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Identifying future assembly methods in Scania´s wheel axle factory

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Faculty of Engineering LTH Lund University 2012

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Preface

This master's thesis has been carried out at Scania CV AB, Södertälje, in cooperation with the department of Mechanical Engineering at LTH, Lund University. The thesis was produced between November 2011 and April 2012 and constitutes the last stage of our Master's degrees in Mechanical Engineering.

Firstly we would like to express our gratitude to our manager Andreas Olivin, Henrik Grankvist and our supervisor Gustaf Ramnell at Scania´s wheel axle factory. We would also like to thank all the people at DTTB and at Scania´s wheel axle factory for their support and helpful advice.

We would like to express our gratitude to our supervisor professor Jan-Eric Ståhl at Lund University (LTH) as well as to our Examiner, Matias Jönsson (LTH) for helping us in different aspects concerning this work.

In addition we would like to thank all the persons who have helped and supervised us in the different way during the implementation of this master thesis.

Lund, april 2012

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Sarwar Omar Hassan Bakrawi

Abstract

Title: Identifying future assembly methods Scania's wheel axle factory.

Authors: Sarwar Omar and Hassan Bakrawi, *Division of Industrial production.*

Supervisor: Jan-Eric Ståhl, Professor, Industrial production at Lunds University, Lund.

Andreas Olivin Manager at DTTB, Scania's wheel axle factory and Gustaf Ramnell, Project leader at Scania's wheel axle factory.

Objective: To identify how the assembly methods and interfaces should appear to enable the aim. The report will be used as a guide for future production/construction projects.

Method: This master's thesis was both based on research and implements the new assembly methods on Scania's wheel axle products.

Conclusions: To make the implementation of the assembly methods possible, the product design needed to be redesigned. Design for assembly has been used to achieve the best product design result and to measure the design efficiency on percentages.

Keywords: product development, DFA or DFMA, design, module, assembly methods.

Sammanfattning

Denna rapport presenterar det examensarbete som har utförts i samarbete med Scania CV AB, Växellådor och Axlar i Södertälje. Syftet med examensarbetet är att finna framtida monteringsmetoder som sedan kan implementeras på Scanias hjulaxlar. Detta innebär att dagens produktkonstruktion/produktdesign skall anpassas eller eventuellt ändras helt för att tillämpa dessa nya monteringsmetoder. Monteringsmetoderna ska i sin tur bidra till att sänka dagens monteringstakt tid. Scanias axelfabrik arbetar kontinuerligt med att effektivisera sitt produktionssystem för att uppnå målet som Scania har för framtiden. Detta examensarbete skall vara en vägledning för Scanias axelfabrik framöver för att förverkliga målet.

Scania är en av världens ledande tillverkare av lastbilar, bussar och marinmotorer. Scania erbjuder även sina kunder den bästa servicen för att uppfylla kvalitet på produkterna som företagets varumärke representerar. Med Scanias långa erfarenhet av tillverkning av lastbilar och bussar erbjuder Scania unika lösningar som är särskilt anpassat för exakt vad kunden behöver och önskar. Scania arbetar ständigt med att ha en nära relation med sina kunder och tanken är att kunna tillfredsställa varje kund med det dem behöver och önskar.

All utvecklings- och forskningsarbeten samt monteringsanläggningarna av Scanias produkter och produktion äger rum i Södertälje. Scanias mål med att ha sin utvecklings- och forskningsanläggningar nära sina produktionsanläggningar är att minska utvecklingstiden och med detta erbjuda sin kund unika lösningar och leverera vad kunden behöver i rätt tid. Detta ger Scania möjligheten att utvecklas och leda företaget till ledande positioner inom sin marknad.

Med visionen att finna och tillämpa nya monteringsmetoder gjordes omfattande undersökningar av befintliga litteraturer inom detta område. Tidigare studier och forskningar rekommenderar att fokus bör vara på produktionssystemet som helhet för att lyckas med att uppnå de stora kostnadsvinsterna och effektivisera produktionen på ett kvalitets- och ergonomisk synpunkt.

Scanias axelfabrik satsar på ”Single line concept” som montering för deras hjulaxlar. För att åstadkomma den önskade monteringstakt tiden bör hänsyn också läggas på olika kritiska moment såsom montörernas tid och rörelse vid hämtning och anpassning av komponenterna, var ligger gränsen för monteringstakt tid? Ett kritiskt exempel kan vara att pressmaskiner måste pressa långsamt för att förhindra till exempel friktionssvetsning, kvalitet på utförandet, osv.

Idag finns det flera produktutvecklingsmetoder att använda sig av för att förbättra produkter och minska deras utvecklingstid. De flesta metoderna fokuserar på monteringsaspekter redan i början av produktutvecklingsfasen. En av metoderna som har studerats noggrant och använts i det här examensarbetet är DFA analys alltså design för monteringsanpassning. DFA är en etablerad metod som förbättrar monterings sekvenser för olika produkter. Några nämnd värda fördelar med DFA är att metoden bidrar till att minska antalet komponenter samt minska monteringstiden och dessutom minska produktutvecklingstiden.

Syftet med DFA är att identifiera och uppskatta en monteringseffektivitet samt belysa var det finns möjligheter till förbättring i själva del-montaget. Ett annat syfte med DFA är att hitta ett enkelt och okomplicerad sätt att montera komponenterna med varandra. DFA analys/metod kan också användas som ett hjälpverktyg för produktdesigner för att redan i början av utvecklingsfasen påvisa och belysa var det finns kritiska moment som kan förekomma under monteringsfasen.

Modularisering handlar om att standardisera och kunna anpassa produktdelar utan att gränssnitt ska förändras. Ett fantastiskt verktyg som ger företag ett kraftfullt försprång och konkurrenskraftigt medel att tävla om att inneha topposition i världen. Det är tyvärr mycket svårt att tillämpa det i verkligheten. Man måste tänka i LEGO-tänk, nya generationers produkter ska kunna gå ihop med gamla generationens produkt och en kund ska kunna få valet att special anpassa sin produkt utan att produktionen måste modifiera sin tillverkning och utan att priset skjuter i höjden. Man måste också tänka på att grundformen ska kunna bygga upp den minst komplicerade produkten till den mest komplicerade produkten, alltså i Scanias fall, minsta lastbilen med minst antal produktdelar har samma grund som den största lastbilen med flest tillval. Modularisering fungerar i teorin men i praktiken är det svårt att tillämpa.

Det fanns svårigheter med att hitta monteringsmetoder pga. brist på kurslitteratur samt vetenskapliga artiklar. Företag som hade sina egna lösningar på monteringsmetoder söktes och utvärderades ifall dessa var kunde anpassas till Scanias axelfabrik. Problemet blev att källkritiken blev lidande. Man var tvungen att kritisera sitt eget arbete utifrån egen synpunkt. Nya monteringsmetoderna, efter att de blivit utvärderade och man konstaterat att de kan anpassas till Scanias axelfabrik, blev sedan redesignade för hur man skulle minska takttiden på bästa möjliga sätt och man tittade på hur designeffektiviteten förändrades och hur mycket man kunde minska takttiden med.

Ett viktigt inslag är att samarbeta mellan de olika departementen i företaget. Produktion och produktutveckling bör ha ett nära och djupare samarbete. Ett koncept som ska utvecklas och skapas bör. Produktutveckling och produktion bör kompromissa sinsemellan utan att produktens egenskaper ska försämras.

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Abbreviation

Acronyms, abbreviations and other common terms used throughout the master's thesis are listed below in alphabetical order.

BAX	Back Wheel Axle
CM	Cost Manufacturing (Total assembly cost)
DA	Driveline Axle factory
DFA	Design For Assembly
DFMA	Design For Manufacture and Assembly
DFX	Design For X
DG	Driveline Gearbox
DT	Driveline Transmissions
DTTB	Driveline Transmissions Technical organization group B
FAM	Flexible Automatic Assembly (in Swedish)
FAX	Front Wheel Axle
MFD	Modular Function Deployment
NA	Construction Department
NM	(Theoretical part count)
SAM	Stiff Automatic Assembly (in Swedish)
SAX	Special wheel Axel
SPS	Scania Production System
TM	Time Manufacturing (Total assembly time)
QFD	Quality Function Deployment

1 Introduction

This chapter presents an introduction to the background of the master's thesis, as it clarifies the aim and objective of the thesis, as well as which demarcation has been made.

1.1 Background

It has come to the awareness of many companies that there is a great need to develop a domestic product to maintain the competitiveness as well as the industrial jobs in the nation. Despite the improvement work that has been implemented in many places, there is still undetected and unused production capacity. [LTH-Industrial production [internet, 5] (in Swedish)]

Scania's worldwide goal is to manufacture and deliver 150 000 vehicles in the near future. That is 120 000 trucks and 30 000 buses. The changes require that all departments will face enormous challenges to achieve future requirements.

In order to increase the capacity of the production, the wheel axle factory started a number of development projects to reduce the internal component variations and to transform today's structural construction of wheel axles. Scania's goal represents a challenge to the wheel axle factory: to decrease the rate of assembly tact time (production tact time) by about 50% of today's tact time of 84 seconds for the front axle and 89 seconds for the rear axle. With today's product design, line system and assembly methods, it is almost impossible to further decrease assembly tact time.

Scania's wheel axle factory is continuously working on improvements and wants to discover and utilize the capacity of the production that may exist but not be used in the factory. But further reducing the assembly tact time per axle requires a lot of changes in today's product construction and assembly methods. Because of that it is necessary to analyze and improve the production process and its methods in preparation for the increased demand for production capacity.

To reach these aims, new construction proposals and new assembly methods must be applied and implemented to the current product. Focus should be on decreasing the assembly tact time to accomplish the goal; close collaboration between design and production department is also necessary.

1.2 Aim and objective

Scania's wheel axle factory is now faced with the challenge of producing even more wheel axles per year to cope with the high order intake which is estimated to occur in the future. It is also interesting to optimize the efficiency and production capacity to produce a larger number of wheel axles per year and to increase the profit margins, and reduce the production costs.

As the production volumes at Scania are expected to increase, the wheel axle assembly lines need to be prepared to handle the increased workload. When the volumes increase and the needs get higher, the current system and the current product design will run into bottlenecks requiring new assembly solutions and a rebalancing of tasks. To meet these desires, the wheel axle factory has to reduce today's tact time to be able to deliver in time. Tact time means the time which is required for a wheel axle to be assembled and ready to deliver. Reducing the tact time by about 50% would almost be an impossible task using today's product design. This places huge demands on the solutions having to be developed. The production must be efficient and take ergonomics and quality into account.

1.2.1 Objective

i. The objective is to identify how the assembly methods and interfaces should appear to enable the aim. The report will be used as a guide for future production/construction projects.

1.2.2 Aim

The aims of this master's thesis are:

i. To propose some effective assembly methods which can be applied in Scania's wheel axle factory.

ii. To determine the wheel axle assembly layout in 2022 (31 seconds tact time and ergonomics).

1.2.3 Distinctions

In this thesis, only the product range that Scania wheel axle factory manufactures has been taken into consideration. The product range only covers the rear axles, also called BAX.

Front axles (FAX), Special axles (SAX) and other products through Scania wheel axle factory manufactures, have not been analyzed to any significant degree, although front axles have a lot in common with BAX. The thesis will not result in the future final product solutions, but will instead provide suggestions for solutions to problems. The project should be considered as the first step in the product development phase. Further delimitations are made because of the time period of 20 weeks as the timeframe for the thesis. No cost estimate will be implemented.

1.3 Outline

The report is structured in the same order as the various steps undertaken during the project. First the methods are described to better understand them as they are mentioned in the text. Then the preliminary work describes the studies conducted before focusing on idea generation and development of solutions. With that follows a presentation of developed proposals and screening them, after which we move on to a detailed description of all components. Finally, the results are described and reflections are made.

1.4 Directive

The first directive from Scania's wheel axle factory was to work at assembly lines and experience as a fitter how to assemble a wheel axle and get familiar with the product. The second directive was that the main focus should be on the modules and their interfaces. The purpose of the modular system is to reduce the current axle assembly tact time. How and which focus areas need to be studied was not clarified from the beginning. After the first meeting with our group manager and supervisor at DTTB,[1] it was determined that the focus area would be on the module candidates and their interfaces. The module candidates are based on an earlier master's thesis.

We were supposed to investigate the module candidates and to look for possibilities and difficulties in implementing them in the front and back assembly lines. The focus was also on how the assembly lines would be affected by the implementation of the module candidates and to make a visual layout of the assembly lines. After one and a half months of studies and several discussions with group managers from DTTB, NAA[2] and DTTA[3] it was realized that the thesis was too comprehensive and difficult to implement, and that it would be difficult to reach a good result. It was determined that the thesis needed to be at a more reasonable level. The final outcome was to identify and propose some future assembly methods that would allow reduction of the current assembly tact time with Scania's wheel axle factory.

[1] DTTB is one of five groups in the organization Driveline Transmissions, and works on technical issues from the wheel axles of Scania's axle factory. DTTB is an abbreviation of Driveline Transmissions Technical Organization Group B.
[2] NAA is a design group for wheel axles.
[3] DTTA is one of five groups in the organization Driveline Transmissions, and works on production issues from the wheel axles of Scania's axle factory.

2 Description of the company

This chapter provides a description of Scania CV AB (Scania Commercial Vehicle Ltd/Inc.) and the wheel axle factory, and the product range that the wheel axle factory delivers to Scania chassis assembly factory in Södertälje and the remaining production units in Europe.

2.1 Scania CV AB

Scania is one of the world's leading manufacturers of trucks, buses, engines and service both nationally and internationally. With their long experience in truck manufacturing, Scania provides unique solutions that are not only customer specialized; they can also find customized solutions that are exactly what the customer needs and desires. Scania is constantly working at having a close relationship with their customers and thus being able to satisfy each customer's needs and desires in the best possible way [Scania official homepage [internet, 3]].

Figure 1: Scania produces and sells trucks, buses, and industrial and marine engines [How Scania is managed, December 2011].

"*Scania's aim and vision is to be the leading company in its industry by creating lasting value for its customers, employees, shareholders and other stakeholders*" [Scania official homepage [internet, 2]].

Scania Started in 1891. Scania is a multinational company operating in over 100 countries. About 95% of the production is exported. The total number of employees worldwide is today about 35.000. In 2010, Scania's production reached 56 837 trucks, 6875 buses and 6526 engines. Scania's net sales in 2010 hit a record [Scania's year-end report, 2010].

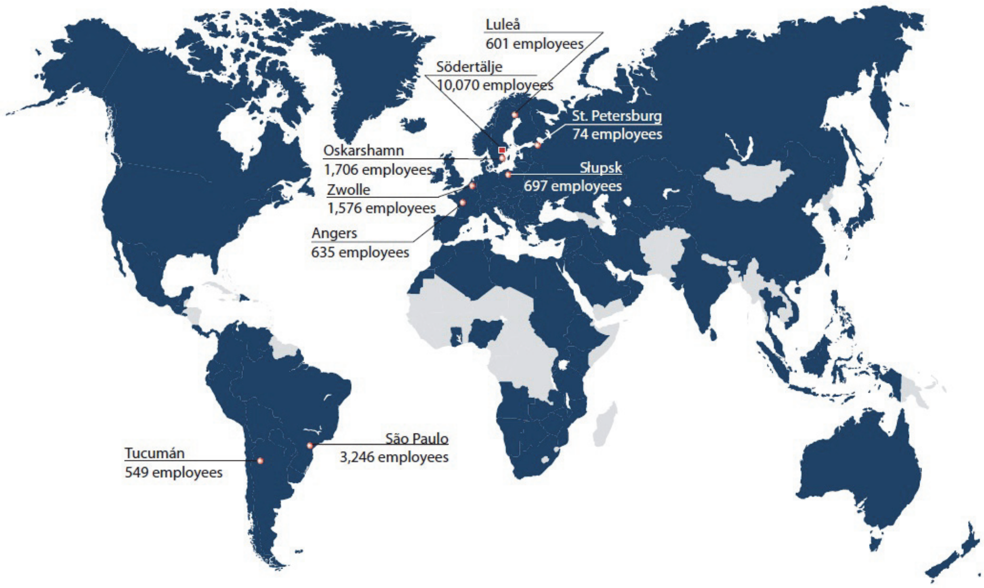


Figure 2: Scania worldwide 2011-2012 [How Scania is managed, December 2011].

In Södertälje (Sweden), truck and bus production consists of three major units, Engine, Transmission and Chassis. The engine and transmission units supply their product to Chassis where trucks and busses are assembled and then delivered to the customer.

Scania has acquired a brand that speaks of quality and of services that the costumer can feel safe and satisfied with. Scania is working at continuous improvements to maintain its leading position over rivals all over the world and to offer the customer the best solutions and the lowest total cost. Demand is constantly changing as are the market with new and increasing demands for transportation funds. This means that an organization like Scania must not only have an awareness of these changes but be the first to find solutions in order to be world leading on the market.

Scania's ambition is to develop, produce, sell and service the market in terms of superior trucks, buses and engines in the heavy segment, and provide the costumer with the lowest possible total cost. Scania wants to offer products for different transport tasks with great profitability for both the customers and for the corporation. Scania has worked consciously on certain basic principles that consist of three core values. Employees at Scania value them high and the core values are “Customers first”, “Respect for the individual” and “Quality”.

By saying “The customer first” Scania believes that one should work with the goals that will satisfy customers’ requirements and preferences and be able to find the best solutions to various problems that customers might encounter. In other words, to be the best in the industry and to find solutions which are modified specifically to customer needs and desires.

“Respect for the individual” covers the part where all of employees should be equals no matter what their position is. Everyone should feel that they are on the same level and that what they contribute to the company is of great value regardless of their background and working position. By practicing how to pay respect to your fellowman internally, one creates a comfortable environment to work in, which benefits all parties. You also learn the importance of how customers should be treated.

The final bottom line is self-evident, quality. Scania is known for its product quality, i.e. quality of products has been a matter of course for Scania’s product policy. Quality of work environment, service and product lifecycle support benefits customers just as much as Scania. These core values make Scania a powerful competitor organization as they keep Scania united. Scania is constantly improving production quality, which is also why Scania has been successful for as many years as the company has been producing vehicles and engines.

Scania’s Production System (SPS) and modular product system were built up over several decades and make it possible for the company to create individual specifications for a large number of different customers by using a limited number of components in its product range. The module program provides smaller component variations and the more common products between trucks, buses and other components. This enables each customer to receive an optimized product, while keeping costs throughout the value chain at a more competitive level than otherwise possible. The modular system aims to understand customer needs and then customize the product to the needs [Scania internal homepage [internet, 7]].

2.2 The wheel axle factory

Scania's Wheel Axle and Gear Factory DT (Driveline Transmissions) is located in Södertälje, Sweden, after it was moved from Falun, Sweden, in 2008. The Axle and Gearbox factories (DA and DG) were two small separate organizations from the beginning, but in the summer of 2010 they merged into one organization named Driveline Transmissions, DT.

Scania's philosophy is to have efficient and profitable product solutions. By having both development and production sites as close together as possible, Scania give their employees unique opportunities to develop products, and these predictions lead to Scania being a successful organization in the industry. This was one of the most central reasons why Scania wheel axle was moved closer to the research and development centers in Södertälje.

The wheel axle factory assembles and delivers front-, rear- and tag-axles to all production sites in Europe, i.e. Södertälje in Sweden, Zwolle in the Netherlands, and Angers in France. In total, about 600 axles, designated for around 250 vehicles, are produced each day. Nearly 400 people work in the front-, rear-, and tag-axles production. Axles are assembled from incoming components and painted before being shipped out to Scania's assembly units around Europe.

Within the wheel axle factory, the axles are produced in three separate lines; one for front-, one for rear-, and one for special-axles. The front and rear lines are divided into different zones and in every zone there is a different station where the components are assembled on the axles. The workflow in the assembly line begins with an order, which is processed at each assembly zone along the assembly line. A simplified version of the assembly flow is visualized in the figure below. Each zone (only five in the example) is represented by a rectangle in the figure and the box flow through the assembly is represented by a flow arrow.

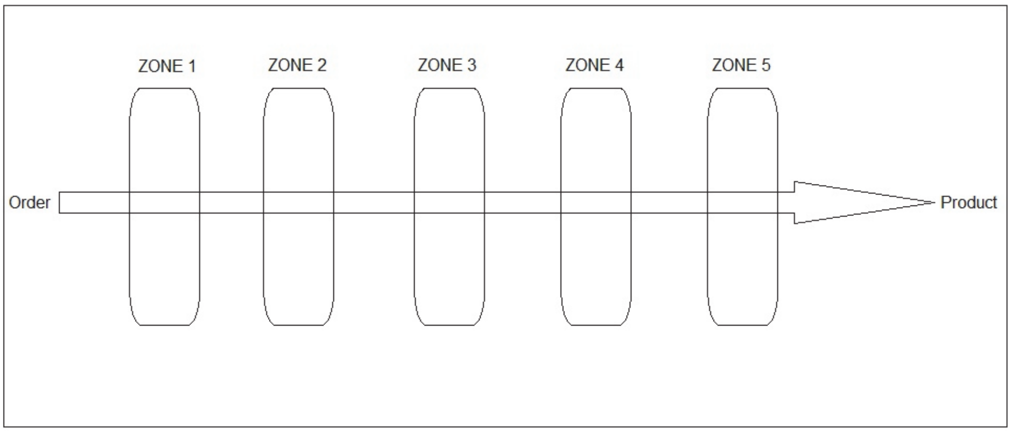


Figure3: Simplified model of the assembling front and rear axle flow.

2.3 The product at Scania's wheel axle factory

Scania's wheel axles may come in many configurations in order to adapt to the customer's individual need. Although one wheel axle may be altered, by changing one or several of the wheel axle's detailed components, the wheel axle is often divided according to the general classification that there are three types of wheel axles, front, rear, and tag axles, which all play a specific role in the vehicle. With these three types, the vehicle is able to steer, carry different types of load, brake, and transmit energy from the engine out to the tires. Besides these features the customers are today able to chose between two braking systems, two different types of suspension, or if the wheel axle should be equipped with a hub reduction gear, and the number of driven wheel axles. [Ramnell G., Jansson R. (2011). Modularization of Wheel Axles].

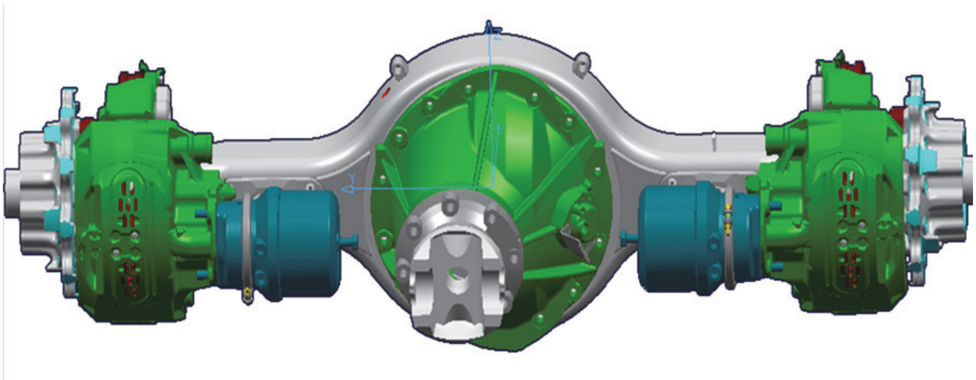


Figure 4: Rear axle housing.

3 Theoretical frame of references

The main focus in this chapter is DFMA and DFA, but also the importance of the product development and modularity. Design is a significant keyword in this chapter.

3.1 Product development

In an increasingly competitive world, product design and customer service may be the ultimate way to distinguish a company's capabilities. Because of the growing importance of product design, Design for Manufacturability and assembly, and Integrated Product Development concepts will be critical. It will be the key to achieving and sustaining competitive advantage through the development of high quality, highly functional products effectively manufactured and assembled through the synergy of integrated product and process design [Design For Manufacturability [Internet, 8]].

3.2 An Introduction to Modularity

How can you make a customized product at the cost of a mass-produced product? This is a question more and more companies are facing today and in the future. Also the companies are struggling to compete with other companies by increasing quality and reliability and to reduce cost and be more efficient. Engineers are facing a fast evolving technology and more complex tasks. The lifetime of a new generation of products is decreased; many car manufacturers introduce a new generation model every 5 years instead of every 10 years because of the competition and the quick technological advancement. All this pressure on companies is forcing them to think in other directions and forces them to solve the problems quick. It is happening in every company.

To cope with the new demands and harsh environment, companies should look at modularization. But what is modularization?

To define modularity is difficult because of its wide variety. We can find modularity in architecture, we can find it in the military, we find modularity in the vehicle industry, and we'll even find it in software companies. We find modularity in the past and we can see it in the present and we will definitely see it in the future.

In the Roman era we can find, in the book "Ten Books on Architecture" (De architectura libri decem), some modularity. The author, Marcus Vitruvius Pollio, wrote about laws on proportions and symmetry in temples and columns and so created a standardized measurement to be used in architecture [Elgård & Miller, 1998].

The Romans also divided their army in module-like relation. The Roman Legion consisted of 10 cohorts. The basic organization of the cohorts within an Imperial legion was as follows:

- 1 contubernium = 8 soldiers
- 1 centuria (century) = 10 contubernia = 80 soldiers
- 1 cohort = 6 centuriae = 480 soldiers
- 1 legio (legion) = 10 cohorts = 4800 soldiers

This gave the Roman army manoeuverability so that the troops could easily be ordered, formed or divided into organized formations.

During the Bauhaus era (1919-1933) the German architect Walter Gropius for the first time combined the idea of standardization with functional thinking and industrial production in building construction. The module was linked to a building block concept (Baukasten), where the building blocks were functional units in buildings, e.g. kitchen, living room, bedroom, etc. The purpose of the Bauhaus building blocks was to create buildings in a more rational way by standardization and prefabricated materials and to be able to make a more thorough and efficient planning [Elgård & Miller, 1998].

Definition of a module changed from a building block to a building block with functionality. But what is a building block with functionality?

An easy example is the fast-food restaurants. When you order a meal you can get a hamburger, fries and something to drink. The hamburger, the fries and the drink are building blocks that create our products. But are the building blocks modules? The answer is yes, because you can order just the hamburger or the fries or the drink, and it will have a purpose according to whether you are thirsty or hungry, or both. The meal consists of modules and fast-food restaurants are a good and easy example to understand the fundamental elements of module-systems. When you order a meal you have a variety of different hamburgers to choose from, you can choose chicken-burger, vegetarian, etc. You can choose a small, medium or large size of fries; you can choose different beverages, like Coca-Cola, water, juice, milk, etc. You can even add an extra hamburger; all this gives you a long range of variety. Offering such variety is all about satisfying the customer.

If you disassemble a car, you will find an engine, a gearbox, an exhaust system, etc. A motor could be a module because it has a purpose and can be used by several models; it can also run without being assembled. What about a gearbox? Although you could use it for several models it has no purpose if it is assembled, but it is still a module.

3.2.1 Demands on Product Design

The globalization of the industrial market has in many ways meant considerable difficulties for many managers. Continuous changes of customers' demands and new arising markets categorize the reality of today's market place. According to [Erixon, et al. 1996] company and production managers have to consider the following complex tasks to be able to fulfill the future customer demands and to keep a strong competitive advantage among other companies:

- Keeping an ongoing struggle for lowering cost through the whole company, due to globalization.
- Managing many different customer demands.
- Reducing product lead-time.
- The amount of work in process has to decrease within the whole process.
- Reducing product development time.
- Being able to cope with changes in variations in volumes, and for adoptions to variety and differentiation.

- Increase efficiency in the manufacturing system.

These problems will, or in some aspect already are, causing companies struggle and it can be difficult to manage this problem as a whole. But in order to remain competitive in an increasingly tough market, the company must consider these problems. To manage them, companies have to continually work with improvements because there is no quick fix to these kinds of problems [Erixson, 1998].

3.2.1.1 Influences on the product design

Many advantages are linked to modularization, such as standardization, fewer parts and a great product variety. By building-block components and subassemblies, the assembly will be easier and time efficient. This modular or building-block design would minimize the number of part or assembly variants early in the manufacturing process while allowing for greater product variation late in the process during final assembly. The benefits will be reducing inventory, improving quality and minimizing the total number of items manufactured. Modules can be manufactured and tested before final assembly. The short final assembly lead time can result in a wide variety of products being made to a customer's order in a short period of time without having to stock a significant level of inventory. Production of standard modules can be leveled and repetitive schedules established.

Standardize and use common parts and materials to facilitate design activities, to minimize the amount of inventory in the system, and to standardize handling and assembly operations. This will result in lower inventories and reduced costs but also higher quality. Simplified operations result in quick learning and the opportunity for automation is increased due to higher production volumes and operation standardization. One should limit unique components because suppliers are less likely to compete on quality or cost for these components.

3.2.2 Quality Function Deployment

The modular candidates are based on Quality Function Deployment evaluation.

Quality Function Deployment was developed by Yoji Akao in Japan in 1966. QFD is a visual decision making tool which shows how closely existing and proposed measures of a process are matched with customer needs.
Ultimately the goal of QFD is to translate often subjective quality criteria into objective ones that can be quantified and measured and which can then be used to design and manufacture the product. It is a complimentary method for determining how and where priorities are to be assigned in product development [Reilly, 1999].

In Akao's words, QFD "is a method for developing a design quality aimed at satisfying the consumer and then translating the consumer's demand into design targets and major quality assurance points to be used throughout the production phase. QFD is a way to assure the design quality while the product is still in the design stage." As a very important side benefit he points out that, when appropriately applied, QFD has demonstrated the reduction of development time by one-half to one-third [Akao, 1990].

The three main goals in implementing QFD are:

1. Defining customer wants and needs.
2. Developing number one into technical specifications.
3. Constructing a quality product or service fulfilling customer satisfaction.

There are four phases of a QFD:

1. Defining customer's needs and requirements and product planning.
2. Transforming Phase 1 into technical specifications and design planning.
3. Processing and manufacturing planning.
4. Establishing process control methods and parameters. Analyzing performance and quality.

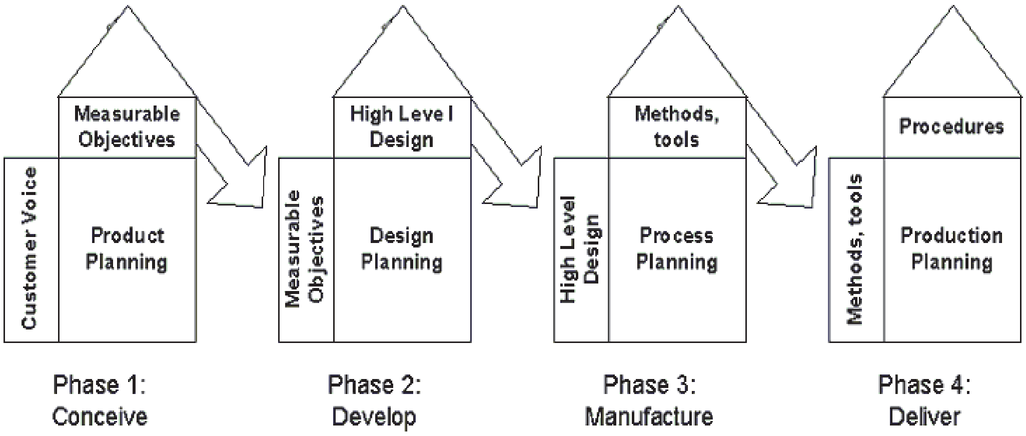


Figure 5: QFD life cycle.

3.2.3 Modular Function Deployment

Throughout the industrial era companies and universities tried to develop tools and methods that could improve a company in ways regarding the products and the services a company offers. This is to improve the efficiency of a company, the profitability and the quality.

Gunnar Erixon developed a method called modular function deployment (MFD). The aim of the method is to find an optimal modular product design especially formed for a certain company.

- First step: Define customer requirements. With a Quality Function Deployment (QFD) analysis the company should be able to fulfill a customer's demands. With the results the QFD method transforms customer's demands into design quality. With this output from the analysis those properties of the design in which the product must satisfy are defined.
- Second step: Select technical solutions. The analysis from step one becomes the basis for determining the technical solutions. The product is then divided into functions and sub-functions with the purposes to fulfill customers' demands and to smooth the progress of the construction of modular product designs. Pugh selection matrix, which is an evaluation matrix, is used to choose the best product design.
- Third step: Generate modular concepts. The technical solutions are evaluated to determine which parts should be separate module candidates. Other reasons of determining if design should become

modules are also considered. At the end the technical solutions with the same module driver are at this point clustered together in the Module Indication Matrix (MIM). First concept sketches are in progress too.

- Fourth step: Evaluate the modular concepts. In this progress the interfaces are important to evaluate because it will be an important part of the modular product. The flexibility and the benefits of determining interfaces at an early stage are crucial to having an effective modular design. In addition to the interface evaluation, the economical aspects are considered in this phase.
- Fifth step: Improve each module. MIM is used to improve and optimize each module. Prioritizing what is essential for the respective modules makes the design ideal. A module specification document is created to visualize and concretize the product.

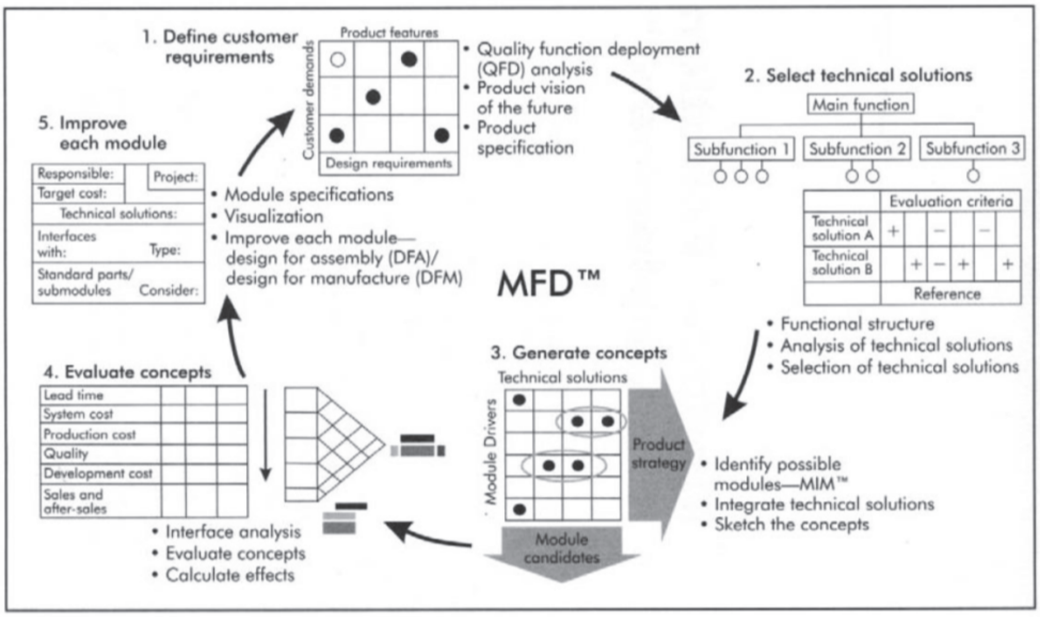


Figure 6: The five main steps of the MFD method in a lifecycle [Ericsson & Erixon, 1999].

3.3 Methodology

There are several design methods available to support product development. The methods are focusing on the assembly aspect/parts in the beginning of the design phase even though the assembly part of a product is the end of production processes before the product is delivered to a customer or another subdivision. The methods are used to avoid well-known production problems from the conceptual phase to deliver the product to the market, including manufacturing and assembly problems. The objective of the methods is to make sure that manufacturing and assembly problems that are likely to occur in the production processes are eliminated before the products are delivered.

It is not economically justified in the long run to make the same mistakes repeatedly, only to discover them later in the development processes [Stephan Eskilander et al, 2001]. A survey in printed circuit board (PCB) assembly industry revealed that engineers claimed that more than 70% of the manufacturing problems are problems that have happened before [Stephan Eskilander et al, 2001].

The theoretical basis for some methods that can be used during a product development is presented below.

3.3.1 Design for Manufacture and assembly

Design for Manufacture and Assembly can be abbreviated DFMA. DFMA is a system combined of two methodologies: design for manufacture or design for manufacturability (DFM), and design for assembly (DFA). According to [Boothroyd G., Dewhurst P. and Knight W. et al. 2011] The DFMA method was developed to evaluate the design for ease of manufacture of the product parts and the design of product for ease of assembly. The objective of DFMA was to produce tools which could be used by product designers, and these tools were supposed to guide the designers or design teams to know where the problems in a proposed design lay.

The practice of applying DFMA is to identify, quantify and eliminate waste or inefficiency in a product design. DFMA is a system comprised of various principles that will improve the ability for a design to be easily manufactured and assembled.

This system can be divided into three major sections. The first is the raw material. Choosing the right material is the foundation of a good design. The second is the machines and processes used to work the raw material. The right process is essential for creating finished parts that will meet your design requirements. The third is the assembly of the product. It is during the assembly of the finished product that the greatest opportunity to apply DFMA principles is provided.

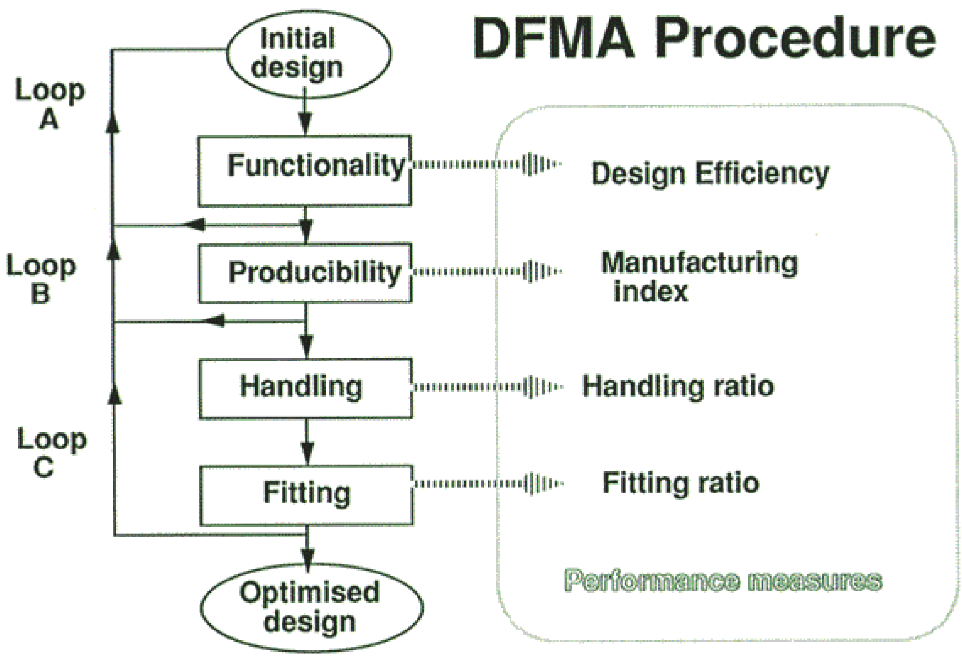


Figure 7: DFMA procedure

In the 1960s, there was much talk about designing product parts in many separate parts so that they could be manufactured more easily. They supposed that several simple-shaped parts are less expensive to manufacture than a single complex part. Today's manufacturing technology makes it possible and less expensive to manufacture or produce complex product parts than before. To assert that many simple-shaped parts are less expensive to manufacture and that the assembly time and cost is more offset by the savings in part cost would be a mistake.

Product design and assembly should be mistake-proof so that the assembly process is unambiguous. Components should be designed so that they can only be assembled in one way; they cannot be reversed. Notches, asymmetrical holes and stops can be used to mistake-proof the assembly process. Design verifiability into the product and its components. For mechanical products, verifiability can be achieved with simple go/no-go tools in the form of notches or natural stopping points. Products should be designed to avoid or simplify adjustments. Of course, the additional cost of building in diagnostics must be weighed against the advantages.

The result in table 1 and figure 8 shows that the assertion was wrong.

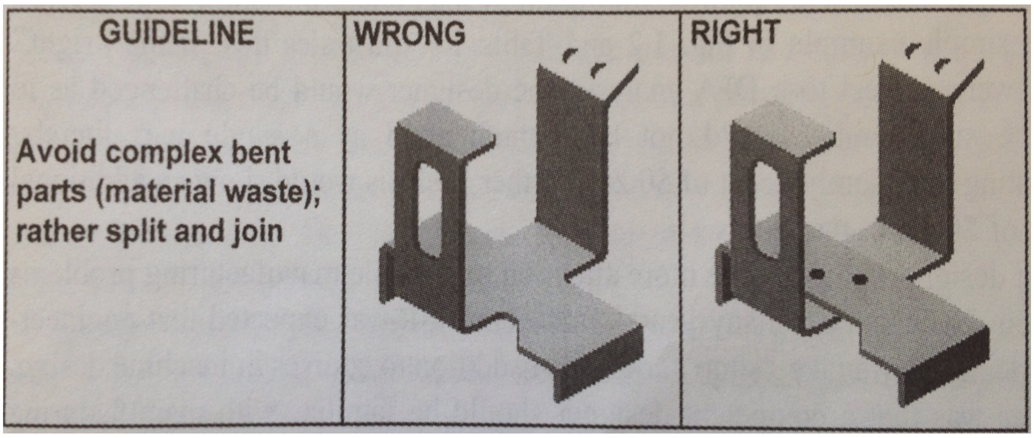


Figure 8: Misleading producibility guideline for the design of sheet metal parts [Boothroyd G, Dewhurst P. and Knight W. et al. 2011].

Table 1: Estimated costs for the wrong and right parts.

Estimed costs in dollas for the two examples in the figure above if 100,000 are made

Parts	**Wrong**	**Right**
Setup	0.015	0.023
Process	0.535	0.683
Material	0.036	0.025
Piece part	0.586	0.731
Tooling	0.092	0.119
Total manufacture	0.678	0.850
Assembly	0.000	0.200
Total	0.678	1.050

Once methods for analyzing assembly difficulties were developed in the 1970s, it became recognized that there was a conflict between producibility and assembly. It was found that the simplification of products by reducing the number of separate parts could easily achieve substantial reductions in assembly costs and even greater savings could be achieved in the cost of the parts.

According to [Boothroyd G., Dewhurst P. and Knight W. et al. 2011] the DFMA shows that extra time spent early in the design process is more compensated for by saving time when prototyping takes place. Thus, in addition to reducing product cost, the application of DFMA shortens the time to bring the product to the market. The figure below shows the time saving by implementing the DFMA in the product design process.

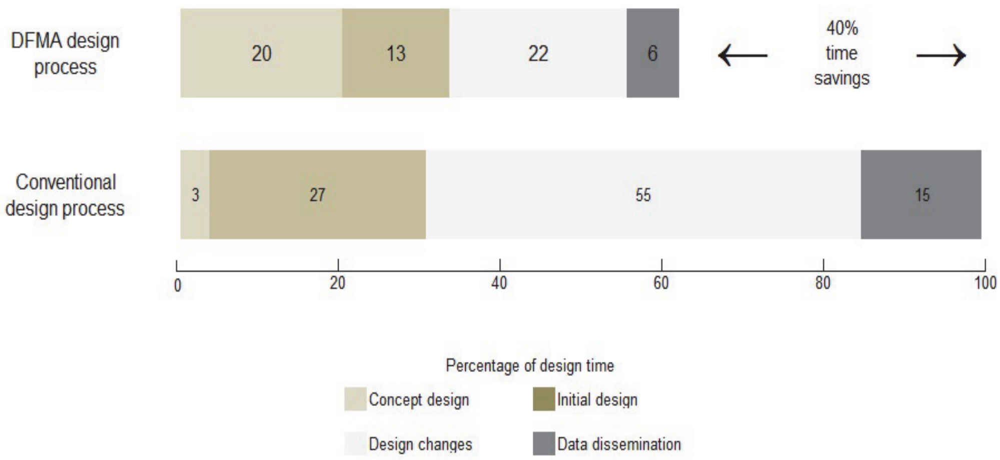


Figure 9: DFMA shortens the product design process.

3.3.2 Design for manufacture

The term Design For Manufacture (or DFM) refers to the manufacturing of the individual component parts of a product or assembly [Boothroyd G., Dewhurst P. and Knight W. et al. 2011]. According to Dr. David M. Anderson [2008] Design for Manufacturability is the process of proactively developing products to:

- Optimize all the manufacturing functions: fabrication, assembly, test, procurement, shipping, service, and repair.
- Assure the best cost, quality, reliability, regulatory compliance, safety, time to market, and customer satisfaction.
- Ensure that lack of manufacturability does not compromise functionality, styling, improvement programs, strategic initiatives, and unexpected surges in product demand.

Dr. David M. Anderson [2008] argued that early consideration of manufacturing issues shortens the product development time, minimizes development cost, and ensures a smooth transition into production for quick time to market.

DFM methodology encourages individual engineers and concurrent development teams to investigate additional processes and materials and to develop designs that may be more economical to produce. Toyota believes that having involved the manufacturing and production engineers very early in the design process is an effective way to highlight the manufacturing issues at the concept development stage. It has a positive effect on production costs and product quality, and time to market decreases.

Design for Manufacture provides guidance in the selection of materials and processes and generates piece part and tooling cost estimates at any stage of product design. The product design stage is important in the product development phase. Many surveys show that about 70% to 80% of the product costs is decided in the design phase. And by the time a product goes into production, 95% of its cost is determined, so it may well be very difficult to reduce the cost at a later stage [Dr. David M. Anderson, 2008].

The product design is not just based on good product or part design; the design should be possible to produce by manufacturing as well. Often an otherwise good design is difficult or impossible to produce.

DFM is a complement to design for assembly. Manufacturing engineers have already recognized the benefits of techniques like DFA, because they have spent many hours resolving difficult assembly problems after the design has been approved for manufacturing. When products are designed for manufacturing, it offers a tremendous potential for cost reduction by simplifying both the product and the related manufacturing system [S. Eskilander el at, 2001].

3.3.3 Design for assembly

The term Design For Assembly (or DFA) refers to the design of the product for ease of assembly. DFA is a methodology for evaluating part designs and the overall design of an assembly. The purpose of the DFA method is to identify and estimate the assembly efficiency and the assembly process and show where the opportunities for improvements are for the specific subassembly.

The DFA method is supposed to be used during the product development process and is considered in all stages of the design process for new products or existing products. The DFA method is used to reduce unnecessary product parts in an assembly and to determine assembly time and costs. By minimizing the product parts in an assembly, the assemble time and the assembly costs well be reduced automatically. If the product parts are provided with characters, which make it easier to grasp, move, orient and insert them, this also reduces assembly time and increases the design efficiency.

If the design is simplified and the number of parts reduced, this will decrease the probability of making a defective part and cause an assembly error. The probability of a perfect product goes down exponentially as the number of parts increases. The total cost of fabricating and assembling the product goes up with increased number of parts. Automation becomes easier and cheaper when fewer parts are handled and processed. Costs related to purchasing, stocking, and servicing also go down as the numbers of parts are reduced. This will of course affect inventory and work-in-process levels positively. This leads to simplified product structure and operations which leads to fewer fabrication and assembly steps being required, manufacturing processes can be integrated and lead times would therefore be reduced.

The designer should go through the assembly part by part and evaluate whether the part can be eliminated or combined with another part, or whether the function can be performed in another way [Design and assembly guidelines [Internet, 8]].

To determine the theoretical minimum number of parts, ask the following:

1. Does the part move relative to all other moving parts?
2. Must the part absolutely be of a different material from the other parts?
3. Must the part be separate to allow possible disassembly?

Select processes compatible with the materials and production volumes. Select materials compatible with production processes and that minimize processing time while meeting functional requirements. Avoid unnecessary part features because they involve extra processing effort and/or more complex tooling.

The method has also been developed to help designers and design teams to easy classification of the assembly difficulties and to estimate the total assembly costs of product or subassembly.

Generally, the DFA process follows by four steps and the points below shows what they are:

1. Select an assembly method for each part and strategy
2. DFA-analyze the parts for the given assembly methods for the product
3. Refine the design in response to shortcomings identified by the analysis
4. Loop to step 2 until the analysis yields a sufficient design

The acronym DFA was launched and developed by Professor Geoffrey Boothroyd in the early 80s when his book "Design For Assembly – A Designer's Handbook" came out. He presented a systematic approach, where the product design is analyzed individually on the assembly views.

3.3.3.1 Implementation of Design For Assembly

The purpose of implementation of the DFA method is to clarify the assembly processes, evaluate assembly efficiency and to determine the potential improvement of an assembly. The DFA method provides a systematic procedure for analyzing a proposed design from the point of view of assembly [Boothroyd G., Dewhurst P. and Knight W. et al. 2011].

3.3.3.2 The benefits of Design for Assembly

What are the advantages of implementing the DFA analysis? The basic rule and the most efficient result with the DFA analysis are to come up with a solution where you can reduce the number of product parts. This means that there are fewer parts to assemble, thereby increasing the product's assembly efficiency.

Design for ease of assembly by use of simple patterns of movement and minimizing the axes of assembly. Avoid assembling in different movements and directions. The design should be based on a base component usually with a large mass; with this base component it should have a low center of gravity so other components can easily be added to it. By assembling vertically with other parts added on top you could use the aid of gravity. This is an easy way to reduce time for temporary fastening or complex fixture and at the same time less need to re-orient the assembly. If the assembly can easily be assembled one should consider assembling with automation. Assembly that is automated will be more standardized, more reliable, and assure higher quality.

Herbetsson (1999) according to [Lindquist C. and Wester A., 2001] points out that there are two main advantages to performing DFA analysis in the product development team:

1. Potential problems are identified early and can be addressed directly rather than being discovered late in the development process.

2. Time of the product development decreases as work is performed in parallel. An example is that the design of the production system is begun before the product is finally formed.

The DFA method seeks to simplify product or part design, reducing the parts count by elimination of parts or combining multiple parts, and with it, it will be harder or almost impossible to make mistakes. It even results in a positive administrative handling, with fewer parts in stock. This in turn leads to less need for physical storage space, which leads to lower costs. One of the purposes with DFA analysis is to make it very hard to make a mistake.

A good performance of DFA analysis can reduce assembly time, increasing the design efficiency, giving lower assembly costs and also lead to better working environment.

3.3.4 Description of DFA-analysis

The DFA method purposes the integration or elimination of product parts, if it is possible, which makes it important that analysis undertaken by personnel who have good product knowledge and with various skills in order to avoid sub-optimization of the product. One must be aware of certain elements and design rules before implementation of assembly analysis.

- An index below 20% indicates that a redesign is being considered.
- Should discuss and make suggestions for changes in design that would facilitate the assembly and if possible reduce the count of parts.

DFA analysis indicates product´s efficiency as a percentage metrics, where a higher percentage means more efficient assembly process. A solution which consists only of a single component or part and is already ready to be used, gives 100% assembly efficiency.

In order to give guidance to the designer in reducing the part count and reducing assembly time, the DFA methodology provides three criteria against which each part must be examined as it is added to the product during assembly.

1. During the operation of the product, does the part move relative to all other parts already assembled. Only gross motion should be considered – small motion that can be accommodated by integral elastic element, for example, is not sufficient for a positive answer.

2. Must the part be of a different material or be isolated from all other parts already assembled? Only fundamental reasons concerned with material properties are acceptable.

3. Must the part be separate from all other parts already assembled because otherwise necessary assembly or disassembly of other separate parts would be impossible?

3.3.5 Other design for assembly methods

The principle of DFA method is to demonstrate the theoretical minimum counts of part needed to meet the product's functioning and in almost all DFA methods have the same consideration and objectives. But the methods' approaches differ slightly from each other.

Here are some names of DFA methods, which have been used by many companies worldwide. The principle of the methods is largely the same, and they show a good result if they are implemented properly:

- B & D (DFMA, Boothroyd & Dewhursts, 1988)
- DAC (Design for assembly Cost-effectiveness, SONY)
- AEM (Assembly Evaluation Method, Hitachi)
- LUCAS (Lucas Engineering and System and University of Hull)
- DAF2 (Design For Automatic Assembly, IVF)
- AviX DFX-DFA (Design for assembly, SOLME AB- balancing and methods)
- FMEA (Failure Mode and Effect Analysis)

The methods were developed during the last 30 years by different professors, PhD students and companies worldwide.

4 Production development

This chapter describes the challenges that many companies have to deal with in their project development and production processes. This chapter will also describe the steps that occur from conceptual phase to the final product.

4.1 Challenges with which production development is faced

Different activities that both product- and production development involve, and interactions of these, both with one another and with the market are shown in a schematic way in figure 10 In efforts to achieve both successful productions generally and high production values, one needs to deal as effectively as possible with chains of information that can often be difficult to grasp. There are 5 different feedback loops that can be noted:

1. A feedback loop that serves to maintain a balance between what is important to the customer and what is important from a production standpoint.
2. One aimed at ensuring that any adjustments in the product that need to be made prior to the start of production (2A) and the tools and the machining system that are needed are available and installed (2B).
3. A feedback loop for optimizing production while it is underway.
4. One for optimizing the value of already established products from the customers' standpoint, and the production values achieved in manufacturing them.
5. A feedback loop aimed at utilizing experience gained in connection with established products for optimizing new products and new production systems.

Loops 1-5 provide the basis for a variety of different challenging production-related research and development projects.

Examples of challenges in production and development research.

Loop	Examples loop-for loop of the different challenges involved
1.	a. Assessment of the production value achieved through changes in the material and the design of an already established product. b. Assessment of the manufacturing costs in the case of varying production volume (due to difference in demand).
2.	a. Involvement of competing subcontractors in connection with adaptation of a product during manufacturing. b. Use of freed production capacity for the manufacture of newly developed products, and concrete relationships between product development strategies and investment strategies in deciding upon new production equipment to employ. c. Utilizing information and experience concerning current or earlier production in new product and production system development.
3.	a. Maintaining and enhancing strong mutual dynamic effects achieved through interactions between administrative and developmental functions as shown in Fig. 2 earlier (so as to develop and improve competence at all levels in the company). b. Organizing and employing the production data that has been collected so as to provide an adequate basis for environmentally based decisions. c. Optimizing production processes from an environmental standpoint without this being based primarily on economic incentives. d. Obtaining key performance indicators relating directly to the manufacture of a given part.
4.	a. Involving computer subcontractors in the task of optimizing a product or part with the aim of improving its producibility, i.e. for increasing its production value.
5.	a. Systematizing knowledge and experience gained from production that is already underway (or was carried out earlier) for use of it in product development and in the development of new products.

More concrete technological challenges are those concerned, for example, with use of lead-free work material that can make the machining of many components, particularly those of small dimensions, more difficult, and also challenges connected with sustainable development involving machining carried out with reduced amounts of process additives such as cutting fluids or oil. Production steps such as those of grinding, for example, which is energy-demanding and environmentally troublesome, can be avoided by increasing the degree of hard machining carried out, i.e. the machining of components consisting of hardened steel.

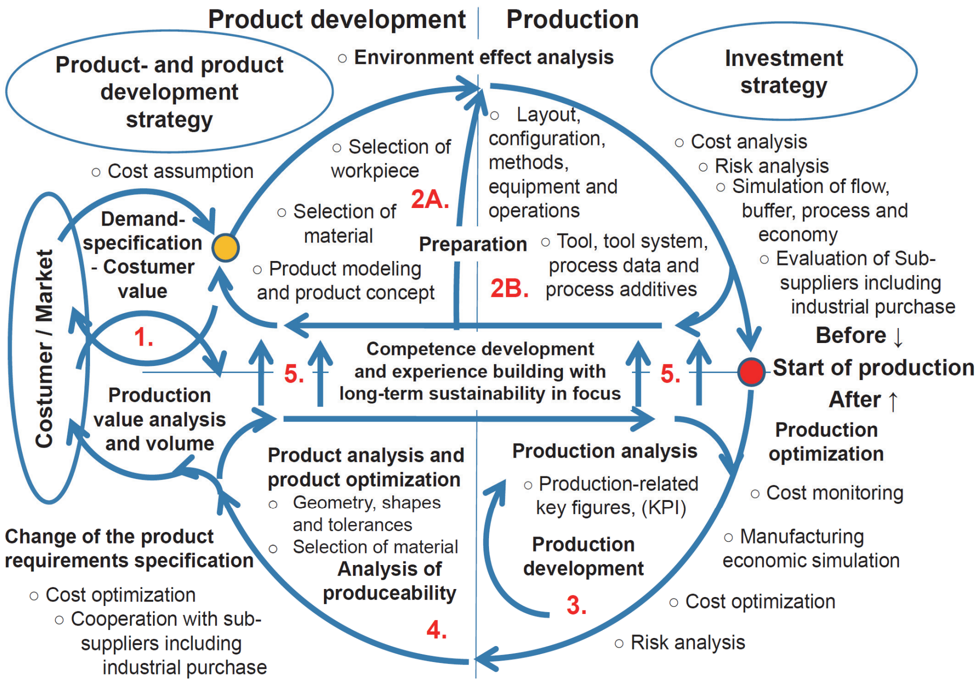


Figure 10: Diagram of the continual interaction between the market, product development and production, which leads to successive increases in value to the customer and in production value, partly through its resulting in increased product ability and in a lowering of part costs, which can be seen as representing or leading to a NEXT STEP technology.

5 Assembly methods

This chapter describes different assembly methods that could be useful in Scania's wheel axle factory. These assembly methods are gathered from different companies and Internet searches. The advantages and disadvantages are also described.

5.1 Tube clamps

Figure 11: Using tube clamps.

First open fully and place tube. Second pre-assemble by squeezing the bracket. End by squeezing the clamp joint.

- Smooth pipe mounting.
- Fast, easy and secure locking.
- Effort-saving mounting method.
- Quick clamping – just press the screw by hand. No tools are required.
- Fine adjustment of the locking bolt with metric thread. It also gives you the possibility to loosen and straighten tube position afterwards and then lock by pushing on the screw again.
- Opened as usual with slot or crosshead screwdriver.

5.2 Hose clamps

Hose clamps are made in a variety of types to match load, assembly, and cost specifications. Although there are many modifications within each type, the four major ones are worm-gear drive, latch, ear, and quick-connect straps. Worm-gear metal hose clamps are available in different sizes for many load conditions. Most have a smooth internal face to avoid damage to hose surfaces. Latch clamps often have a ratchet tooth-locking action to retain clamping load. Typically used for light loads, the clamps are tightened into place with pliers. Single-use ear clamps are usually applied in light-load situations. The clamp is slipped over a hose or duct and the ears are crimped with special tools. Quick-connect straps are suitable for large-diameter ducts and light loads. The strap is pulled to a loose fit, and then tightened by turning the screw.

Figure 12: Different types of hose clamps [Steel and stainless steel hose clamps [Internet, 6]].

5.3 Snap fits

Although they have been around for many years as an assembly method, they haven't been popular. But recently companies have discovered their flexibility and how simple they are. Snap fits are very useful because they eliminate screws, clips, adhesives, and other joining methods. Depending of the design they can be disassembled and reassembled several times without any problems. Also, snap fits can be designed as a permanent snap or as a multiple snap. The difference between permanent and multiple snaps is that it either requires disassembly of the product or not; permanent snaps are used as disposable parts that are never meant to be disassembled, while multiple snaps are used in most designs where disassembly for service is required.

Benefits with snap fits:

- An integral element part – no other components
- Can replace screws, nuts, and washers
- Easy automation can reduce assembly costs
- No other fasteners, adhesives, solvents, welding, or special equipment
- Design can minimize risk of improper assembly
- Can be designed to engage and disengage

Things to be aware of when using snap fits:

- Some designs may require more complex or expensive tooling
- Snap fits that are assembled under stress will creep
- It is difficult to design snap fits with hermetic seals. If the beam or ledge relaxes, it could decrease the effectiveness of the seal.
- Can be damaged by mishandling and abuse prior to assembly

While designing for screw assembly is easy, a proper snap fit design will be more complex and requires more time of engineering. This generally means that parts will be more expensive and complicated to produce but the gains and savings in assembly costs will be much higher than the added cost of the redesign of the parts for the snap fits.

There is a considerable amount of calculation and engineering that goes into designing a good snap fit; this section will show different design techniques.

Snap-fit joints are the most widely used way of joining and assembling plastics. They are classified according to their spring element and by separatibility of the joint: Will it be detachable, difficult to disassemble, or permanent? The most common snap fit is the cantilever. It is based on a flexural beam principle where the retaining force is a function of the material's bending stiffness.

5.3.1 Snap fit cantilever

The most common snap fit is cantilever. Typically, a hook is deflected as it is inserted into a hole or past a latch plate.

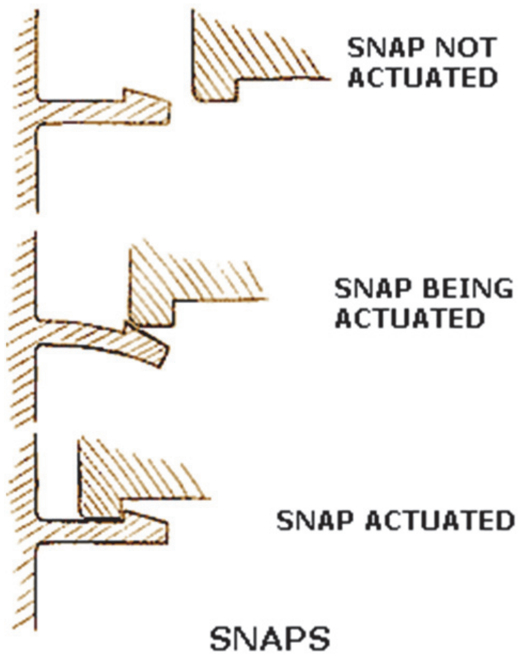


Figure 13: Shows a typical cantilever snap fit.

Figure 14 shows four different methods of designing snap fits regarding disassembly.

Figure 14-a shows a snap fit design, which cannot be disassembled.

Figure 14-b is using an angled surface for both the cantilever and the nook. This means the cap can be disassembled with the same force used for assembly.

Figure 14-c has the same design as 4a but the designer put a window from the side to allow the snap fit to be disengaged for disassembly.

Figure 14d uses a U type beam to disassemble the snap from the outside.

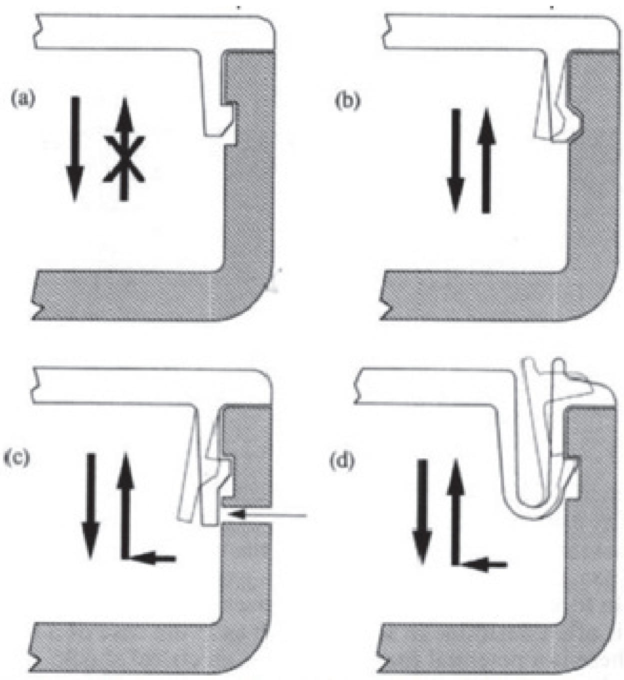


Figure 14: Shows different disassembly methods.

There is a difference between figure 14c and figure 14d because of the possible risk that the snap fit breaks. In figure 14c we can see that we can push the snap fit too far and it can break. If this happens it is usually impossible to repair the snap fit. While in 14d one can only push it to a limited stop; this is something one should keep in mind when designing the different snap fits.

5.3.2 Torsional snap joint

The second most widely used is the torsional snap joint. Deflection comes from torsional deformation of the joint's fulcrum and shear stresses carry the load after assembly.

5.3.3 Annular snap joint

There is a third type of snap fit, and that is the annular snap joint (ASJ). An easy example is the ballpoint pens with snap-on caps but also child-proof caps on medical bottles. A part doesn't have to be annular if one should choose ASJs. ASJs could easily be chosen for compact and solid joints. Although ASJs are generally stronger, they need greater assembly force than the cantilevered types.

The smaller-diameter male component (plug) has a bump or ridge feature around its circumference. The ridge diameter is slightly larger than the inside diameter of the mating tube-shaped female hub. Key to ASJ operation is to make the plug from a more rigid material than it’s mating female hub. Then the ridge will deflect the hub outward. Deflection imposes a relatively high once only or repeated short-term load (hoop stress) distributed along the axis of the hub as the plug slides into it. The ridge feature engages into an undercut grove molded into the inside diameter of the hub, at which point the assembly returns to a stress-free condition.

5.3.4 Molded snap fits

As stated at the beginning of this section, adding snap fits can significantly increase the complexity and cost of the mold. It is important to understand the implications of the part design on the moldability of the part. Many times, seemingly minor part design changes can greatly decrease mold complexity.

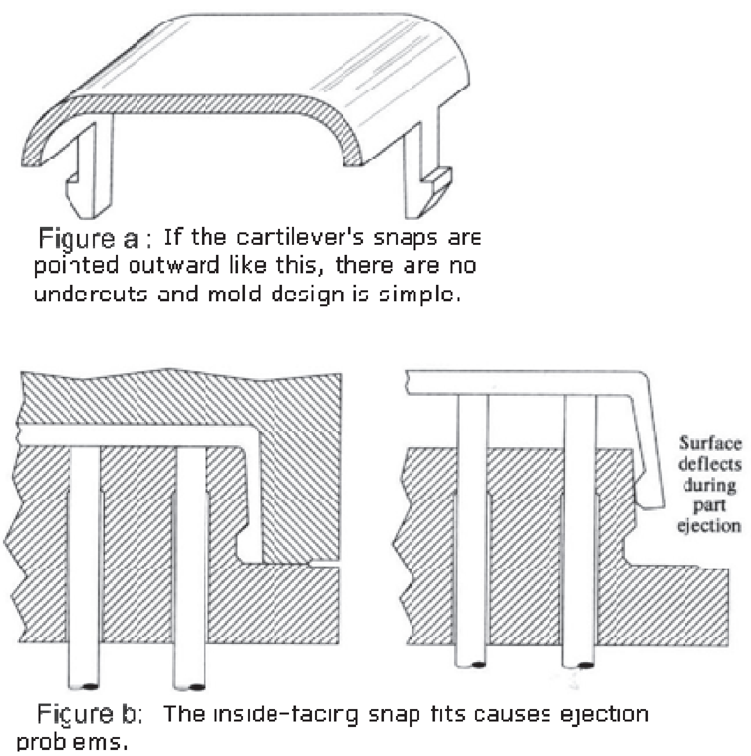


Figure 15: Shows a part with cantilever snap fits that point outward.

This does not present a molding problem, since the part can be ejected with no special mold action. If the snaps are turned around the other way, however, the mold design becomes much more complicated. The snaps will hold onto the mold core, keeping it from ejecting. Figure 15 shows the situation with inward-facing snaps. A possible solution to this problem would be to design the snap fit with angled corners so it can deflect and slide off as it is ejected. Unfortunately, deflecting the plastic when hot (immediately after molding) could cause some permanent deformation. It would be very difficult to hold tight tolerances on the snap fit using this method.

5.4 Screws, bolts and studs

Defining bolts and screws is difficult because of the different variations of definitions. In general, people don't know the difference between a screw and a bolt. Scania's own dictionary defines screw like this:

"Fastener of steel or other metal which has a completely or partially threaded cylindrical or slightly conical, often long and narrow, body with the head at the unthreaded end"

Scania's definition of bolt is:

"Small, rod shaped part used to provide a strong connection, usually with a head and threaded"

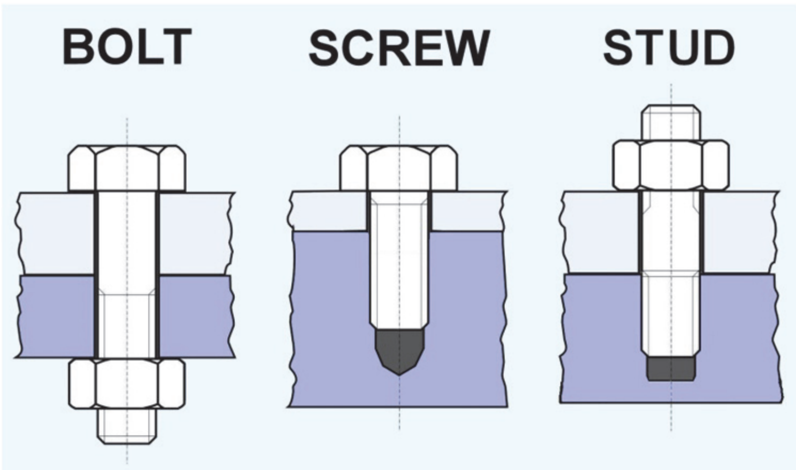


Figure 16: Illustrations of bolt, screw and stud.

The difference between the two is defined by Garret D. Euler:

“Bolts are defined as headed fasteners having external threads that meet an exacting, uniform bolt thread specification (such as M, MJ, UN, UNR, and UNJ) such that they can accept a nontapered nut. Screws are defined as headed, externally-threaded fasteners that do not meet the above definition of bolts”

- Both screws and bolts can be fully or partially threaded.
- A bolt does not have to be a screw if you extract a nut and even if one should not use the bolt it is not changed into a screw.
- Bolts and screws are untapered, although screws are often tapered.
- Screws always cut their own internal threads when initially installed. Conversely, however, it is possible for a bolt to be self-tapping.
- Both screws and bolts come in different type size of the head on the fastener.
- If bolts are small or come in miniature, that does not mean it stops being a bolt.

Those screws that are unsuitable to use as bolts are wood screws, lag screws, sheet metal screws and all screws that fall into the category of self-tapping screws. Examples of bolts that cannot be used as screws are carriage bolts, plow bolts and track bolts. If an externally threaded fastener is tightened by the head into a captive nut (nut-plate, etc.), it is still a screw.

The words "bolt" and "screw" are vague. One should think about how they are used instead of what they are; then it will be clearer what a bolt is and what a screw is.

There are general standards in Machinery’s Handbook, the various government and military parts standards, and ASMEii parts standards, standards we as engineers rely on.

5.5 Quick-operating Fasteners

Quick-operating fasteners should be considered in assembly when you need to access a component repeatedly. Design simplicity is important and the operation of the fastener plays a major part. It should be easy to install and easy to disassemble.

There are different types such as:
Lever-actuated, turn-operated, slide-action, push-pull, lift-and-turn, magnetic catches, and spring-loaded devices.

5.5.1 Lever-actuated fastener

Lever actuated: Draw-pull catches have a U-shaped wire bail or a flat spring-steel J-hook connected to a lever that pivots within a housing bracket mounted on one element of the closure assembly. Others have an engagement point built into a combined lever/cover that conceals all the catch assembly components in order to protect the lock and present a clean appearance.

The keeper is the element that engages the bail and is usually on the movable element of the closure assembly. These fasteners pull the two elements together tightly and lock by means of an overcenter linkage.

Some lever-actuated fasteners have coil springs or an adjustable threaded hook. These features compensate for installation inaccuracies, wear, gasket set, or damage.

The cam-actuated fastener has a cam which engages, pulls in, and locks a pin mounted in a separate keeper. The cam can be an inherent part of the lever, or it may be a separate component interconnected by a housing.

Figure 17: Cam-actuated fastener.

5.5.2 Push pull fastener

There are many variations of this type; usually the fastener is equipped with a knob or button that can be linked to the locking device on the opposite side of the panel. The receiver is usually a hole or lip of the frame, sometimes a shaped striker. By using pressure, you can lock the fastener. Push pull fasteners have numerous ways of manual locking: push to lock/push to release; lock on closing/push to release; push to lock/pull to release; and pull to lock/pull to release.

The advantage is quick and easy access without using special tools. Unfortunately, it is only suitable for use on lightly loaded panels and the panel should not be clamped against a frame or gasket.

Figure18: Push pull fastener.

5.5.3 Spring loaded fasteners

Spring-loaded devices: The purposes are to detent or hold parts in place. The body contains a spring and a plunger or sometimes a ball. The plunger resembles a threaded insert, and plunger bodies and inserts come in a variety of thread sizes and with various locking devices. The spring force varies from a few ounces to tens of pounds, which is transmitted to the plunger or ball. The plunger or ball presses against a flat surface on the mating part, or into an indentation or hole, which provides further locking action.

Plungers are available with various lengths of travel, and end force increases, as the plunger is depressed. Ball plungers have very little travel, and provide a rolling action instead.

Advantages of spring-loaded plungers include quick operation and variable positioning. Such devices are available in a variety of materials for standard and special purposes, such as for use as electrical contacts.

Figure 19: Spring loaded fastener.

5.5.4 Lift and turn latches

These combine lever-actuated latches and turn-operated pawl-type fasteners. A rotatable threaded shaft is used with a radially projecting pawl that can be positioned along the shaft to accommodate panel thickness. The shaft and pawl move axially when the lever is lifted or depressed, causing the pawl to move to the inner edge of a frame member. The pawl is rotated from its engagement behind the frame by rotating the lever while it is raised.

Lift-and-turn latches have the wide adjustability and compression found in turn-operated pawl-type fasteners, plus the quick action, good grip, and styling variations of lever-actuated latches.

Lift-and-turn fasteners are selected where elongated levers instead of round knobs are better suited to styling or where the better grip and mechanical advantages of levers allow tighter panel-to-frame compression. They are chosen for compression or sealing applications where quick operation is desirable and because the lever position allows a quick visual check on the status of an application where a number of such latches are used together.

Such latches are available with raised handles or with "flush" handles that lie close to the panel. Flush latches are operated by pushing in at one end of the lever, grasping the other end, and turning. Keylock styles are also available.

Figure 20: Lift and turn latches.

5.6 Welding

Welding is joining of materials, usually metals or thermoplastics, by causing coalescence. Usually contacting surfaces are joined by applying heat, pressure, or both, and often adding some filler material. Work pieces are melted and joined together at their common surfaces; these are the most common industrial welding methods by fusion processes. Fusion welding methods, chiefly gas, arc, and resistance, are the most widely used and are less restrictive as to the materials that can be joined. Diffusion welding is employed primarily to join high-strength materials [Welding [Internet, 9]]. There are different environments that the welding can be used in, like open air and under water, but also in outer space. It is very hazardous to weld, and you need to take security measures and precautions because of the risk of getting burned, eye vision damage, or inhalation of different poisonous gases and fumes.

5.6.1 Arc welding

Heat is generated when an electrode and a work piece are connected by an arc. It is important to shield the molten weld metal from the atmosphere so that no unwanted gases react with the molten metal. Otherwise it could lead to strength-reducing oxides and inclusions within the weld. Arc-welding processes vary mainly in the way the weld is shielded and the methods of applying filler material.

5.6.2 Shielded-metal arc welding (SMAW)

SMAW or stick welding, a more known name, is usually done manually. The welder feeds a consumable, coated electrode is feed in the work area. The coating serves various functions during the welding process, such as providing a shielding agent from the atmosphere which protects the molten pool, acting as fluxing agents to cleanse the weld metal deposit, establishing the electrical characteristics of the electrode and gases to displace air, metal, and slag to protect, support, and insulate the weld metal [Welding [Internet, 11]].

Although labor and material costs are high it is portable and can be done in limited areas. Also, its simplicity and versatility make it the most commonly used welding process [Welding [Internet, 12]].

5.6.3 Flux-core arc welding (FCAW)

Weld heat is produced from an arc between the work and a continuously fed filler-metal electrode. In the core the electrode is hollow with flux. In some cases, by adding materials the arc stability can be improved, also enhancing the weld-metal properties and improving the weld contour.

The application areas are only on ferrous metals, primarily mild and low-alloy steels. Some electrodes are self-shielding while others require an external shielding gas. The common gas is carbon dioxide, which is fed through a nozzle.

This process is suitable in all positions, producing a rapid, clean weld. FCAW is sometimes referred to as MIG welding. It requires less skill than SMAW.

5.6.4 Gas-Tungsten arc welding (GTAW)

In GTAW, this type includes a non-consumable tungsten electrode. The arc is generated between the electrode and the work areas. The work is shielded by helium or argon gas and wire filler metal is fed in separately. The process, also called TIG (tungsten inert-gas welding), is usually used on thinner metals such as aluminum, magnesium, titanium, and high-alloy steels.

Although GTAW costs more than SMAW, the results are high-quality [… word(s) missing?] a very wide range of thicknesses, positions, and geometries. Also, the process can be fully automated.

6 Ergonomics and Layout

This chapter provides a description of ergonomic principles and a brief layout. The description contains ways of decreasing risks of being injured and how to avoid them. The benefits of having an ergonomically sound environment are also mentioned.

6.1 Ergonomics

The definition of ergonomics is simply the study of work. Rather than adapting the employee to the work, one should adapt the work to the employee. Designing the ergonomics at a workplace is a science and it is difficult. There are many considerations one should think of. Does the workplace change or is it constant? How many employees are working at the same workstation? Does the design output suit every employee?, etc. These considerations and many others are the basic principle of ergonomics.

Tasks, equipment, tools and machines are other factors in designing ergonomics in a workplace. These need to be adapted to the worker to relieve him/her of physical fatigue and stress.

Repeated tasks are hazardous and may result in injuries for the worker. Repeated lifts, carrying, pulls and pushes of loads are usual at workplaces. These repeated activities need to be reduced, or made easier for the employee to handle.

6.1.1 Ergonomic Tools

The purpose of having ergonomic hand tools is to reduce the risk of musculoskeletal disorders and injuries. The design of the ergonomic tools is to ease the awkward postures and forceful hand actions. Bending the wrist, performing rapid wrist movements or something that requires a forceful handgrip increase the risk of causing muscle strain, pain, carpel tunnel syndrome and other related injuries.

6.1.2 Reduce risks

The worker must be able to perform the task and still obtain neutral and comfortable postures of elbow, wrist and other joints.

Try to avoid contact stresses by eliminating sharp edges and make handles user friendly.

Renew design to adapt to workers hands, wrists, joints and other parts of the body.

Try to avoid tasks that cause vibrations and repetitive moves. This can lead to injuries that will develop in the future by frequent use of tool.

Excessive force or pressure, lifting and pushing, and awkward positions at the workplace easily develop into injuries and diseases.

It is very important that the workstation should be user friendly. The workplace should be designed so that the worker reaches every tool or material with neutral moves. Any actions above the shoulders should not exist. The worker should reach all the tools and materials from an arms distance.

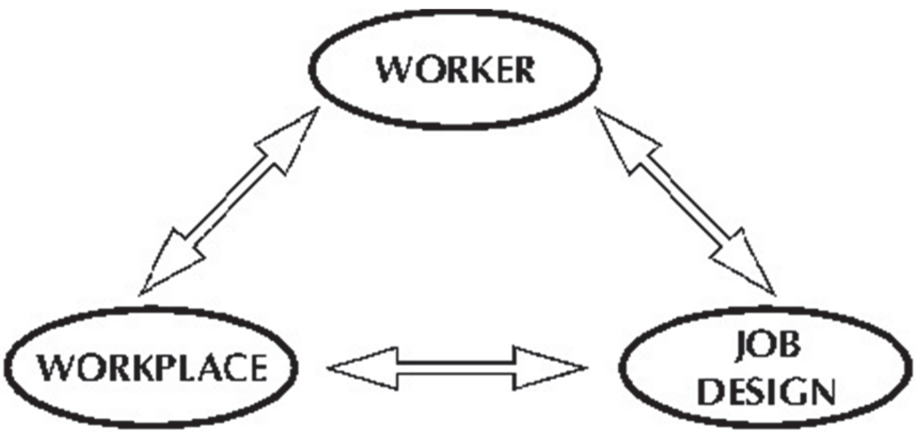


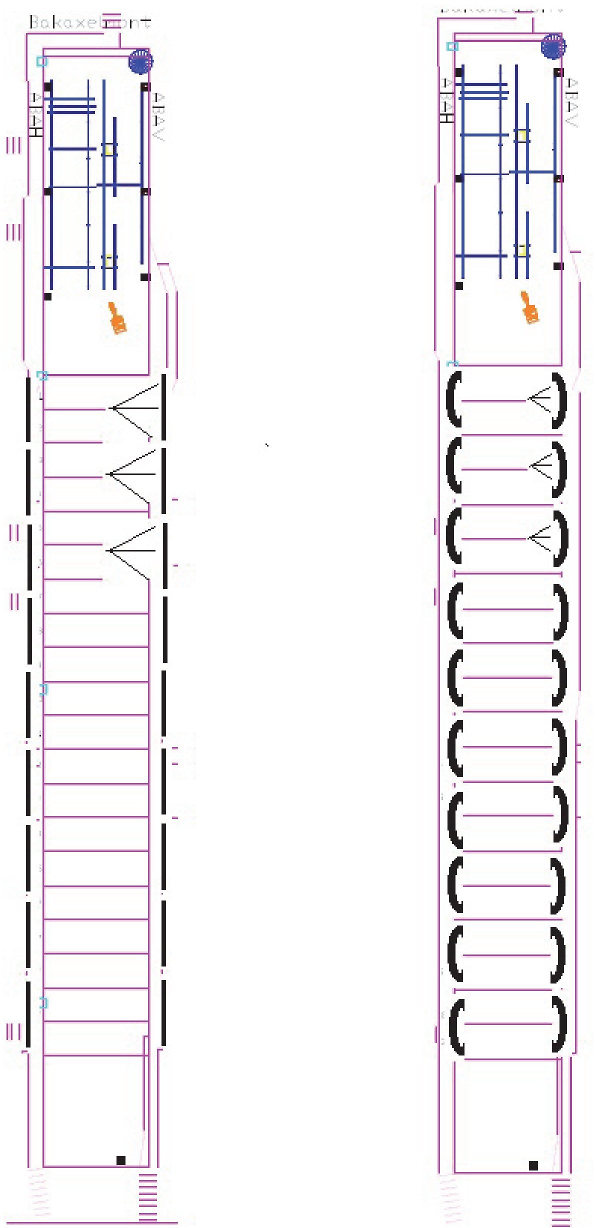
Figure 21: Improvement cycle.

6.1.3 Productivity

Using ergonomics can increase the worker's productivity. When the work is correctly adapted to the worker it is much more likely that the worker will concentrate on the work, which will result in higher productivity. Everything should be taken into consideration; furniture or equipment can be adjusted for several individuals. When productivity is increased, the company's profit is increased and the worker's risks of hurting himself are decreased.

Health related injuries or problems cause lost working time because of hospital visits, recovery time off work and so on. Ergonomically designed workstation, equipment and furniture would decrease the lost working time and increase the quality health of the worker. It is also important to remember that a safe and efficient company has a good reputation. This will result in more applications from workers that will consider working for them, and the company in this way gets more skilful workers. More skilful and qualified workers will improve the company's efficiency and profit. All these factors are related to each other; one leads to another, one way or another.

6.2 Layout



Layout today Layout in the future

Figure 22: Layout

By decreasing the movements of the workers, the tact time would be decreased.

7 Results and discussions

In this chapter the results are presented and some reflections are discussed. The results primarily involve the solutions, and the focus is on area 1 of the rear axle housing. The improvements are the results of the suggested DFA analysis.

7.1 Result

The results are based on DFA analysis of the subassembly of the rear axle housing. Several sub-assemblies have been examined in a DFA-analysis table; see table 2. Furthermore, five of the sub-assemblies have been considered for redesign. All DFA analyses are presented in Appendix E.

Table 2: DFA-analysis.

The number of DFA analysis	
1. Assembly of central gear	**9.** Assembly of nipple
2. Assembly of Blanking piece	**10.** Assembly of brake system to the rear axle house
3. Assembly of Oil pipe	**11.** Assembly of Bracket
4. Assembly of brake shield	**12.** Assembly of dics with hub
5. Assembly of spring disc	**13.** Assembly of angle iron
6. Assembly of cable duct	**14.** Assembly of brake caliper
7. Assembly of studs to drive axle	**15.** Assembly of hub
8. Assembly of oil filter	

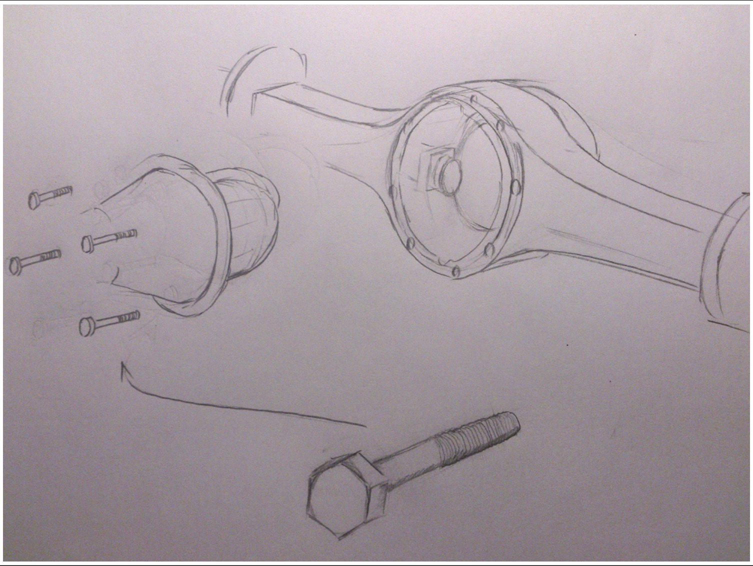
The top five DFA analyses are also redesigned and presented as solutions for assembly line. The current use of assembly methods is replaced by new suggested assembly methods. The purpose is to decrease the tact-time by implementing them in Scania's rear axle housing assembly line.

7.1.1 Solutions

7.1.1.1 Assembly of central gear

Table 3: Suggestions of redesign for central gear and rear axle housing.

DFA-analysis - Redesign of Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 0,17*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of central gear**
1	1		27,9		7,1	35	5,95	1		Rear axle housing
2	1		6,7		3,3	10	1,7	1		Return lifting tools
3	1		0		1	1	0,17	1		Lock of rear axle housi
4						0	0			Studs
5						0	0			Control stud sketch
6						0	0			Fixing studs
7	1		5,7		4,8	10,5	1,79	1		Gasket
8	1		31,7		10	41,7	7,09	1		Central gear
9						0	0			Nuts
10						0	0			Assemble nuts
11						0	0			Fixing nuts
12	7	10	1,5	01	2,5	28	4,76	0		Assemble screws
13	7		2,2		6,8	63	10,7	0		Fixing screws
Tot. Nr	**19**					**TM**	**CM**	**NM**	Design efficiency = (3*NM)/TM	0,08
						189,2	32,2	5		

The assembly of central gear is carried out as follows: Rear axle house is lowered to the workstation and fastened. Control stud sketch and mount the 14 studs. Fixing the studs and gasket is applied. The central gear is lifted and lowered on the rear axle housing. The nuts are mounted to the studs and assembled to be fix in the last workstation.

As shown in the DFA analysis the red-marked are those components or sub-operations that are eliminated or replaced by another component. The redesign resulted in eliminating studs and nuts and only using screws.

By replacing all the studs and nuts with screws difficulties may occur and contribute with obstacles during the assembly. For example it could be problematic to centre the hole patterns between central gear and rear axle housing. The solution could be to redesign and adapt the central gear and rear axle housing, which facilitates the installer to adapt the hole patterns. The figure below demonstrates how the solution should be designed.

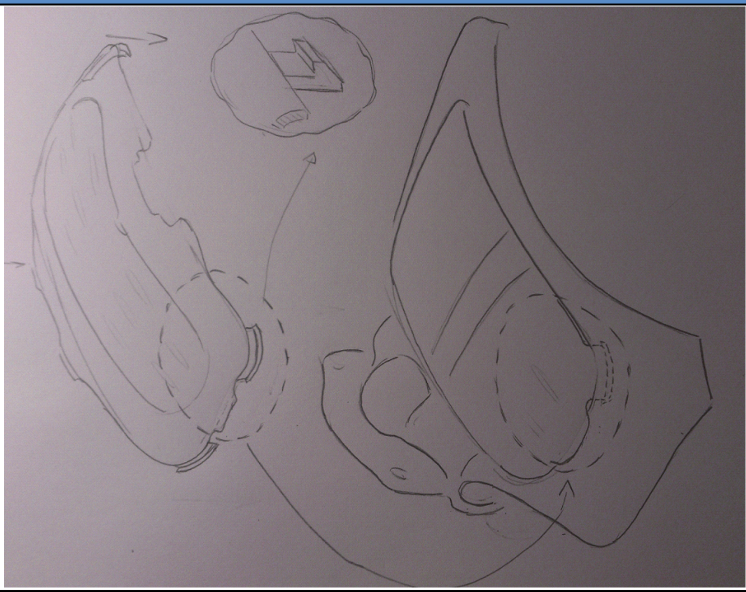
An alternative to the solution above is to use only four studs and replace the remaining studs with screws. The purpose of the four studs is to facilitate the centering of the hole patterns and assemble the central gear on rear axle housing. This solution will be beneficial during disassembly, the central gear will be held in its place.

Several other solutions were undertaken but due to oil leakage they were not feasible. The new design efficiency became 8 percent and the sub-assembly time was decreased from 324 seconds to 190 seconds; this sub-assembly time (TM) is only an estimated time and it could be different from real time.

7.1.1.2 Assembly of blanking piece

Table 4: Suggestions of redesign for blanking piece and brake caliper.

DFA-analysis - Redesign of sub-assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of Blanking piece**
1						0	0			Brake caliper
2	1	30	1,95	40	4,5	6,45	32,3	1		Blanking piece
3						0	0			Cover screws
4						0	0			Fixing blanking piece
						0	0			
						0	0			
						0	0			
						0	0			
Tot. Nr	1					TM	CM	NM	Design efficiency = (3*NM)/TM	0,47
						6,45	32,3	1		

The blanking piece is redesigned to a cantilever molded snap fit. Another solution was undertaken but after a detailed evaluation the best solution was chosen. The redesign is simple to assemble and it only needs to press the blanking piece to its position. Disassembly is made easily by using a sharp and flat tool to release the blanking piece.

The use of screws would not be necessary and two components or sub-operations are therefore deleted. The new design efficiency will increase to 47% and the assembly time decreased to 6,5 seconds; this sub-assembly time (TM) like the first suggested solution is only an estimated time and it could be different from real time.

7.1.1.3 Assembly of spring disc

Table 5: Suggestion of redesign for spring disc.

DFA-analysis - Redesign of Sub-Assembly

1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of Spring disc**
1						0	0			Rear axle housing
2	1		8		5	13	65	1		Spring disc
3	1		8		5	13	65	1		Spring bracket
4						0	0			Nuts
5	1		5		0	5	25	1		Control of spring disc
6	2					0	0	2		Screw
7	1		2,5		3	5,5	27,5	1		Screw wrench*
8	1		4		0	4	20	1		Return screw wrench
Tot. Nr	7					TM	CM	NM	Design efficiency = (3*NM)/TM	0,52
						40,5	203	7		

The assembling of spring disc is carried out with the following steps: the rear axle house is mounted and locked to the station. Mounting of spring disc 1 and 2 is mounted and nuts secure the fastening of spring discs. Screw wrench is used to fix the spring discs.

The spring disc is a special variant that Scania and Scania's wheel axle factory has customized. During the assembly of the rear axle housing, the spring disc is not assembled on all rear axle housing. It is still of great importance to optimize the design of the spring disc to decrease the assembly tact time and to decrease the costs of the assembly.

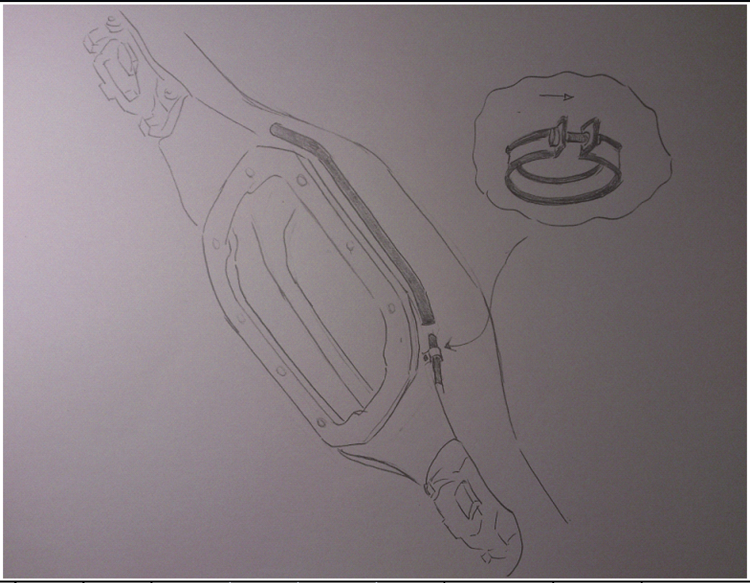
The chosen solution is demonstrated on the figure below. This solution has a couple of weaknesses that must be carefully looked into and examined. It is challenging to come to an optimized design due to the great stress and strain that the spring disc is exposed to.

The new design efficiency will increase to 52% and the assembly time decreased to 41 seconds; this sub-assembly time (TM) like other suggested solutions is only an estimated time and it could be different from real time.

7.1.1.4 Assembly of oil pipe

Table 6: Replacing tube clamps instead screws and nuts.

DFA-analysis - Redesign of Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of oil collector and oil pipe**
1			0		0	0	0			Rear axle housing
2	1		1,9		2	3,9	19,5	1		Oil collector
3	1		3,6		7,2	10,8	54	1		Oil pipe, right
4	1		4,3		4,3	8,6	43	1		Oil pipe, left
5	0					0	0			Screw
6	0					0	0			Screw
7	0					0	0			Nut, right
8	0					0	0			Nut, left
9	0					0	0			Fixing screw, right
10	0					0	0			Fixing screw, left
11	1		0	00	1,5	1,5	7,5	1		Tube clamps
Tot. Nr	**4**					**TM**	**CM**	**NM**	Design efficiency = (3*NM)/TM	0,48
						24,8	124	4		

The assembling of oil collector and oil pipe are carried out by the following steps: the assembler picks oil collector, oil pipes and screws and puts them in rear axle housing. First of all the two oil pipes assemble to the oil collector and these are fastened and fixed by screws and integrated nuts.

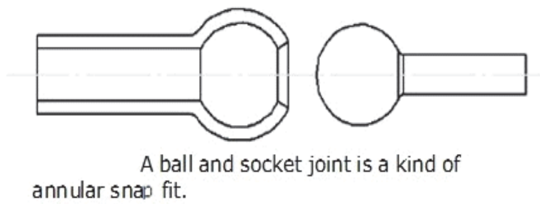
By using tube clamps the screws and integrated nuts are no longer needed. The tube clamp is easily disassembled by using an ordinary screwdriver. The screws, nuts and the fixing of screws are not needed. This means that the red marked components and sub-operations are eliminated.

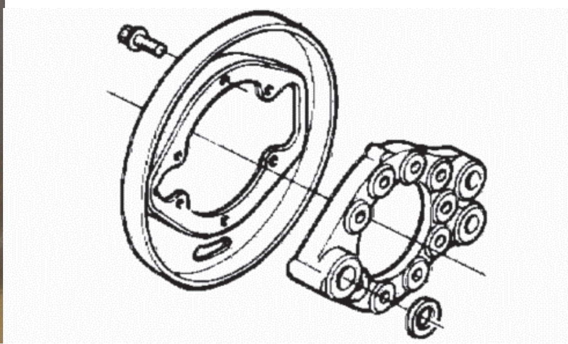
New design efficiency increases to 48% and sub-assembly time is decreased to 25 seconds; this sub-assembly time (TM) like other suggested solutions is only an estimated time and it could be different from real time.

7.1.1.5 Assembly of Brake shield

Table 7: Replacing annular snap fits instead screws.

DFA-analysis - Redesign of Sub-Assembly





1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of brake shield**
1	1		5		3,1	8,1	1,38	1		Brake bracket
2	1	83	2	50	6	8	1,36	1		Brake shield
3						0	0			Screws
4						0	0			Fixing screw
						0	0			
						0	0			
						0	0			
						0	0			
Tot. Nr	2					TM	CM	NM	Design efficiency = (3*NM)/TM	0,37
						16,1	2,74	2		

By replacing screws with annular snap fits the sub-operations of screws and fixing screws are eliminated. The brake bracket needs to redesign the hole patterns for the screws to adapt to the annular snap fits. The brake shield needs to be equipped with the annular snap fits.

New Design efficiency increases to 37% and sub-assembly time is decreased to 16 seconds; this sub-assembly time (TM) like other suggested solutions is only an estimated time and it could be different from real time.

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[5] Peter Gröndahl, Assistant Professor at Division of Industrial production, Royal Institute of Technology, personal conservation, 9 February 2012

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[7] Gustaf Ramnell, Project leader at Scania’s Wheel Axle Factory, personal conservation, 20 November 2011

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[9] Robert Bjärnemo, Professor at Division of Machine Design, Lund University, personal conversation, 23 February 2012

[10] Gorgios Nikoleris, Associate Professor at Division of Machine Design, Lund University, personal conversation, 23 March 2012

Appendix A: AviX

A.1 Avix – DFA-method

Scania have already the system in their organization. They use it as a help method for balancing the workflow in the assembly lines.

Avix is an efficient tool for analysis where videotaping of operation and subsequent analysis of the computer is used for establishing the facts of production processes. AviX as a system helps many companies worldwide to continuous improvements and developing of personnel, processes and products within manufacturing and assembly industry. The film sequence is analyzed by using AviX and broken down into different assembly time applications, for example: handling, insertion, fixing etc.

Production engineers and technicians on the line can easily study the different sequences, and then try eliminating waste and errors that deviate from the standard. Using the program, employees can also eliminate poor ergonomics in the assembly line.

There are five parts in the AviX system, which can be used for different aspects in the company.

1. AxiX Method - Method is used for method development, assembly time reduction, continuous improvement and instructions, etc.
2. AviX Balance - Method is used for line structure and to minimize balancing losses.
3. AviX FMEA - Method is used for avoidance quality of work, products and processes.
4. AviX DFX - Method is used for design improvements and producibility issues.

5. AviX Ergo - Method is used for improvements of ergonomic issues.[4]

The AviX system has been developed by SOLME- Solutions and methods. The company started in 1998 with the idea to create a computer system, which will support and combine video analysis with time-studies based on standard times for the analysis of manual assembly processes. [Internet, 4].

Figure 23: The AviX system logo.

[4] The company who developed the system is placed in Värnamo.

Appendix B: Scania's Production System

B.1 SPS-house

Description of the four basic principles of Scania's Production System.

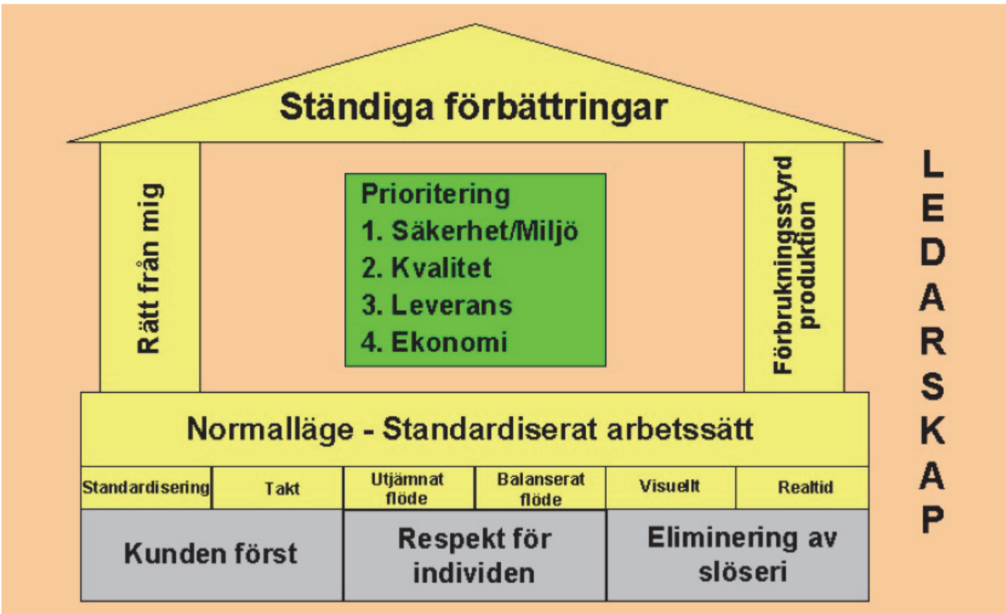


Figure 24: Scania house (Scania's Production System, Scania 2012)

Normal Situation – Standardized working method

The idea is that Normal Situation is a working method where all employees must strive for continuous improvements in order to facilitate this, standardized work method. Normal situation is based on standardization, a fixed tact time, and well-balanced flow through whole the production chain. The reason is that all employees should see when something is abnormal and needs to be corrected.

Right from me

Right from me means doing things right from the beginning. The strategy is to use suitable tools, instructions and methods that make it impossible to make mistakes or errors and so ensure the quality. Everyone should see the next step in the process as a customer and consider the quality.

Consumption – controlled production

The term means that production will not produce anything until a customer signals a need, and a customer does not necessarily mean the final customer, it could be the next step in the process. This can be done for example by utilizing visual buffers so that everyone can see when a need takes place, and start producing the product.

Continuous improvement

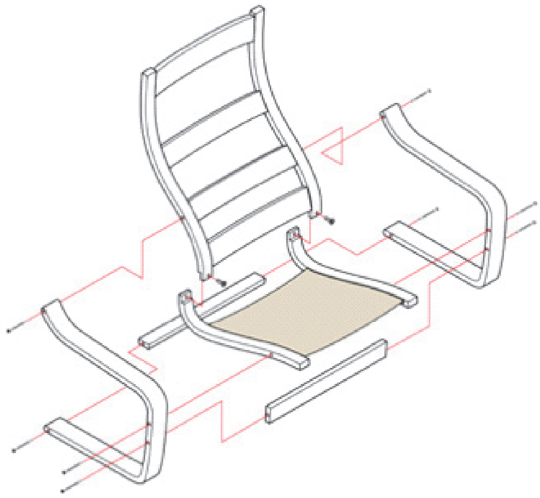
Continuous improvement is to constantly strive to create a new and better normal situation by continuous challenge and elimination of waste. It is about constantly modifying and challenging the process to achieve better quality and higher efficiency.

Appendix C: DFA-analysis description

C.1 DFA-analysis table

Table 8: The DFA-analysis table.

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr.	**Assembly of X**
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
Tot. Nr.	0					TM	CM	NM	Design efficiency = (3*NM)/TM	###
						0	0	0		

TM = Total assembly time

CM = Total assembly cost

NM = (N_{min}) The theoretical part minimum

Tot. Nr. = Total present part count

The theoretical, lowest assembly time for one part = 3 seconds. This is an ideal minimum

Efficiency = Min. Time*Min. Parts/Actual Parts

C.2 Worksheet description

Column 1: ID-number for part of sub-assembly.

Column 2: Number of times the operation is carried out consecutively.

Column 3: Two-digit manual handling code obtained from the handling table (see appendix C.3).

Column 4: Handling time from the handling table.

Column 5: Two-digit manual insertion code obtained from the insertion table (see appendix C.4).

Column 6: Insertion time from the insertion table.

Column 7: The total assembly time for the part. This is obtained by adding columns 4 and 6 and then multiplying by the number of operations in column 2.

Column 8: The total assembly cost for the part.

Column 9: Figure for the estimating of the theoretical minimum number of parts which the product or the sub-assembly could be designed by.

Note: column 9 is particularly important for analysis. To decide or estimate minimum number of parts, the following three questions must be asked for every detail.

1. During operation of the product, does the part move relative to all other parts already assembled? Only gross motion should be considered – small motions that can be accommodated by integral elastic element, for example, are not sufficient for a positive answer.

2. Must the part be of a different material or be isolated from all other parts already assembled? Only fundamental reasons concerned with material properties are acceptable.

3. Must the part be separate from all other parts already assembled because otherwise necessary assembly or disassembly of other separate parts would be impossible?

Is the answer YES to any of these questions, add 1 in column 9, except when multiple parts are indicated in column 2. In this case, add the theoretical numbers of parts needed in column 9. If the answer is NO to the questions add 0 in column 9.

C.3 Manual handling table

Manual handling involves the grasping, transportation, and orientation of sub-assemblies before they are added to the work fixture.

Table 9: Manual handling-estimated times.

MANUAL HANDLING-ESTIMATED TIMES (s)

Key: One hand

		Parts are easy to grasp and manipulate					Parts present handling difficulties (1)				
		Thickness >2 mm			Thickness ≤2 mm		Thickness >2 mm			Thickness ≤2 mm	
		Size >15 mm	6 mm ≤ size >15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm	Size >15 mm	6 mm ≤ size ≤15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm
		0	1	2	3	4	5	6	7	8	9
Parts can be grasped and manipulated by one hand without the aid of grasping tools: (α+β) < 360°	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
360° ≤ (α+β) < 540°	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
540° ≤ (α+β) < 720°	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
(α+β) = 720°	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

Key: One hand with grasping aids

		Parts need tweezers for grasping and manipulation								Parts need standard tools other than tweezers	Parts need special tools for grasping and manipulation
		Parts can be manipulated without optical magnification				Parts require optical magnification for manipulation					
		Parts are easy to grasp and manipulate		Parts present handling difficulties (1)		Parts are easy to grasp and manipulate		Parts present handling difficulties (1)			
		Thickness >0.25 mm	Thickness ≤0.25 mm	Thickness >0.25 mm	Thickness ≤0.25 mm	Thickness >0.25 mm	Thickness ≤0.25 mm	Thickness >0.25 mm	Thickness ≤0.25 mm		
		0	1	2	3	4	5	6	7	8	9
Parts can be grasped and manipulated by one hand but only with the use of grasping tools: α ≤ 180°, 0 ≤ β ≤ 180°	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
α ≤ 180°, β = 360°	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
α = 360°, α ≤ β ≤ 180°	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
α = 360°, β = 360°	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

Key: Two hands for manipulation

		Parts present no additional handling difficulties					Parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)				
		α ≤ 180°			α = 360°		α ≤ 180°			α = 360°	
		Size >15 mm	6 mm≤ size ≤15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm	Size >15 mm	6 mm≤ size ≤15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm
		0	1	2	3	4	5	6	7	8	9
Parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary) (2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

Key: Two hands or assistance required for large size

		Parts can be handled by one person without mechanical assistance									Two persons or mechanical assistance required for parts manipulation
		Parts do not severely nest or tangle and are not flexible								Parts severely nest or tangle or are flexible (2)	
		Part weight < 10 lb				Parts are heavy (>10 lb)					
		Parts are easy to grasp and manipulate		Parts present other handling difficulties (1)		Parts are easy to grasp and manipulate		Parts present other handling difficulties (1)			
		α ≤ 180°	α = 360°	α ≤ 180°	α = 360°	α ≤ 180°	α = 360°	α ≤ 180°	α = 360°		
		0	1	2	3	4	5	6	7	8	9
Two hands, two persons or mechanical assistance required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

C.4 Manual insertion table

Manual insertion involves the positioning of sub-assemblies before they are inserted into the work fixture

Table 10: Manual insertion-estimated times.

MANUAL INSERTION – ESTIMATED TIMES (seconds)

Key: PART ADDED but NOT SECURED

			after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
			easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
			no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
			0	1	2	3	6	7	8	9
addition of any part (1) where neither the part itself nor any other part is finally secured immediately	part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
	part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
	part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

Key: PART SECURED IMMEDIATELY

			no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
					plastic bending or torsion			rivetting or similar operation				
						not easy to align or position during assembly			not easy to align or position during assembly			
			easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
			0	1	2	3	4	5	6	7	8	9
addition of any part (1) where the part itself and/or other parts are being finally secured immediately	part and associated tool (including hand(s)) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
	part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
	part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

Appendix D: Assembly line

D.1 The Rear wheel axle assembly line

Scanias rear wheel axle assembly line is divided in 5 sections and they are divided in each stations. First section has 10 stations.

1.1

The base of axle, rear axle housing, is the first thing that is handled and is lifted with the help of a lifting tool to the first station. When the bridge is lowered on palette this is the first step of the making of the back wheel axle.

1.2

In station 2 one have to fit studs on the rear axle housing depending on the draft. Depending the variant u need to assemble a cylinder bracket an attach it with screws. Spring perch can also be attached depending the variant.

1.3

If the variant requires to attach spring perch it will be done in this station. A pattern around the bridge covering the studs is painted on depending the variant

1.4

Oil collector and oil pipe is attached to the inner part of the bridge.

1.5

In this station the yoke is fastened to the bridge with nuts and screws. This is made for a robot arm which will be able to lift the bridge.

1.6

A machine with 2 sockets is used to set the studs firmly.

1.7

Apply silicon depending the variant. Apply silicon on the banjo surface around the studs. A seal disc is also applied because to seal any possible leak when central gear is fitted.

1.8

Lower the central gear and fit it with the bridge and center the driving slot. Mount the nuts on the studs.

1.9

Mount the differential plug and fasten it. Fasten all nuts to make sure central gear is completely fastened.

2.12

Oil collector and oil filter assemblies to each other and then it is assembled to the axle.

2.13

Brake cups is pre-assembled.

2.14

The brake cup which is assembled in the pre-assembly line at 2.13. These will be assembled with the axle with screws depending the variant.

2.15

Pre-assembly.

2.16

In this station the brake cylinder and walking beam is assembled depending the variation.

2.17

The lever is combined with the indicating device and adjust the lever pin.

2.18

ABS sensor is equipped, spring is attached, get the ACL-nipples. Prepare for cable duct and cable groover.

2.19

Bearing axis, spacing sleeve, carrier and shim. These are assembled and pressed in the axle.

3.20

The hub is pressed, clamp ring is removed, mount new carrier.

3.21

New layer and hub is mounted and pressed.

Sensor is assembled depending the variant.

3.32

Hub is lowered on a palette.

3.33

This is a pre assembly station, this is where layer race and hub is connected with bolts.

3.34

A packing is pressed and placing cog wheel on hub, connect with oil collector.

3.35

10 studs will be mounted on hub and tightened. With other variants u need spacing sleeve and shim and stripe and axle layer to assemble them together.

3.36

The hub is lifted and a disc brake is mounted on the palette. The hub is then connected with the disc brake. In other versions a layer is mounted instead and also a carrier is assembled.

3.37

The screws for disc brake is screwed and fastened. An o-ring is also applied on the hub.

3.38

Lift of the assembled hub from palette.

4.22

Assembly protection washer and lock nut to shaft journal. Connect sensor and adapter for ABS-system.

4.23

Blanking piece is equipped. ABS bracket, wear sensor and yoke screws is also equipped. Drive shaft flange is assembled and tag axle casing is equipped also depending the variation.

4.24

Mount cork gasket at hub. Half shaft is also assembled. Shaft journal is now assembled to the half shaft. Mount the ABS bracket and fasten the protection washer at magnetic washer. Mount the cone fasteners. Bring nuts and mount them to the cone fasteners.

4.25

Lift up and mount the brake caliper to the disc brake. Mount the screws to the brake caliper. Make the screws fastened to the brake caliper. If it is a drum brake make sure to brace ABS sensor to the bridge. Brace the p-pipe at the gear bracket. Assemble spacer and open clamp to fasten the ABS cable. Attach 2 stripes and attach the ABS cable to the cable duct. Prepare for hub reduction gear with 3 screws and one oil plug and mount them to the hub reduction gear. Fasten the oil plug

4.26

A blanking piece is mounted with 2 screws, assemble a stripe to the blanking piece. Assemble cable harness. Beat the brace down carefully. Assemble the nuts to the drive shaft flange. If the variation requires fold the ABS cable with help with a stripe. Test the airflow with a air tool to make sure there is no leaks. Bring the differential tool and plug with differential masking.

5.27

Disc brake:
Bring the brake chamber to tool table. Depending the nipple sketch, assemble nipple to the brake chamber and mask the nipples. Mount the brake chamber to the axle. Grab the air flow adapter and attach it to the air pipe.

Drum brake:
Assemble the 3 screws in the middle of the hub reduction gear and then the 2 outer screws on the flange. Grip the drum with lifting tool and lift it up to mount it to the axle.

5.28

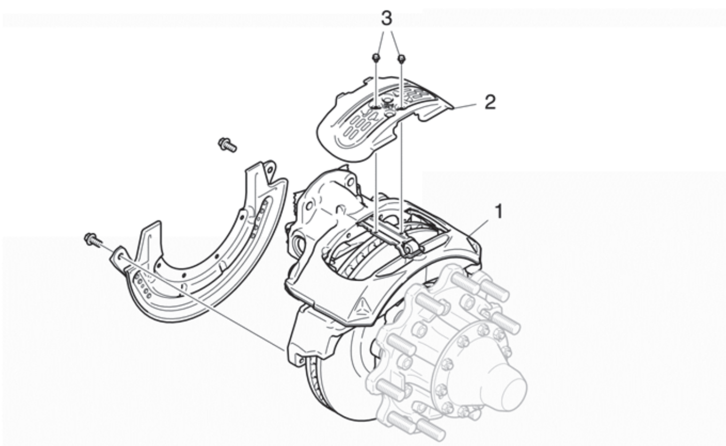
Mount the brake shield with two screws. Mask the drift and the nipple of brake chamber. Mount p-pipe to brake chambers insert connection. Control the leak test and if approved remove the air adapter.

Appendix E: DFA analysis

E.1 Blanking piece

Table 11: DFA-analysis for blanking piece

DFA-analysis Sub-assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I.D. No.	Number of times the operation is carried out consecutively	Two- digit manual handlind code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of Blanking piece**
1			0		0	0	0			Brake caliper
2	1		2,1		3,1	5,2	26	1		Blanking piece
3	2		1,6		3	9,2	46	0		Cover screws
4	2		1,5		2,8	8,6	43	0		Fixing blanking piece
						0	0			
						0	0			
						0	0			
Tot. Nr.	5					TM	CM	NM	Design efficiency = (3*NM)/TM	0,13
						23	115	1		

Description

The blanking piece is mounted to the brake caliper and 2 screws are mounted to be fixed in the end.

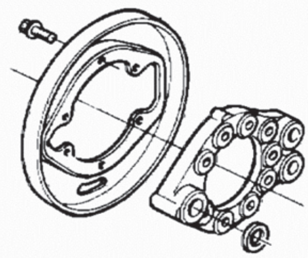
Application of these criteria to the original design:

1. Base or brake caliper is the first part of the sub-assembly, and it is a theoretically necessary part.
2. Blanking piece is a standard subassembly, and it is a necessary part which cannot be eliminate.
3. Cover screw is theoretically not necessary.
4. Fixing blanking piece with two screws will be eliminated when the cover screws are not necessary.

E.2 Brake shield

Table 12: DFA-analysis for Brake shield

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 0,17*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of brake shield**
1	1		5		3,1	8,1	1,38	1		Brake bracket
2	1		2		3	5	0,85	1		Brake shield
3	6		1,6		1	15,6	2,65	0		Screws
4	6		1		1,6	15,6	2,65	0		Fixing screws
						0	0			
						0	0			
						0	0			
						0	0			
Tot. Nr.	14					TM	CM	NM	Design efficiency = (3*NM)/TM	0,14
						44,3	7,53	2		

Description

The brake shield is assembled with 6 screws on brake bracket.

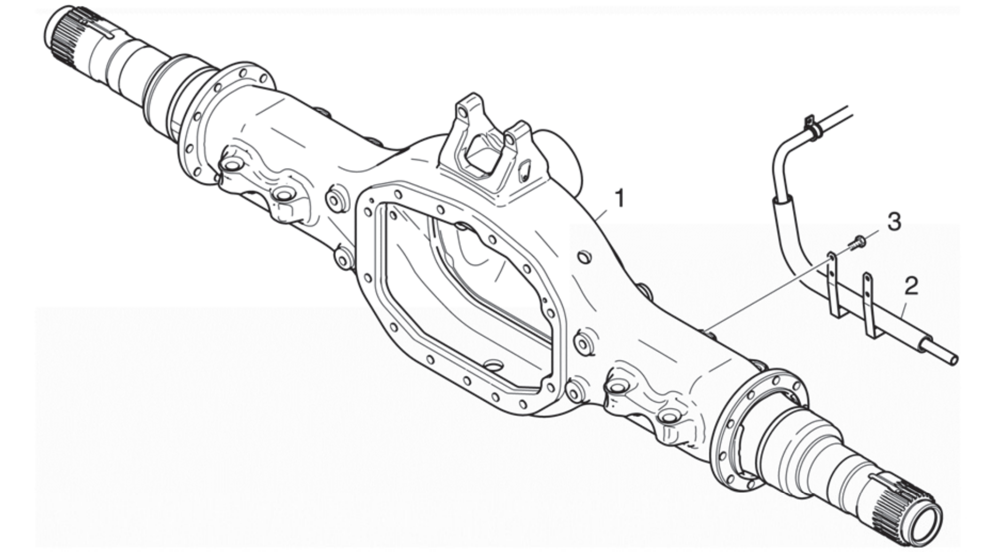
Application of these criteria to the original design:

1. Brake bracket is the base part of the sub-assembly, and it is a theoretically necessary part.
2. Brake Shield a necessary part, needed to protect the brake system from dust and dirt.
3. Shields screws theoretically not necessary and cloud be eliminated.
4. Fixing Screws will be reduced or eliminated when the numbers of screws are reduced.

E.3 Cable duct

Table 13: DFA-analysis for cable duct

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two-digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of Cable duct**
1	0		0		0	0	0	0		Spring disc
2	1		3		3,9	6,9	34,5	1		Cable duct
3	2		2		2,5	9	45	0		Screws
4	2		2		2,4	8,8	44	0		Screw fastener
5	1		2,6		0	2,6	13	1		Adjusting cable*
						0	0			
						0	0			
						0	0			
Tot. Nr.	6					TM	CM	NM	Design efficiency = (3*NM)/TM	0,22
						27,3	137	2		

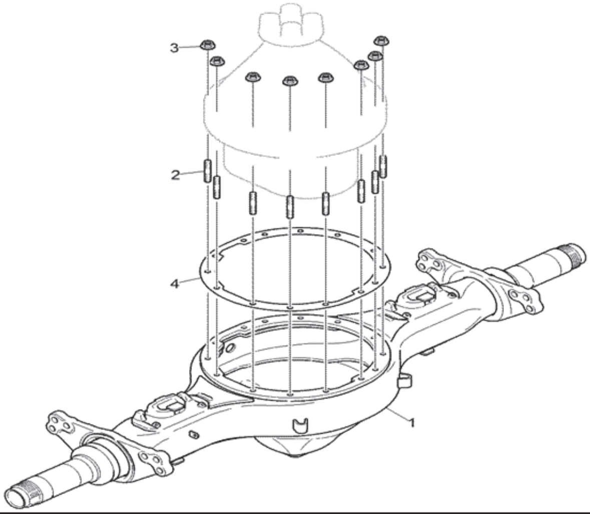
Description

A cable duct is assembled on the rear axle housing with two screws.

E.4 Central gear

Table 14: DFA-analysis for central gear

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 0,17*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of central gear**
1	1		27,9		7,1	35	5,95	1		Rear axle housing
2	**1**		**6,7**		**3,3**	**10**	1,7	**1**		Return lifting tools
3	1		0		1	1	0,17	1		Lock of rear axle housing
4	**7**		**1,8**		**3,1**	**34,3**	5,831	**0**		**Studs**
5	1		2,9		0	2,9	0,493	0		Control stud sketch*
6	7		1,4		8,9	72,1	12,26	0		**Fixing studs**
7	1		5,7		4,8	10,5	1,785	0		Gasket
8	**1**		**31,7**		**10**	**41,7**	7,089	**1**		**Central gear**
9	7		0,6		5,5	42,7	7,259	0		Nuts
10	**7**		**0,5**		**1**	**10,5**	1,785	**0**		**Assemble nuts**
11	7		2,2		6,8	63	10,71	0		Fixing nuts
Tot. Nr.	**41**					**TM**	**CM**	**NM**	**Design efficiency = (3*NM)/TM**	**0,04**
						323,7	55,03	4		

Description

Rear axle house is lowered to the workstation and fastened. Control stud sketch and mount the 14 studs. Fixing the studs and gasket is applied. The central gear is lifted and lowered on the rear axle housing. The nuts is mounted to the studs and fixed in the last workstation.

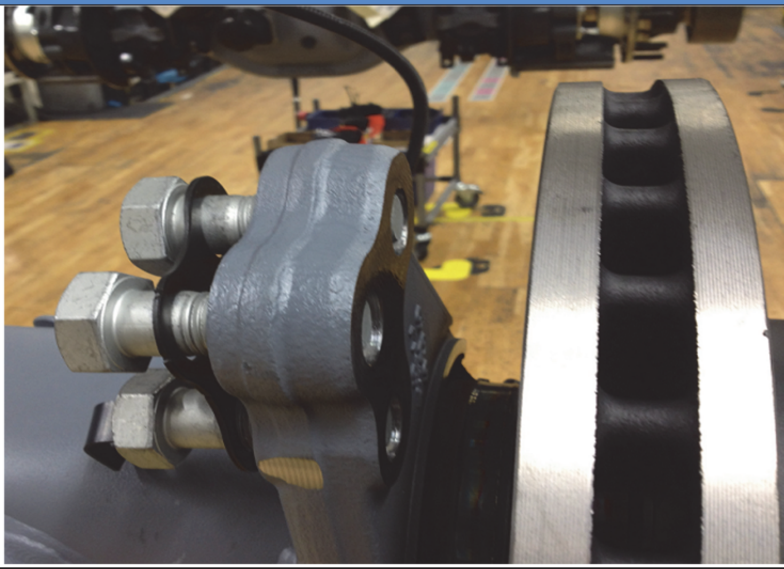
Application of these criteria to the original design:

1. Base or rear axle housing is the first part of the sub-assembly, and it is a theoretically necessary part.
4. Studs are theoretically not necessary to have all 14 studs. The number of studs can be reduced.
5. Control stud sketch is a necessary moment for doing thinks right from beginning.
6. The count of fixing studs will automatically be reduced when the number of studs is decreasing.
7. Gasket is a necessary part to eliminate leakage.
8. Central gear is a standard subassembly and it is a necessary part.
9. Nuts could be eliminated if the studs are replaced with screws.
10. Fixing nuts could be eliminated.

E.5 Brake caliper

Table 15: DFA-analysis for brake caliper

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two-digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of brake caliper**
1	1		0		0	0	0	0		Brake disc
2	1		0		0	0	0	0		Rear axle housing
3	6		1		1	12	60	2		Screws
4	1		14,1		13,3	27,4	137	1		Brake caliper
5	6		0,5		1,7	13,2	66	2		Assemble screws
6	6		5,4		15,2	123,6	618	2		fixing brake caliper
						0	0			
						0	0			
Tot. Nr.	21					TM	CM	NM	Design efficiency = (3*NM)/TM	0,12
						176,2	881	7		

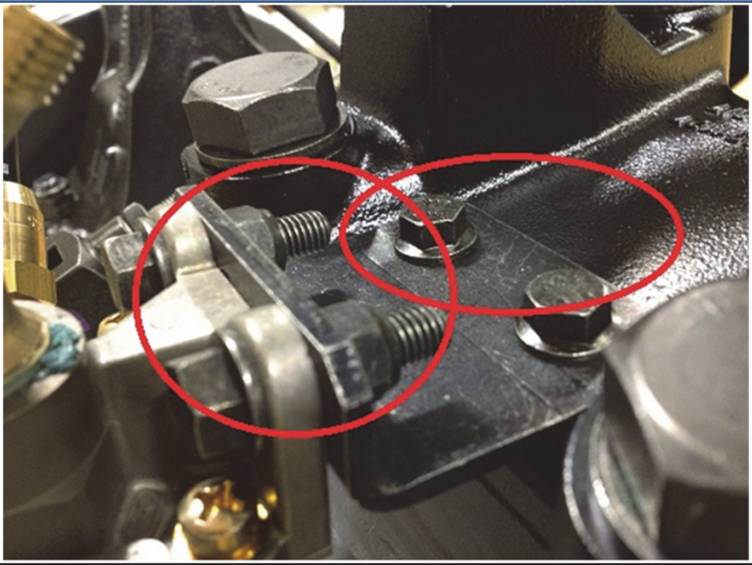
Description

When the brake caliper is assembled a prefixing of the screws is performed and finally a fixing of the screws are done.

E.6 Angle iron

Table 16: DFA-analysis for angle iron

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of angle iron**
1	1		0		0	0	0	0		Rear axle housing
2	1		1		1,5	2,5	12,5	1		Angle iron
3	1		2,5		3,5	6	30	1		Air control valve
4	4		0,5		0,5	4	20	1		Screws
5	4		1		2	12	60	0		Fixing screws
6	4		0,5		0,5	4	20	1		Nuts
7	2		1		1	4	20	1		Fixing nuts
						0	0			
Tot. Nr.	17					TM	CM	NM	Design efficiency = (3*NM)/TM	0,46
						32,5	163	5		

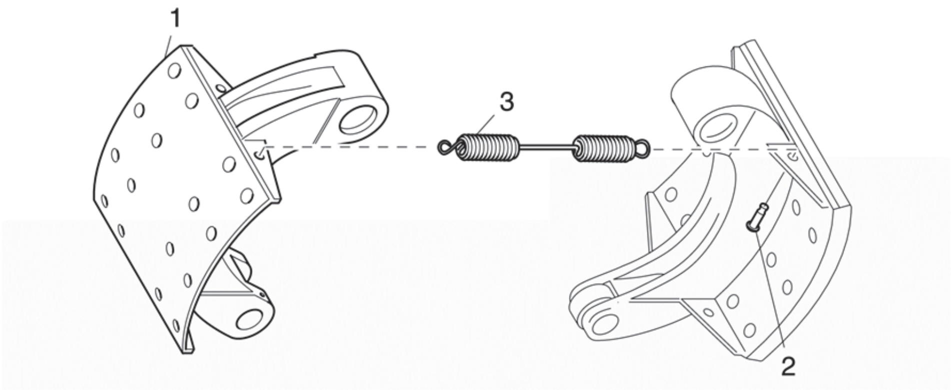
Description

Angle iron is attached with an air control valve by screws and nuts and fixed by an electric wrench.

E.7 Nipple for brake lining

Table 17: DFA-analysis for nipple for brake lining

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two-digit manual handlind code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, kronor 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	Assembly of nipple for brake lining
1	1		2,6		1,2	3,8	19	1		Brake lining
2	1		1		1	2	10	0		Nipple
3	1		1,5		4	5,5	27,5	0		Hammer
						0	0			
						0	0			
						0	0			
						0	0			
						0	0			
Tot. Nr.	3					TM	CM	NM	Design efficiency = (3*NM)/TM	0,27
						11,3	56,5	1		

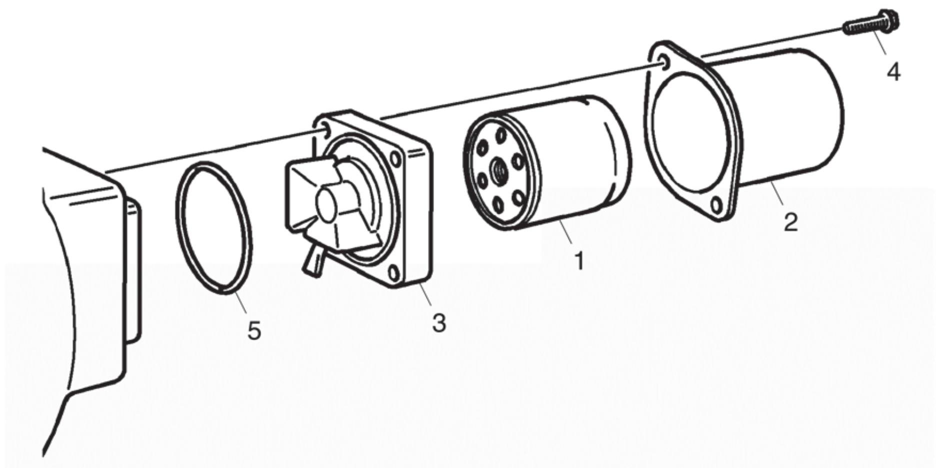
Description

The nipple is hammered for brake lining.

E.8 Oil filter and oil collector

Table 18: DFA-analysis for oil filter and oil collector

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum	Scania art.nr	**Assembly of oil filter and oil collector**
1	1		0		0	0	0	0		Rear axle housing
2	1		2,5		0,7	3,2	16	1		Oil collector (Preassemble)
3	1		1,7		5,5	7,2	36	1		Oil filter (Preassemble)
4	1		3,1		8,3	11,4	57	1		Brush
5	1		2,2		2,2	4,4	22	1		Torque wrench
6	1		1,4		3,1	4,5	22,5	1		O-ring
7	1		3,7		10	13,7	68,5	1		Oil filter and oil collector
8	1		1,2		2	3,2	16	0		Oil cover
9	4		0,4		1	5,6	28	2		Screws
10	4		7,4		1,8	36,8	184	1		Fixing screws
Tot. Nr.	16					TM	CM	NM	Design efficiency = (3*NM)/TM	0,3
						90	450	9		

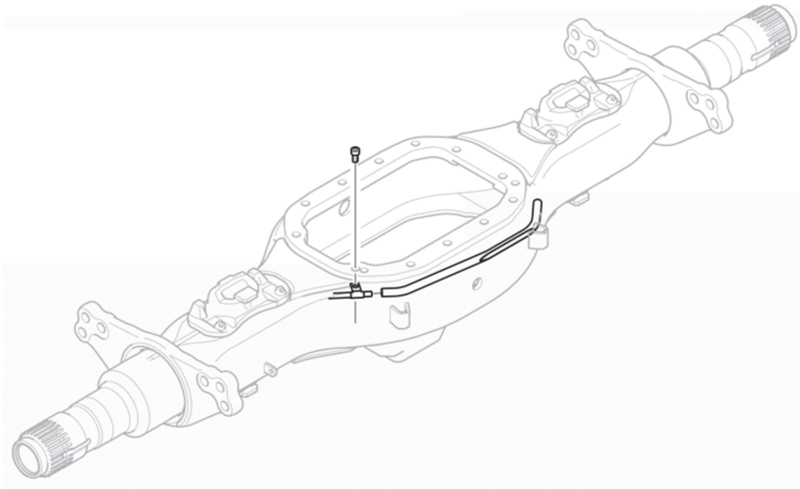
Description

The assembler takes an oil collector and places it in the workstation and then retrieves an oil filter that is brushed with grease and mounted it on the oil collector. A torque wrench is used to fix the oil filter. An O-ring is placed on the oil collector and grease is brushed on O-ring. Mount the assembled oil filter and an oil cover on the shaft and the screws are fixed on the oil filter by an electric wrench 4 screws.

E.9 Oil collector and oil pipe

Table 19: DFA-analysis for oil collector and oil pipe

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	Assembly of oil collector and oil pipe
1			0		0	0	0			Rear axle housing
2	1		1,9		2	3,9	19,5	1		Oil collector
3	1		3,6		7,2	10,8	54	1		Oil pipe, right
4	1		4,3		4,3	8,6	43	1		Oil pipe, left
5	1		1,9		0,8	2,7	13,5	0		Screw
6	1		1,9		0,8	2,7	13,5	0		Screw
7	1		0		0	0	0	0		Nut, right
8	1		0		0	0	0	0		Nut, left
9	1		0,7		2,5	3,2	16	0		Fixing screw, right
10	1		0		3,2	3,2	16	0		Fixing screw, left
Tot. Nr.	9					TM	CM	NM	Design efficiency = (3*NM)/TM	0,26
						35,1	175,5	3		

Description

The assembler picks oil collector, oil pipes and screws and puts them in rear axle housing. First he assembles the both oil pipes to the oil collector and these are fastened and fixed by screws and integrated nuts.

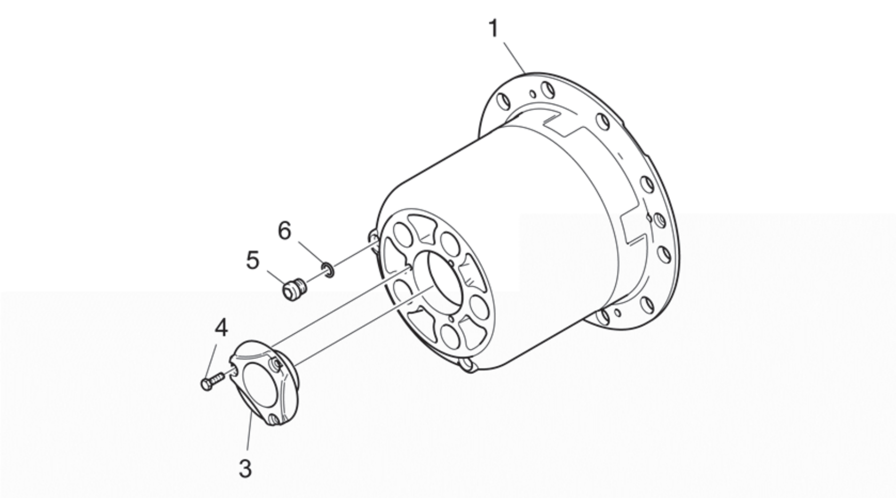
Application of these criteria to the original design

1. Rear axle housing is the base part of the sub-assembly, and it is a theoretically necessary part.
2. Oil collector is standard part and it is necessary part.
3. Oil pipe could be integrated or combined with oil collector and the parts are theoretically not necessary to have them separately.
4. Screws and nuts are theoretically not necessary. They could be replaced with another assembly method for example tube clamp.
5. Fixing screws will be reduced when the screws and nuts are eliminated.

E.10 Hub

Table 20: DFA-analysis for Hub

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two-digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	Assembly of hub
1	1		5,1		8,6	13,7	68,5	1		Oilplug
2	3		0,6		1,8	7,2	36	0		Screws
3	1		1,6		3,3	4,9	24,5	1		Torque wrench
4	1		2,4		0	2,4	12	0		Withdraw hub
5	1		16		19,5	35,5	178	1		Hub
6	2		2		3,2	10,4	52	0		Screws
7	5		0,9		2,5	17	85	0		Fixing Screws
						0	0			
						0	0			
						0	0			
Tot. Nr.	14					TM	CM	NM	Design efficiency = (3*NM)/TM	0,1
						91,1	456	3		

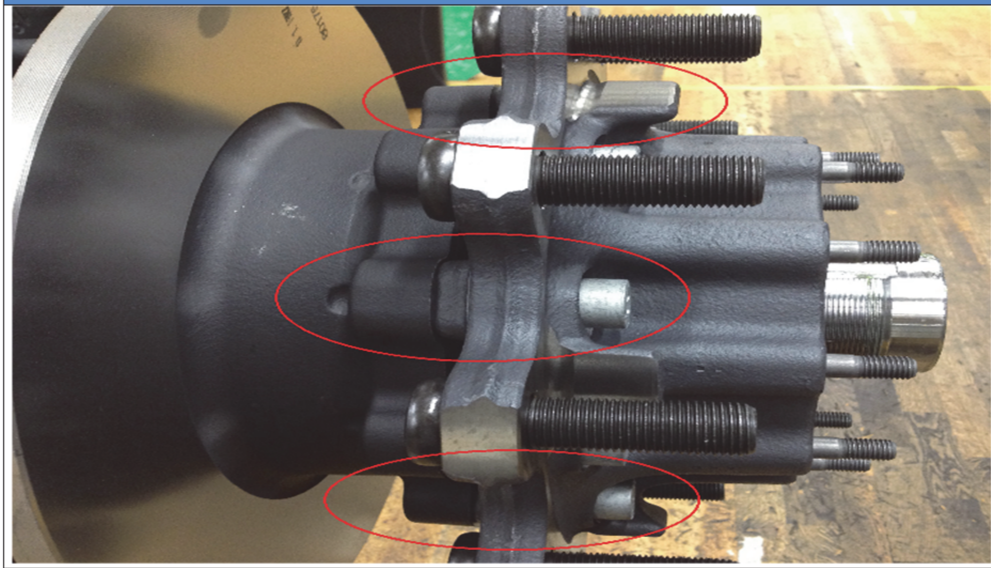
Description

Preassembly of an oil plug and 3 screws are mounted to the hub. Torque wrench fixes the oil plug and the hub is assembled to the axle. Additional 2 screws are mounted to the hub and all 5 screws are fixed further in the line

E.11 Assembly of disc into the hub

Table 21: DFA-analysis for assembling the disc

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two-digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	Assembly of disc with hub
1	1		0		0	0	0	0		Brake disc
2	1		3		3,9	6,9	34,5	1		Hub
3	10		0,38		1	13,8	69	4		Screws
4	1		0,9		0	0,9	4,5	1		Check of screws*
5	2		4,9		9	27,8	139	1		Fixing brake disc and hub
						0	0			
						0	0			
						0	0			
Tot. Nr.	15					TM	CM	NM	Design efficiency = (3*NM)/TM	0,43
						49,4	247	7		

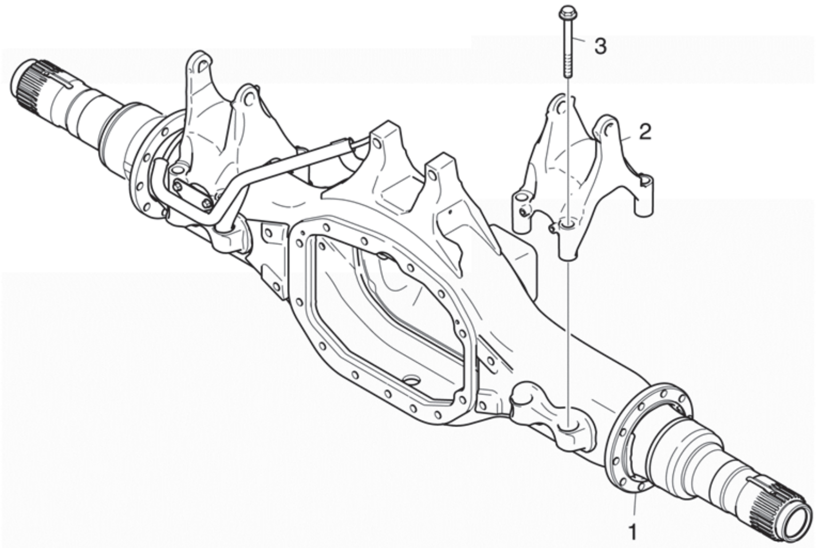
Description

The hub is connected to brake disc and screws are fixed to assemble them together.

E.12 Spring disc

Table 22: DFA-analysis for spring disc

DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two-digit manual handlind code	Manual handling time per part	Two-digit manual insertion code	Manual inserion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of Spring disc**
1						0	0			Rear axle housing
2	1		8		5	13	65	1		Spring disc
3	1		8		5	13	65	1		Spring bracket
4	4		1,6		1,2	11,2	56	0		Nuts
5	1		5		0	5	25	1		Control of spring disc
6	2		2,5		3	11	55	0		Screw wrench*
7	1		4		0	4	20	0		Return screw wrench
						0	0			
						0	0			
Tot. Nr.	10					TM	CM	NM	Design efficiency = (3*NM)/TM	0,16
						57,2	286	3		

* Screw wrench is assembling/fixing two screws at a time.

Description

The rear axle house is mounted and locked to the station. Mounting of spring disc 1 and 2 is mounted and nuts secure the fastening of spring discs. Screw wrench is used to fix the spring discs.

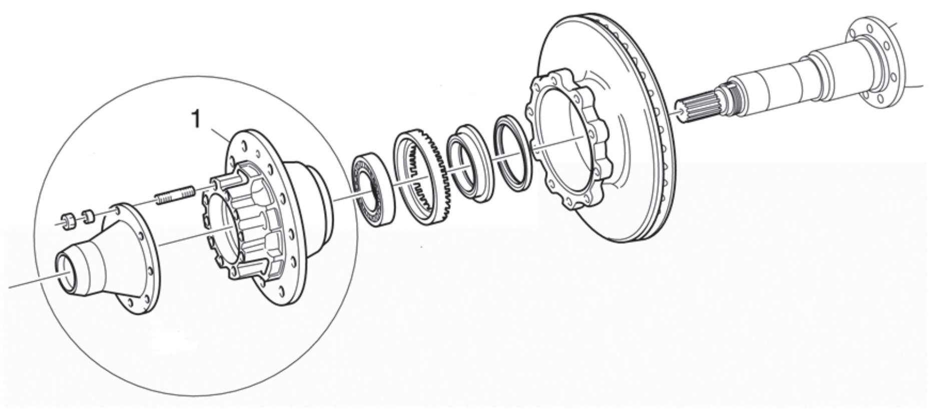
Application of these criteria to the original design

1. Base or rear axle housing is the first part of the sub-assembly, and it is a theoretically necessary part.
2. Spring disc is a standard parts and it is theoretically necessary to have.
3. Screws and nuts are theoretically not necessary and they could be replaced with another assembly method.
4. Screw wrench/Fixing Spring discs operation will be reduced with screws and nuts.

E.13 Drive shaft flange

Table 23: DFA-analysis for drive shaft flange

DFA-analys Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two-digit manual handlind code	Manual handling time per part	Two-digit manual insertion code	Manual insertion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	Assembly of drive shaft flange
1	1		0		0	0	0	0		Hub
2	1		2,4		1,8	4,2	21	1		Drive shaft flange
3	6		0,5		2,1	15,6	78	2		Studs
4	6		0,5		1,1	9,6	48	2		Cone
5	6		0,9		2,2	18,6	93	2		Nuts
6	6		0,8		2,4	19,2	96	2		Hjulmedbringardragare
7	2		0,5		5,2	11,4	57			fixing studs
8	1		4,4		9,9	14,3	71,5			Half shaft
						0	0			
Tot. Nr.	29					TM	CM	NM	Design efficiency = (3*NM)/TM	0,29
						92,9	465	9		

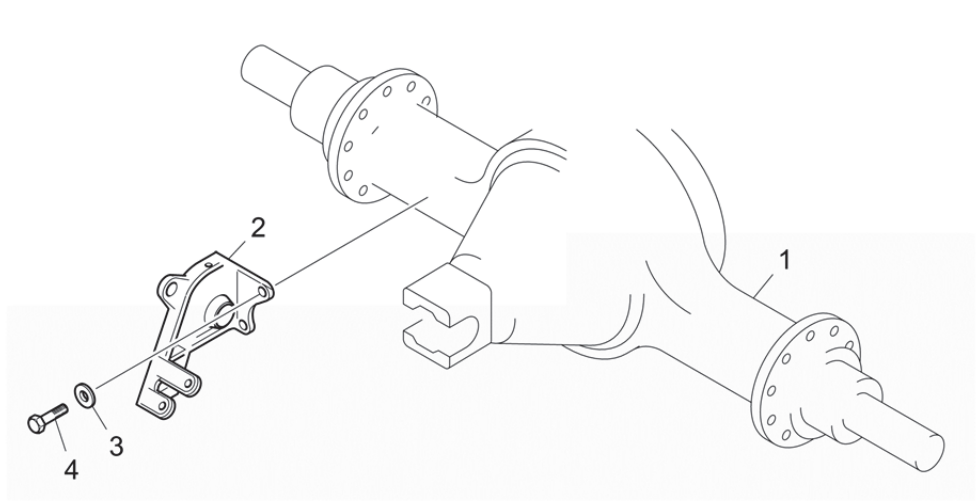
Description

Studs are fixed in the pre-assembly of a brake disc. The drive shaft is mounted in the axle. Drive shaft flange mounted on the axle. Cones and nuts are mounted at the studs. Wheel spend wrenches fixes the combined cones and nuts.

E.14 Bracket

Table 24: DFA-analysis for Bracket

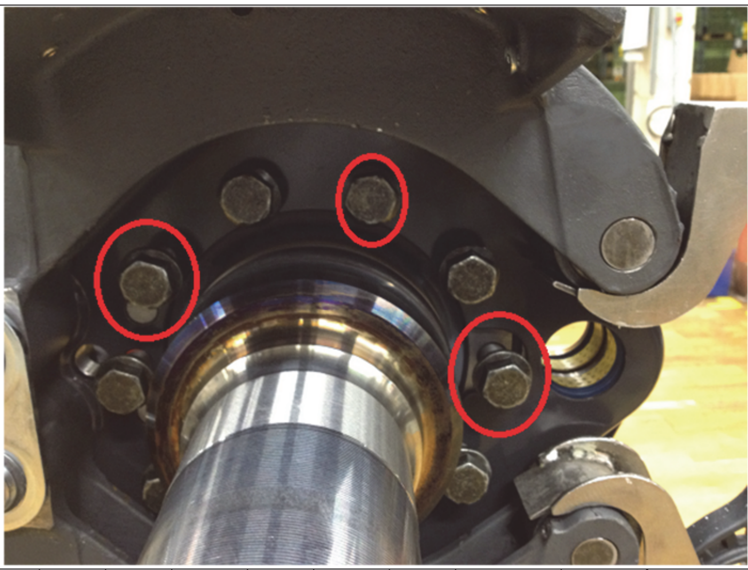
DFA-analysis - Sub-Assembly



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two-digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of Bracket**
1	1		0		0	0	0	0		Rear axle housing
2	**1**		**2,3**		**2**	**4,3**	**21,5**	**1**		**Bracket**
3	2		0,3		0,3	1,2	6	0		Washer
4	**2**		**1,6**		**1,8**	**6,8**	**34**	**1**		**Screws**
5	2		2,1		4,8	13,8	69	1		Fixing bracket
						0	**0**			
						0	0			
						0	**0**			
Tot. Nr.	**8**					**TM**	**CM**	**NM**	**Design efficiency = (3*NM)/TM**	**0,34**
						26,1	**131**	**3**		

E.15 Brake system for only Drum brakes

Table 25: DFA-analysis for Brake system



1	2	3	4	5	6	7	8	9	10	Name of Assembly
Part I:D: No.	Number of times the operation is carried out consecutively	Two- digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion time per part	Operation time, seconds (2)*[(4)+(6)]	Operation cost, SEK 5*(7)	Figures for estimation of theoretical minimum parts	Scania art.nr	**Assembly of brake system (Drum brake)**
1	1		0		0	0	0	0		Rear axle housing
2	**1**		**3,8**		**4,2**	**8**	**40**	**1**		**Brake system**
3	10		1		1,4	24	120	4		Screws
4	**10**		**0,86**		**2**	**28,6**	**143**	**4**		**Assemble screws**
5	5		1		4	25	125	2		Fixing brake system
						0	**0**			
						0	0			
						0	**0**			
						0	0			
Tot. Nr.	**27**					**TM**	**CM**	**NM**	Design efficiency = (3*NM)/TM	0,39
						85,6	428	11		

Description

The brake system is assembled in preassembly station and screws assembled to the brake system for fixing in the line.