
	Wrong component		1	1	1	3	1	5	56			56						
												0						
	Placed incorrectly	1	2			3	1	5	15			15						
												0						
	Performed incorrectly	2	3			5	1	5	25			25						
												0						
	Total					15						155						
38	Screw related error		1			1	0,5	5	3			3	4	4			5	5
												0						
	Not performed		1			1	1	5	5			5						
												0						
	Wrong component		1			1	1	5	5			5						
												0						
	Placed incorrectly		1			1	1	5	5			5						
												0						
	Performed incorrectly	1	2	2	2	7	1	5	117			117						
												0						
	Total					11						134						
39	Screw related error	2	3			5	1	10	25			25	5	5			16	16
												0						
	Not performed		1			1	2	10	10			10						
												0						
	Wrong component		1			1	2	10	10			10						
												0						
	Placed incorrectly		1			1	2	10	10			10						
												0						
	Performed incorrect		1			1	2	10	10			10						
												0						
	Total					9						66						
40	Screw related error		1			1	0,5	5	3			3	4	4			5	5
												0						
	Not performed	1	2			3	1	5	15			15						
												0						
	Wrong component		1			1	1	5	5			5						
												0						
	Placed incorrectly		1			1	1	5	5			5						
												0						
	Performed incorrect		1			1	1	5	5			5						
												0						
	Total					7						33						
				Total		**1999**						**41640**						