Evaluation of "Design For Assembly" as a working approach at Atlas Copco Tools

ALEXANDER ANTURI

JENNY TIGER

Evaluation of "Design For Assembly" as a working approach at Atlas Copco Tools

av

Alexander Anturi
Jenny Tiger

	Examensarbete TMT 2012:69
	Utvärdering av "Design For Assembly" som ett arbetssätt på Atlas Copco Tools
	Alexander Anturi
	Jenny Tiger

Godkänt 2012-08-20	Examinator KTH Namn	Handledare KTH Jan Linell
	Uppdragsgivare Atlas Copco Tools AB	Företagskontakt/handledare Andris Danebergs

Sammanfattning

Denna rapport presenterar resultatet av ett examensarbete där en utvärdering av DFA(Design For Assembly)- metoden som ett arbetssätt på Atlas Copco Tools utfördes. DFA är en metod som handlar om att designa en produkt så att dess egenskaper kommer att ha en inverkan på monteringsvänligheten av produkten. Det främsta målet med DFA är att reducera antalet ingående detaljer i en produkt.

Atlas Copco Tools är ett företag som har påbörjat sin resa mot ständiga förbättringar och fokuserat sig bland annat på att förbättra produktutvecklingsprocessen. Därav har företaget visat ett stort intresse för DFA-metoden som ett arbetssätt inom konstruktionsavdelningen. Idag använder sig inte Atlas Copco Tools av en specifik metod som stödjer DFA-metodiken vid utveckling av deras produkter. Den stora frågan i detta examensarbete är därför huruvida DFA lönar sig att implementeras på Atlas Copco Tools i deras produktutecklingsprocess och i så fall hur arbetet med DFA ska ske samt vilka tillvägagångssätt ska användas.

En studie på företag som framgångsrikt implementerat DFA i deras produktutecklingsprocess har utförts. Studien var gjord med hjälp av benchmarking och de intervjuade företagen var DeLaval i Tumba, Scania i Södertälje och Sony Mobile Communications i Lund. Vi utförde benchmarking med syftet att undersöka hur dessa tre företag arbetar med DFA idag och vilka medel de använt sig utav för att implementera det framgångsrikt. Vidare intervjuades konstruktörer på Atlas Copco Tools, delvis för att få en giltig bild av hur produktutvecklingsprocessen går till idag men också för att ta reda på hur de som målgrupp föredrar att arbeta med DFA. Förutom detta gjordes studiebesök till produktionsanläggningen i Tierp där vi testade att montera mutterdragaren Tensor ST 10 Revo och annan viktig information om monteringsvänlighet samlades in.

All faktainsamling var analyserad och en checklista som stödjer DFA-metodiken var framtagen. Checklistan testades och utvärderades på en produkt från Atlas Copco Tools som befinner sig i förstudiefasen. Till checklistan adderades kompletterande riktlinjer som ett hjälpande dokument för att besvara frågorna i checklistan och för konstruktören något att eftersträva vid utformning av produkter. Examensarbetet resulterade också i en beräkning på monteringsvänligheten av mutterdragaren Tensor ST 10 Revo. Utöver detta gavs några specifika rekommendationer på hur DFA borde implenteras på Atlas Copco Tools.

Nyckelord

DFA, checklista, implementering, monteringsvänlighet, produktutvecklingsprocess.

Approved 2012-08-20	Examiner KTH Name	Supervisor KTH Jan Linell
	Commissioner Atlas Copco Tools AB	Contact person at company Andris Danebergs

Abstract

This report is the result of a thesis work in which an evaluation of the DFA (Design For Assembly) method as a working approach at Atlas Copco Tools has been done. DFA is a method about considering design features that may have a significant relevance on the assembly efficiency of a product. Its main goal is to reduce the number of parts included in a product. Atlas Copco Tools is a company in search of continuous improvements and from that it has been focused on, among others, on enhancing the product development process. Therefore, the company shows interest in the DFA method as a working approach within the design department. Today Atlas Copco Tools do not use any particular method that supports the DFA methodology in their development of products. The question is whether DFA is worth implementing at Atlas Copco Tools in the product development process and in that case, how exactly DFA can be implemented and which approaches should be used.

A research of companies that successfully implemented DFA on their product development process has been done. The research was done using benchmarking and the contacted companies were DeLaval, Scania and Sony Mobile Communications. We benchmarked in order to find out how these companies work with DFA and how to implement DFA in a successful way. Furthermore, interviews with the designers from Atlas Copco Tools were done; partly to get a valid picture of the process development process and also to find out how they would prefer to work with DFA. In addition, excursions to the production plant in Tierp were made, where we tested to assemble the nutrunner Tensor ST 10 Revo and important information about assembly efficiency was gathered.

All the collected information was analyzed and a checklist that supports the DFA method was developed. The checklist was tested and evaluated on a specific product from Atlas Copco Tools. Additionally, the checklist was added with complementary guidelines that explain each question on the checklist and also provides with helpful DFA advises. This thesis work also resulted in a calculation of the assembly efficiency on the nutrunner Tensor ST 10 Revo. Moreover some specifics recommendations on how DFA should be implemented at Atlas Copco Tools were given.

Key-words

DFA, checklist, implementation, assembly efficiency, product development process.

Preface

This thesis work has been performed at the School of Industrial Engineering and Management at the Royal Institute of Technology (KTH) for Atlas Copco Tools AB. The thesis covers 10 weeks of fulltime work and is the final part of our bachelor education in mechanical engineering.

We would like to thank our supervisors Andris Danebergs at the R&D department in Nacka and Morgan Rhodin at the production plant in Tierp for good guidance and gratifying moments throughout the thesis work.

During this thesis work the authors of this report have received help and support from many, different people.

Thanks to:

Mikael Hultqvist, DeLaval

Dick Bergman and Erik Jaenssen, Scania

Mattias Bognäs, Sony Mobile Communications

Furthermore, we thank the designers and the operators at Atlas Copco Tools for their help in getting us to understand the processes and patiently answering our questions. We also have to mention the helpfulness of our colleagues and friendly attitude we have experienced during our time at Atlas Copco Tools.

At last we would like to thank our supervisor at KTH Jan Linell, for rewarding and insightful conversations during the thesis work.

Hopefully this thesis work would be useful for Atlas Copco Tools in their future work with DFA (Design For Assembly).

Nacka, June 2012

Alexander Anturi   Jenny Tiger

ii

Glossary

DFA	Design For Assembly
DFA2	A method supporting Design For Automatic Assembly
DFX	Generic name for DFM, DFS, DFA, DFMA etc.
DFM	Design For Manufacturing
DFAA	Design For Automatic Assembly
DFMA	Design For Manual Assembly OR Design For Manufacturing and Assembly
Assembly efficiency (M)	In this case an index from DFA2 that measure the assembly efficiency at products (the higher the index the better assembly efficiency)
CAD	Computer Aided Design
ProEngineer	CAD software
GSD	"Group Standards Department", a database for mechanical articles
FMEA	Failure Modes and Effects Analysis
R&D	Research & Development
PDP	Product Development Process
EBD	Engineering for Business Development
WIP	Work in process

Table of content

1. Introduction

In this chapter the reader gets an insight in the problem set up for this thesis work in this project as well as the thesis' purpose and the methods chosen to achieve the objectives.

1.1. Background

This thesis work is made by two mechanical engineering students at KTH and arises from Atlas Copco's endeavor for continuous improvements in the product development process. The company has worked for a long time with various improvements to constantly become better, for example, daily management via PULSE boards, structured educational courses for the employees, and the managing of improvement projects of various kinds.

Both the design department at Atlas Copco Tools in Nacka and the production plant at Atlas Copco Tools in Tierp works in a long term to improve their processes, and an increasing focus on the process of industrialization have been found. Therefore a curiosity for the DFA (Design For Assembly) method emerged. This thesis is intended to strengthen the collaboration between the design and production department.

1.2. Problem

The thesis work will focus on whether DFA is worth implementing at Atlas Copco Tools in the product development process and in that case, how exactly DFA can be implemented and which approaches should be used. All this in order to investigate whether a product's "time-to-market" can be reduced and in that way increase Atlas Copco Tools' competiveness and also save money. This could be obtained mainly by a leaner production, for example reducing the unique and total amount of ingoing parts of a tool applying the DFA method.

1.3. Purpose

The purpose of the thesis work is to investigate and evaluate the application of the DFA method as a working approach and what would this mean in terms of benefits and disadvantages for Atlas Copco Tools.

Besides the above the purpose is to develop a checklist as a working approach for Atlas Copco Tools.

1.4. Objectives

This thesis work has some specific goals presented below:

- Develop a checklist that supports the DFA method.

- Test and evaluate the DFA checklist on the nutrunner Tensor ST 10 Revo from Atlas Copco Tools.

- Calculate the assembly efficiency index on the nutrunner Tensor ST 10 Revo from Atlas Copco Tools with a well-known DFA method.

- Propose design changes at the nutrunner Tensor ST 10 Revo (if time).
  - Calculate the potential economic benefits <u>after</u> eventual design changes are implemented.
  - Compare the potential benefits against the eventual increasing manufacturing costs of the nutrunner Tensor ST 10 Revo.

1.5. Delimitations

The thesis work covers 11 weeks of fulltime work (corresponding 15 credits) and is delimited according to the points below:

- The assembly simplification should not have a negative effect on the product's performance.

- The thesis work will not take into account the electronic design within the product. Only the necessary electronic components will be considered as mechanical components.

- A new product will not be developed in this thesis work.

- The thesis work will not take into account any other production plant than the one in Tierp.

1.6. Requirements

The following requirements are set for this thesis work:

1.6.1. Documentation requirements

- A technical report of the thesis work.
- A checklist that supports the DFA method.

1.6.2. Time requirements

- 800 hours budget for the entire project.

1.6.3. Budget requirements

- The company is financing the trips between the different locations.

1.6.4.   Desired Demands

- The checklist to be integrated into Atlas Copco Tools' PDP (Product Development Process).

1.6.5.   Deadlines

- 24 of April presentation midway through the thesis work in Tierp.
- 7 of May presentation midway through the thesis work in Nacka.
- 24th of May preliminary report.
- 31st of May final presentation.

1.7. Methods

In consideration with the objectives set for the project, a number of methods were selected. These methods have been selected in order to solve the problem in a proper way.

Literature review -Through this method we want to get well informed about the DFA method; how it works, its advantages, disadvantages and its liability.

Benchmarking – This method will be used with the aim of investigate and find out how other companies have successfully implemented the DFA method in their product development process.

Interviews **-**By using this method we intend to compile a great part of the required information to make a reliable status description and to find out how the company's product development process looks like. Additionally, interviews will be done while benchmarking other companies and in order to get response from the testing results obtained during the project.

Field studies and observations – They are going to be useful when collecting the necessary data when visiting the production plant of Atlas Copco Tools in Tierp and also visiting the laboratory in Nacka continuously.

Calculations – Calculating will be made in order to find out the economic benefits that could be brought from testing the checklist on an existing product or a product under new development. Economic benefits could include such as manufacturing time and material cost.

1.8. Working process

During this thesis work we will: research how other companies work with DFA, collect literature about DFA, analyze the collected information, develop a checklist that supports DFA, evaluate the checklist on an existing product from Atlas Copco Tools, calculate assembly efficiency of a product from Atlas Copco Tools, evaluate if there is room for design changes and calculate the potential economic benefits (if design changes are done). Furthermore, we will: analyze the results from the

evaluation of the checklist and the assembly efficiency calculations and finally give recommendations on how DFA should be applied to Atlas Copco Tools product development process.

This thesis work is structured and managed as a project in consistency with what we learned during our study time at KTH. Fig. 1.1 presents an illustration of how the working process for this project has been planned. The project is divided in four phases (KTH Projekthandbok, 2009).
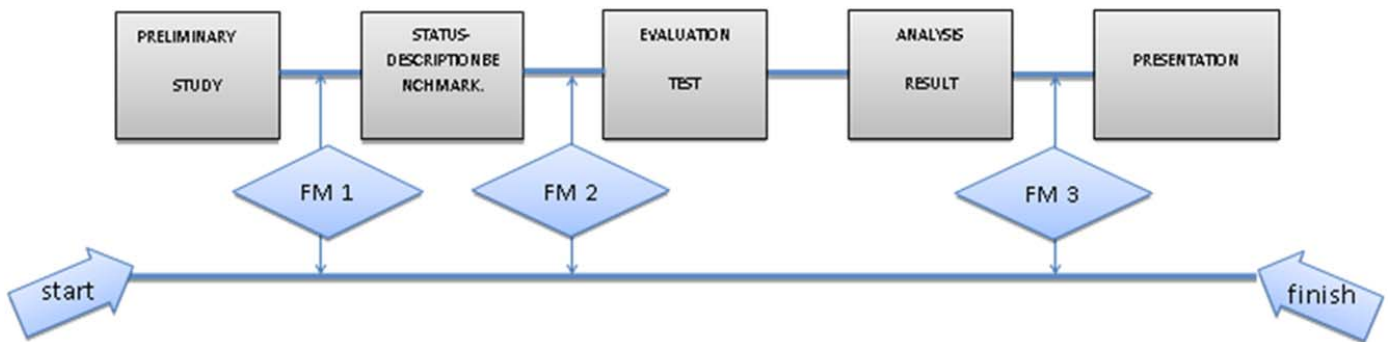
Fig 1.1: The project's approach

The first phase is problem analysis where a deep analysis of the problem is done. In this phase purpose, objectives, delimitations and solution methods are defined.

The second phase is aimed to collection of the necessary information for the project's accomplishment, where a status description of the company focusing on the current problem is made.

The third phase is where all the development of the results is executed. During this phase of the project, tests, evaluations and analysis are made.

The fourth phase is reserved to write the report, where conclusions and recommendations are also determined. Finally a presentation of the project will be done.

1.9. FMEA

A risk analysis on the project has been done. The chosen method is FMEA which consists in identifying the potential risks that may occur during a certain process. For every detected risk there must be described: what kind of failure it is, the cause why it happened, the effects that the risk may have on the process, a recommended action to the problem and also a responsible person that ensures the necessary actions being done. Additionally, a RPN index has to be calculated. RPN stands for Risk Priority Number and results from the multiplication of three values: Occurrence (O), Severity (S) and Detection (D). These values are commonly arranged in a 1-10 scale and are set by the executors of the study(Ullman, 2009).

An assessment from the resulting RPN indexes should be done with the intention of avoiding as much as possible the problems with the highest RPN. If a problem still occurs then the FMEA analysis provides with a responsible person that can take the necessary actions to solve the problem

4

or minimize the impact of it. In conclusion, the result from the risk analysis is the awareness on potential problems that we may have to face in order to perform this thesis work successfully (see appendix 5).

2. Status description

Through interviews with designers and managers at Atlas Copco Tools in Nacka, together with an industrialization group and an improvement group at the production plant in Tierp a good picture of the status of the company has been made.

Atlas Copco Tools does not use any specific method today to improve the assembly efficiency at their products. DFA, "Design For Assembly", is a method that the most designers at pre development as well as EBD (Engineering for Business Development) have heard of before but don't know very well at all.
When designers at the R&D department nowadays think about terms of assembling their main focus is on making the parts being able to fit together. Since the projects last during a short period of time and the customer demands are high the quality and the function of the product is the most important aspects when developing new products and generations.

The product development process (PDP) at Atlas Copco Tools starts at the very first beginning with a customer need that has been identified by the market department (see fig. 2). In consensus with relevant program managers the customer need leads to a business case which moves on to a pre study phase if the case is considered worth investing in. This is decided by The Product Steering Committee and works as a decision-making body before each new phase of the development process.
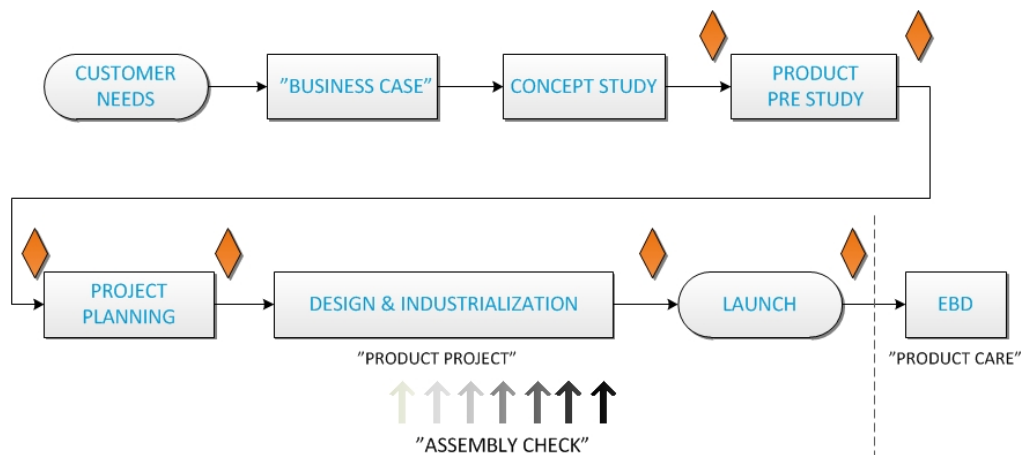
Fig 2: Current "assembly check" in the product development process

During the pre-study phase which is usually ongoing for a year, the very first prototypes are made in Nacka. The prototypes give the designer in a project an idea of how well the parts fit together in the reality but the main focus is on testing the performance of the product.
It takes until the industrialization phase when an industrialization group from the production plant in Tierp is involved in the product project working on making the product ready for production. The industrialization group in Tierp is planning the upcoming production aiming at, among others, finding suitable subcontractors and integrating new parts into the system. People in the

industrialization group have a key-role and with a perspective from the production plant they receive the new products/versions from the R&D department. Right before a product starts being produced it is tested for assembly in the pilot assembly in Tierp. This test is the first proper assembly check on the product which is considered by people in many cases being too late.

The past year an improvement group has been formed in Tierp intended to work with improvements in the production plant which is a step in the right direction. The production plant has identified a need for minimizing the amount of parts which would generate, among others, a simplified and improved logistics. Considering that fact, the production plant has been interested whether an enhancement due to the assembly efficiency can be possible. It is a new dialogue that been held with the R&D department in Nacka.

3. Theory

In this chapter the necessary facts are gathered to understand the procedure and results generated in this project.

3.1. DFA

DFA stands for Design For Assembly and is a method that started to develop during the 1960's when the labour costs increased and a need for automatic assembly in the factories was identified. The result of that became a greater knowledge about the relations between product design features and automatic assembly processes. In the early 1980's the first real DFA methods were out and the last decade a dozen more different DFA methods have been available.

The basic thought with Design For Assembly is to at an early stage during the development process design products for a more easy and efficient assembly. The DFA methods have their focus on reducing the amount of parts since it is a very simple way to shorten the assembly time and save money. By reducing the amount of parts the assembly process will be shorter and therefore instantly have a positive impact on the production process as well on the staff. Furthermore it will lead to a minimized storing area and decrease the amount of manufacturing equipment among others.

There are also other relevant areas in which products can be improved concerning the assembly efficiency:

- By dividing a product into suitable modules.
- By using standard components.
- By reducing the number of assembly directions.
- To easy the handling and orientation of a part by making the geometric shape either completely symmetrical or distinctly asymmetrical.
- By designing surfaces that are easy to grip.
- By designing for easy insertion, e.g. using chamfers.

(Jarfors et al, 2008)

3.1.1. DFA2

DFA2 is an evaluation method developed by Stephan Eskilander in 2001. The method is mainly reserved for automatic assembly but has been useful also for products that are assembled manually since "Any product designed for automatic assembly will be easier to assemble manually" (Eskilander, 2001).

The DFA2 template consists of two evaluation levels; product level and part level (fig. 3.1). Each level has certain evaluation criteria and matching guidelines. The product level is based on questions

of the product (or a module or a component) whereas the part level has questions concerning each part. Both levels address questions about the assembly sequence as well.
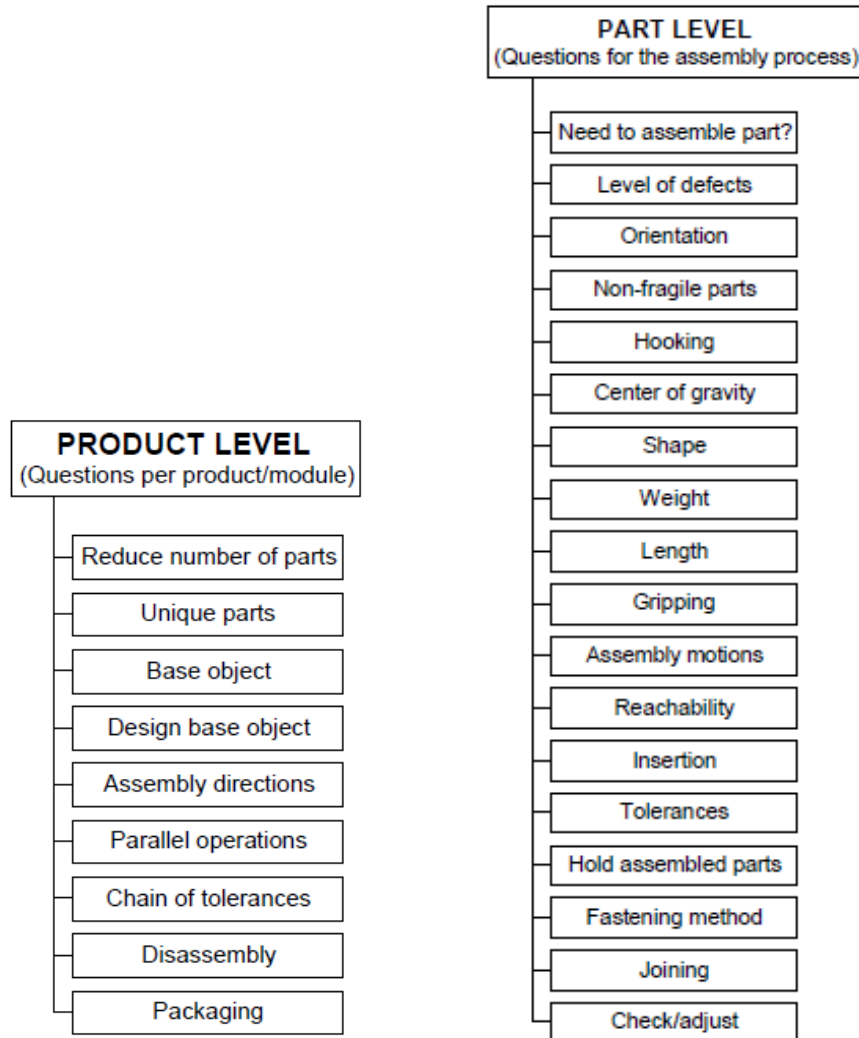
Fig 3.1: Evaluation criteria on product and part level –DFA2 (Eskilander S,2001)

The evaluation itself is about grading every criterion depending on how easy or how good an assembly task/product/part is (see figure 3.2). The best possible grade represents an index of 99 % while the worst possible grade represents an index of 11 %. For every grade there is a belonging statement which makes the evaluation easier to perform. Furthermore the template is easy to use since it is structured as a "step by step" method. The structure helps therefore the executor to focus on one aspect at a time while it at the same decreases the risk for overlooking important areas.

1. The best solution from an assembly efficiency perspective is worth 9 points.

2. An acceptable solution, but not completely successful is worth 3 points.

3. An unwanted solution from an assembly efficiency perspective is only worth 1 point. These solutions should be fixed before the product is put in production.

Best solution: 9 Points

Acceptable solution: 3 Points

Undesired solution: 1 Point

Fig 3.2: Basis for grading a product/part according to DFA2 (Eriksson T, 2012)

3.2. DFX

DFX
Design For X

DFM
(Manufacturing)

DFS
(Service)

DFR
(Recycling)

DF...
(Anything)

DFF
(Fabrication)

DFA
(Assembly)

DF...
(Anything)

DFAA
(Automatic Assembly)

DFA for
manual assembly
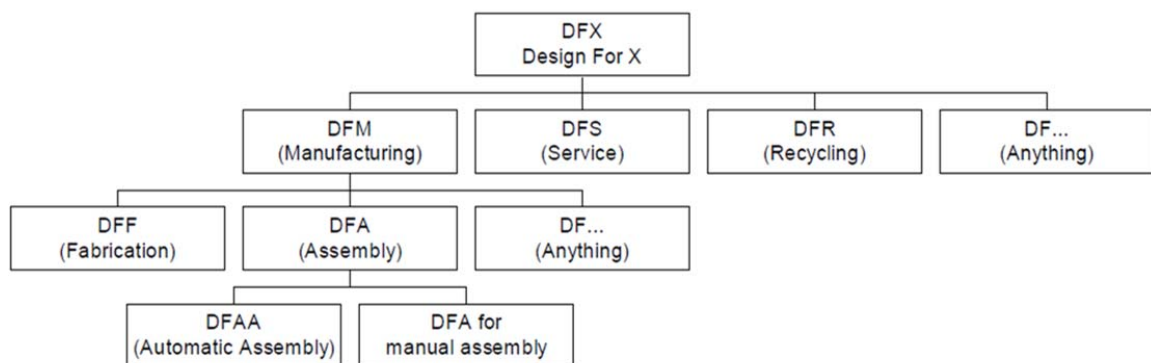
Fig 3.3: DFA in relation to other DFX (Boothroyd et al, 2002)

There are several other supporting methods than DFA when designing products. The generic names for these methods are called DFX where the X stands for a variable that takes into consideration during the design process. The variable can be a specific section of the entire development process, as for instance manufacturing (DFM) or it can be about a specific property of a product e.g. cost.

The best overall picture when designing a product is achieved through a combination of these different variables. It receives the best total economic picture of a product and therefore worth bringing up a few of them in this chapter that follows (Eskilander. S, 2001).

3.3. DFM

DFM stands for Design For Manufacture and focuses at making the individual components easier and less expensive to manufacture. However the term Design For Manufacture is today widely used but poorly defined (Ullman, 2009). DFM has no specific method developed for designing products easy and efficient to manufacture, however there are some guidelines having in mind:

- Utilize standard tolerances, rounds, holes and releases to minimize the need for different tools.
- Design parts with suitable surfaces for fixturing and also for easy localization.
- Avoid designing weak holes and threads, the tools can easily otherwise break.
- Avoid designing geometric shapes that requires for special made tools.
- If possible choose a material that is easily machined.

To sum it up Design For Manufacture is much about minimizing the costs of extra equipment and design for an easy and smart manufacturing (Jarsfors et al, 2008).

3.4. DFMA

DFMA is when designing both for manufacturing and assembly during a development process. Taking both variables into consideration generates the best result since e.g. an integration of two parts also could mean an increased manufacturing cost. Due to that combining these two aspects gives the best economics. The working process with DFMA can possibly look like the illustration below.
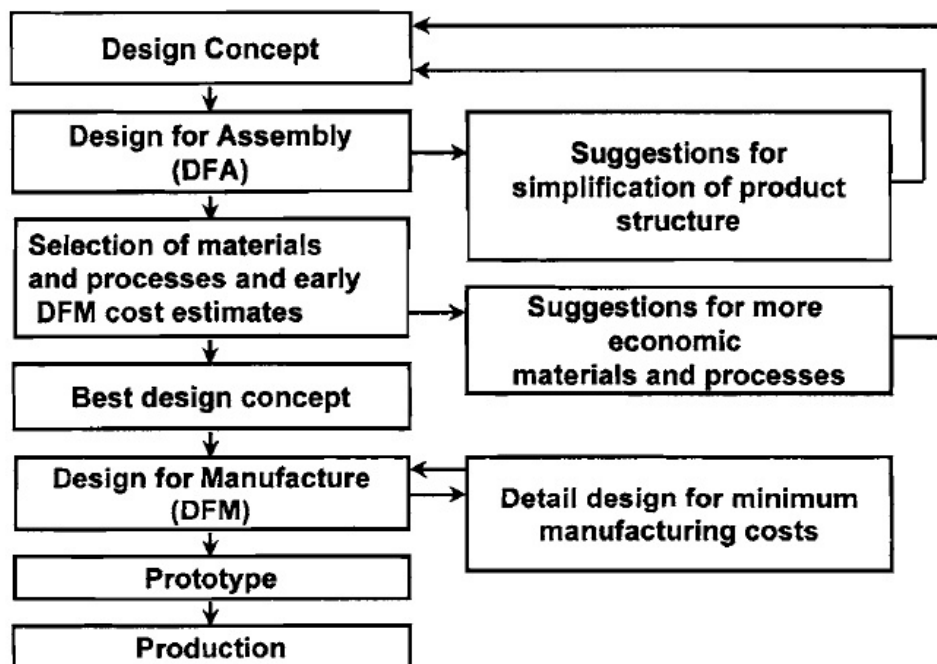
Fig 3.4: The working process with DFMA (Boothroyd et al, 2002)

3.5. Benchmarking

Benchmarking is a method to facilitate learning from other companies. The method consists of comparing itself with the best companies. The comparison can be based on a specific product or process, and the aim is to learn from each other (Berggren, 1992).

Among the benefits of using benchmarking we found:

- Through benchmarking gathering together the best applications promoting generation of new ideas.
- Get information about setting realistic targets that can be completed.
- New ways of solving problems can be recognized using benchmarking.
- With benchmarking the company gets an increasing awareness about cost, performance, products and service compared to the competitors.

4. Procedure

In this chapter presents how we approached and used the previously chosen methods in order to accomplish the objectives set for this project.

4.1. Collected data

Information was collected from different sources, initially from well-known literature as books, doctoral thesis and thesis works. Furthermore, information was collected through interviews with people and companies that could provide relevance to the development of the project.

4.1.1. Benchmarking

Already at the beginning of the project we decided to use benchmarking in order to collect quality information about implanting DFA and working with it. We interviewed three companies that successfully have implemented DFA as a working mode. The interview was half-structured (Rose, 2010) and we pulled together 21 questions that we thought were important (see appendix 3). The questions were asked to the three companies and there was room for supplementary questions if wanted. All three companies were very open and kind when answering the questions. When getting in contact with the companies a contact with the corresponding DFA responsible was to prefer.

Delaval is a world leading producer of industrial solutions to the milking industry and produces a wide range of products from milking robots to industrial luminaires. Some of the emblematic items they produce are the VMS (Voluntary Milking System) and the AMR (Automatic Milking Rotary) which are automatic milking robots. Our contact person within the company was Mikael Hultqvist. Mikael did his thesis work at DeLaval concerning DFA. At the moment he is the responsible for driving the work with DFA forward at the company.

DeLaval has been working with DFA since barely one year ago. They work with two DFA documents; a DFA checklist and some DFA guidelines. They work with DFA already in the concept stage of the product development process. Then later in the process DFA is applied to prototypes. Also there is a plan for introducing a test line there you can test prototypes from new products and test its assembly efficiency. The company thinks the earlier the better. The usage of the checklist is not a requirement for the designers, it is more used like a tool when help is needed. When it comes to the collaboration between the design - and production departments the company has structured weekly meetings but also daily contact when needed. The company doesn't use any method to calculate their products assembly efficiency. They explained that it is necessary that the staff that executes the calculation has enough knowledge about DFA. The company considers disassembly when developing a product as very important. As a disadvantage working with DFA the company means that it requires time to learn about it, introduce and apply DFA into the working process, but at the same time they think it will pay off later.

Scania is a world leader in the vehicle manufacture industry. They also design, manufacture, produce and assemble their engines in Södertälje. We contacted Dick Bergman and Erik Jaenssen, both production technicians at the engine assembly at Scania in Södertälje. Dick and Erik are in charge of driving the DFA forward in order to develop engines with higher assembly efficiency.

Scania has been working with DFA since 1990 and they also use another tool that assists the DFA work and it is SES (Scanias Ergonomi Standard). In the case of Scania it is notable that their checklist consists of 130 questions and it is used like a tool. They have also created through the years a knowledge bank there they have collected examples of smart mechanical solutions. This knowledge bank was created in order to take advantage of the knowledge of their staff. Scania has a "development line" where they control the assembly efficiency of prototypes of all kinds. Scania doesn't use any method to calculate their products assembly efficiency. The company means that when calculating the assembly efficiency of a finished product it occurs too late in the product development process. The company doesn't use any DFA software but Scania is on its way to create one in collaboration with Solme a software company. This software is based on their checklist and the DFA2-method. The company thinks that it is important considering disassembly when developing a product. Scania considers the communication between the departments of design and production as very important and have structured meetings and keep daily contact between. When it comes to disadvantages Scania thinks that it takes time to learn about DFA and to apply the method properly but also that it is an investment and the benefits come later. They also emphasized in the importance of promoting the DFA method to the management thus they have to believe strongly in it.

Sony Mobile Communications is a world leading company in the communications industry. Sony has its design department in Lund, Peking and Tokyo, while the production and assembly is based in China. The contact person within Sony was Mattias Bognäs, he work as a process and producibility engineer.

Sony has been working with DFA for at least 10 years. Sony uses what they call a DFM- checklist with 60 general requirements and 200 guidelines. There is also a database called "lessons learned" there you can find clever design solutions developed before. They have a well established process in terms of DFA work within continuous improvements. They use the checklist and guidelines early in the concept stage of the product development process. The DFA work is executed in industrialization projects. Sony claims that at the moment it doesn't exists a proper method that calculates producibility and assembly efficiency particular on mobile telephones. As a drawback they think that the DFA2-method doesn't match completely to the company and it has to be adapted for their specific needs. Daily contact between design and production departments is important in order to compromise about design decisions.

4.1. Development of a checklist

In order to develop the DFA checklist required for this thesis work, various documents was taken in consideration and have been analyzed. Any checklist from the three benchmarked companies wasn't

available for us to examine, instead we looked at a checklist presented in the book "*The Mechanical Design Process*" by David Ullman and a checklist presented in the thesis work report "*Implementering och upprätthållande av DFA*", by Hoffman and Hultqvist, in order to get inspiration creating our own checklist. Furthermore we studied the DFA2 template together with our own experiences from the visit to the production plant in Tierp. Additionally, a workshop with the designers was arranged where questions and ideas arose and were taken into account during the development of the checklist.

During the creation of the questions in the checklist, the need of explanation for each question arose in order to bring even more understanding to the designers and provide the designers with recommendations when designing a product more assembly efficient. We decided then to create some complementary guidelines to each question in the checklist. The guidelines are intended to facilitate the answering of the questions.

4.2. Testing of the checklist

Already at the beginning of the project the objective was to develop a checklist that supports the DFA methodology and to test it on a specific product, in this case the Tensor ST 10 Revo. On the final stage of the development of the checklist we found that it will be difficult to test the checklist on an existing product as the Tensor ST 10 Revo. After all, the checklist is intended to be used on products under new development. Consequently in consensus with our supervisor from Atlas Copco Tools in Nacka we decided to test and evaluate the checklist on a product that is still under development. The chosen product was a high-end spindle and each cirterion on the checklist was tested and evaluated on product's CAD model in ProEngineer. The test and evaluation was executed in cooperation with our supervisor Andris Danebergs. Afterwards the checklist was send to the production plant in Tierp for further evaluation by production technicians and assembly operators. The comments resulting from this evaluation were also taken into account when editing the checklist.

4.3. Assembly efficiency calculation

One of our objectives was to evaluate the assembly efficiency on Tensor ST 10 Revo by using a well-known DFA method. Since the DFA2 template, described earlier in the thesis, is a method that is easy to understand and is an established method we chose that one to work with. The product was analysed based on our best ability to determine on which grade each part should get with the help from the additional guidelines.

We decided to look at a certain level of components for not digging in too deep into the design of the tool. Looking at every single part within the product would probably be a lot of work and not that much to gain from it either. We chose to look at subassemblies that are delivered to the final

assembly as individual components. The decision was made in agreement with our supervisor in Nacka.

Before the evaluation of the tool we went through together with our supervisor the tool's complexity and function for making the upcoming evaluation easier to perform. We did also discuss the parallel operations that exist when the tool is being assembled in Tierp.

During the evaluation itself we analysed components by viewing them in ProEngineer but also spending time in the laboratory and mounting as well as dismounting parts. We realized also that one particular criterion, "Level of defects", was too difficult to find information about for the specific parts which lead not taking it into account during the evaluation.

Calculations were made with the aim of getting a value of how assembly efficient Tensor ST 10 Revo was, and to analyse the product and see if there was potential for changes in its design that could make it more assembly efficient.

Fig 4.1: The red circle indicates the examined area of the nutrunner Tensor ST 10 Revo

5. Result

5.1. Checklist and guidelines

The main result from this project is a DFA checklist with its corresponding DFA guidelines (see appendix 1).

The checklist has 20 questions and they can only be answered with YES or NO, the goal is to answer YES on everyone. By answering NO the designer is encouraged to think of a possible solution in terms of turning the answer to a YES. At the same time the possibility to consult the DFA guidelines that complement the checklist exists.

5.2. Testing of the checklist

In general the checklist completes its purpose to increase the awareness of the designers thinking design for assembly. Some questions are more difficult to answer than others but the introduction of guidelines in accord with the checklist would facilitate both the understanding of the question and its answering. An additional result from testing the checklist to the high end spindle is a list of commentaries and observations. The commentaries were about rephrasing some question in the checklist and also dividing them into categories. The appropriate rectifications on the checklist were done and a new version of the checklist was handled to both supervisors at Atlas Copco Tools. No further testing of the latest version of the checklist was done thus the early made changes would not affect relevantly the result from the checklist.

5.3. Assembly efficiency calculation

The rates (down below) calculated from the assembly efficiency evaluation are a bit difficult to value since DFA2 has no general benchmarks for what indicate a good product regarding its level of assembly efficiency. On the other hand the resulting indexes give the company values for the assembly efficiency on their existing product generations that further can work as references for comparison when new developing.

Collection of index from DFA2 on Revo	
Product level:	M ≈ 40 %
Part level:	M ≈ 63 %

Table 1: Assembly efficiency indexes

From the assembly efficiency calculation the analysis on product level (see appendix 4.1) generated an index of 40 %. The evaluation resulted in a couple of low grades for Tensor ST 10 Revo. The

following criteria generated the lowest grades: "reducing the number of parts", "design base object", "assembly directions" and "chain of tolerances". These are areas that are worth to work further with when or if improving the product.

The analysis on part level (see appendix 4.2) generated an index of 63 %. Here also the evaluation resulted in lower grades for some of the parts. The concerning criteria for those low grades were mainly "shape", "gripping" and "tolerances". Worth having in mind is that "shape" and "gripping" are typically adapted criteria for automatic assembly and probably also therefore many of the parts in the tool received the lowest grade when these questions were asked (Tensor ST 10 Revo is after all designed for manual assembly). On the other hand, designing a product for automatic assembly by taking concern to automatic criteria could only mean something positive for manual assembly which is something to aim at as well (if something is easy to assemble automatically it will also be easy to assemble manually).

In this industry it is also very essential with narrow tolerance dimensions which in this case could have had an unfair effect on the evaluation result of Tensor ST 10 Revo since this industry simply demands for narrow tolerances.

5.4. Suggestions for improving assembly efficiency

During the assembly efficiency calculation we naturally started to think about improvements for aiming at a higher level of the assembly efficiency on Tensor ST 10 Revo.

It was found quickly that the product contained many different types of screws and a need for minimizing the variety of them. Interviews with operators from the production plant in Tierp as well as staff from the laboratory in Nacka shared the same thought about the screws. By using fewer types of screws the assembly time easily can be reduced as a result of diminishing the number of tools that tighten the different types of screws etc. Fewer types of screws also mean smaller amount of parts within the product which contributes to minimized costs for the product.


Fig 5.1: Different types of screws found in Tensor ST 10 Revo

One question in the part level section is about the actual need for a part to be assembled. The question can be answered by asking three particular questions:

1. Does the part move, relative to other already assembled parts during normal use of the finished product?

2. Does the part have to be of other material than already assembled parts, or isolated from them?

3. Does the part have to separate from other already assembled parts because assembly or disassembly would otherwise is impossible?

If all the questions above are answered with a "No" then the part should be considered being integrated or eliminated. Two parts that were analyzed received "No" on all these three questions:

- One of them was a washer (designation 4220367105) that is placed behind the gear. We questioned its necessity as a separate part and thought about integrating it with the part that is assembled after (the part on the right side in the figure 5.2). Due to lack of time the time for analyzing the possibility of integration is recommended for further work.
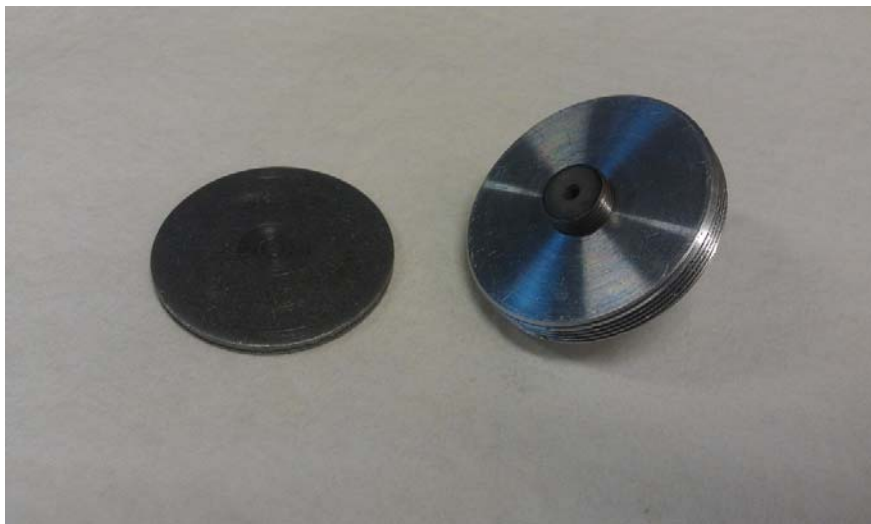
Fig 5.2: Parts that possibly can be integrated with each other

- The other part that had potential for elimination or integration is a separate plastic "button" (designation 4220285706). This can easily be integrated into the part that is on the left side in the figure below (designation 4220401780). Both of them are of plastic and in other Tensor

tools these two parts are integrated with each other. Therefore it has all the reasons to be one unit. The small button is located above the trigger in Tensor ST 10 Revo.
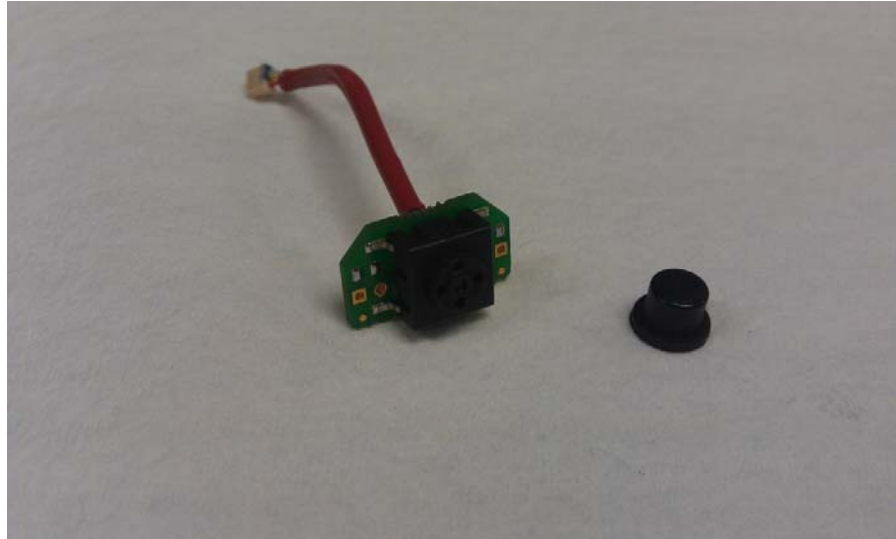
Fig 5.3: Parts that can be integrated with each other

5.5. Analysis of effects when implementing DFA

The effects of introducing the DFA checklist are supposed to be an implementation of assembly efficient design in the final products. Being the main goal to reduce the amount of parts in the products and reduce its assembly time. By introducing the DFA checklist and guidelines eventual changes in the product development process can be predicted. These changes can affect the process and the designers positively and negatively. Evidently by introducing the checklist would mean an additional task for designers in their working process and consequently it would take a longer time than usual. The estimated time for checking the checklist is about one hour time, if the designer has to check the guidelines then it would take additionally time (up to one more hour time). It is also assumable that after working with the checklist a couple of times, the checking time will be much shorter. The additional working time is intended to be earned in terms of reducing the redesign of a product and reducing the assembly time of the product. The necessary design changes of a product before it is introduced into serial production would be significant reduced and therefore it would generate a shorter industrialization. Besides that, the task would not be much harder to execute.

The effects of designing more assembly efficient products due to the DFA checklist, regarding operators are positive. Designing more assembly efficient tools would mean products with fewer parts and easier assembly (e.g. fewer tools and fewer fixtures), faster assembly (e.g. shorter assembly time) and less risk for injuries during assembly (e.g. parts without sharp edges).

22

For the customers, an implementation of DFA when designing with the help by the checklist would involve: products with fewer parts and better quality, less purchasing thus fewer and/or integrated parts (e.g. via: lower material cost, lower WIP and storage) together with faster service and maintenance thus fewer parts and better accessibility.

6. Conclusion

To develop a checklist that supports the DFA method was an objective set for this project which has been satisfied. Beyond that some guidelines for each question in the checklist were developed. The guidelines were an unforeseen objective and appeared later on during the thesis as an additional document for the checklist (1).
The checklist was successfully tested on a tool from Atlas Copco Tools that is under new development. It was realized that it wasn't appropriate to test it on an existing product like in this case Tensor ST 10 Revo thus the checklist was mainly aimed to be used on products under new development (2).

- The conclusion from this objective above (1) is that a checklist fulfills its purpose at its best with additional and supporting guidelines. The guidelines make the questions in the checklist easier to answer and give the designer an idea how to think more for design for assembly for each section. The benchmarking result also shows that the interviewed companies are using guidelines during the development of a product's design which is an experience to learn from.

- Another conclusion (2) is that the designer gets the most out of the checklist and its helping guidelines when designing new products. During the product pre study phase there is still the least restrictions about the design and the more design decisions are made, the ability to change the product will be increasingly limited (Ullman. D, 2010). Though this fact being said, these documents can also be applied during further development of products for increasing the awareness of assembly efficiency of every designer during product development. Additionally a design can still be improved, with some limits, in an existing product with the help from the documents.

To calculate the assembly efficiency on the nutrunner Tensor ST 10 Revo is also an accomplished objective for this thesis. Since there hasn't been any calculation of assembly efficiency on any other product from Atlas Copco Tools before, the obtained values can't be compared in order to get an idea of how good or bad the tool is from an assembly efficient point of view (3).
Some potential for improvements in the tool's design were found during the evaluation with the DFA2 template. However, the evaluation and following the entire DFA2 template was time consuming for the thesis (4).

- The conclusion (3) from calculating the assembly efficiency on Tensor ST 10 Revo is partly that the calculation requires time and resources for having the possibility to compare assembly index between products in the future. The DFA2 template is produced for general evaluation of products for automatic assembly. Potentially a more fair assembly index could be achieved if the template would be more adapted for Atlas Copco Tools and manual assembly.

- Further the evaluation contributed to an enhanced understanding for assembly efficiency and the factors that affect the assembly efficiency on a product. That fact resulted in ideas (4) for

potential improvements in the tool's design and confirms the benefits of thinking DFA when designing products at Atlas Copco Tools. The conclusion however is that the DFA2 template is not optimal for integrating a way of thinking DFA since it's a lot of work. There are other basic ways of achieving an awareness for efficient assembling. On the other hand DFA2 is a structured and efficient way to discover potential for improvements in a product.

Small design changes on the Tensor ST 10 Revo have been suggested in order to improve its assembly efficiency as mentioned as a desired objective for this thesis. Unfortunately due to lack of time any calculation of the potential economic benefits of the eventual implementation of these changes could not be executed. Nor the comparison of the potential benefits against the eventual increasing manufacturing cost could be done, also because of lack of time (5).

- The unforeseen objective to create guidelines that appeared later on in the thesis made us prioritize that document since it played an important role for the checklist. It resulted in less time for examining the suggestions for design changes at the Tensor ST 10 Revo and its economic effects (5).

6.1. Recommendations

After analyzing the results and coming to conclusions we base the following recommendations for Atlas Copco Tools on our work.

- At firsthand we strongly recommend introducing the checklist and its corresponding guidelines (see appendix 2) to Atlas Copco Tools' product development process (PDP). The result from the benchmarking speaks for having a checklist integrated into the PDP as well.
  - o We mainly suggest the usage of the checklist and guidelines in pre-study projects and product projects to at an early stage already then have the possibility to make products assembly efficient and prevent future design mistakes. We also strongly believe in the document for its effects as a working approach on making all the designers (experienced or not) aware of the importance and advantages with DFA.
  - o If the document that we recommend is introduced into the PDP then it would be suitable in the document "Concept Study and Product Pre-study Management" in the section "3.3.3 Reviews" as well as "4 Reviews" in the document "Project Management".
  - o We suggest that the checklist and the supporting guidelines should be updated and taken care of by the mechanics line since it contributes with designers for all kind of projects (also at EBD) at the R&D department. Beneficially it should receive input from the production plant for keeping it up to date.
  - o After a certain time with the document being applied in a couple of projects we recommend doing an evaluation concerning its effects and usage.

- We do not recommend in the first place introducing the DFA2 template since it would be an extensive and complex job at a beginning. The template also requires the evaluation being

done on existing products which do not make it effective for pre-study projects and product projects. Even though the DFA2 method would be more adapted for products at Atlas Copco Tools it would still be time-consuming at a start which will probably not suit the company concerning the status right now. The benchmarking also proves that the existing DFA2 template is less optimal since the benchmarked companies do not calculate any assembly efficiency at their products today.

- We recommend arranging short courses/workshops at the design department as well as the production plant in order to spread the knowledge and achieving a common understanding about DFA. We believe that the incentive to work with DFA will be greater if everyone that is involved will know more about the area and its benefits.

- We also believe that it takes a responsible person or an enthusiast for this area for driving the work with DFA forward. As a suggestion someone within the industrialization group at the production plant as well as the design department.
  In general the whole organization would have to believe in implementing DFA and see the benefits for wanting to fully invest in it. It is alpha and omega for successfully implementing DFA.

7. Discussion

We put into discussion the possibility for Atlas Copco Tools to consider calculating the assembly efficiency on their existing products (or those who have a critical amount of parts or show clearly low assembly efficiency) in order to find possibilities of improvement from the products. Additionally, the calculation brings the possibility of comparison that facilitates the understanding whether a products assembly efficiency value is good or bad.

We have studied two different quantitative methods that calculate assembly efficiency. Further studies can be done in order to find out whether a more appropriate method that calculates assembly efficiency on products that are assembled manually can be found.

It is not easy to get numerical results that show the profit after working with DFA. A comparison is to wish when designing the same product, with and without DFA influence.

Any eventual DFA method developed for Atlas Copco Tools should consider the fact that the assembling of the tools is mainly manual and there is no production line but assembly stations.

To create the guidelines was a time consuming task, that time could has been assigned for a deeper analysis and development of design changes on Tensor ST 10 Revo.

8. Further work

We have established that there are a few areas to further investigate after finished thesis work. We recommend this report as a basis for continuous work within the area of DFA for Atlas Copco Tools.

During this thesis a first version of a checklist and guidelines supporting the DFA method have been developed (see appendices 1 & 2). The document has been evaluated to some extent but will probably need further development and improvement for keeping it as an effective help when designing products.

In addition a further investigation regarding the DFA2 template or another method for measuring the assembly efficiency should be executed for deciding if Atlas Copco Tools can gain from it. The benchmarking shows that Scania and Sony Mobile Communications are both interested in applying a method for calculating an index to measure products' assembly efficiency.

From the interviews with the designers at the R&D department a need has been identified for improving the database "Mechanical Articles-GSD". If it was easier to find existing parts in the register the encouragement to use already existing parts would be greater.

During the assembly efficiency calculation we found potential for improving the Tensor ST 10 Revo but didn't have the time to visualize the new suggestions in ProEngineer. A further work for EBD would be to examine the design changes whether they could result in economic benefits for the product's production.

9. References

Literature and figures:

Bengtsson J-E. 2011. *Process Description*. Atlas Copco Tools and Assembly Systems. Nacka.

Berggren E, 1992, *Benchmarking-ett sätt att lära av andra*, Inge Nilsson Consulting/Jan Olsson Reklam/Volvotryckeriet, Göteborg, p. 7-8.

Boothroyd G and Dewhurst P. 2002. *Product Design for Manufacture and Assembly*. Second Edition. Knight Winston. New York. p. 1, 9, 15, 86.

Engerstam, M. 1973. *Monteringsanpassad konstruktion av produkter och detaljer*. IVF. Göteborg. p.1,11.

Eriksson T. 2012. Föreläsningsanteckningar från kursen Produktion FK1, HM1016, KTH i Södertälje.

Eriksson T. 2009. *Projekthandbok*. Tillämpad Maskinteknik KTH Södertälje, p. 48-50.

Eskilander S. 2001. *Design For Automatic Assembly- A Method For Product Design: DFA2*. KTH. p. 26, 34, 155-156,159-162, 177, 182-185.

Hoffman A and Hultqvist M. 2011. *Implementering och upprätthållande av DFA*. KTH. Södertälje.

Jarfors A et al. 2008. *Tillverkningsteknologi*. 3:2. Studentlitteratur. p. 553.

Lindqvist B and Skogsberg L. 2007. *Power Tool Ergonomics*. Second Edition. Strokirk-Landströms, p. 67.

Rose L et al. 2010. *Arbete och teknik på människans villkor*. 2:1. Prevent. Stockholm. p. 411, 486.

Ullman D. 2010. *The Mechanical Design Process*. Fourth Edition. McGraw-Hill. New York, p. 19, 350-353, 328-349.

Oral references:

Asplund Daniel, Atlas Copco Tools, 2012-04-17

Bergman Dick, Scania, 2012-04-18

Bergström Caroline, Atlas Copco Tools, 2012-04-17, 2012-05-07, 2012-05-10

Bodin Andreas, Atlas Copco Tools, Tierp, 2012-04-24

Bognäs Mattias, Sony Mobile Communications, 2012-04-25

Danebergs Andris, Atlas Copco Tools, löpande under arbetets gång

Eriksson Markus, Atlas Copco Tools, 2012-04-19, 2012-05-07, 2012-05-10

Forsgren Cecilia, Atlas Copco Tools, 2012-05-07, 2012-05-10

Fröjel Jessica, Atlas Copco Tools, 2012-04-17, 2012-05-07, 2012-05-10

Holmin Mats, Atlas Copco Tools, löpande under arbetets gång

Hultqvist Mikael, DeLaval, 2012-04-18

Jaenssen Erik, Scania, 12-04-18

Järvi Jennie, Atlas Copco Tools, Tierp, 2012-04-17

Kastensson Petra, Atlas Copco Tools, löpande under arbetets gång

Linell Jan, Lean konsult, KTH, löpande under arbetets gång

Rhodin Morgan, Atlas Copco Tools, Tierp, löpande under arbetets gång

Sjöblom Torbjörn, Atlas Copco Tools, 2012-04-17

Wendel David, Atlas Copco Tools, löpande under arbetets gång

Zander Johan, Atlas Copco Tools, 2012-04-17, 2012-05-07

Östling Gunnar, Atlas Copco Tools, 2012-04-16, 2012-05-07, 2012-05-10

Appendices

Appendix 1: DFA Checklist

(DFA) Design For Assembly Checklist		
Note that there are complementary guidelines to each checkpoint to look at.		
Criteria	**YES**	**NO**
Amount of parts		
1. * Has the product minimal amount of parts?		
2. * Has the product minimal amount of fasteners?		
3. Are the fasteners used in the product of standard sizes and standard types?		
4. Can unique parts or fasteners in the product be replaced with other ones that are already used in other tools?		
Handling		
5. Contains the product parts that cannot be assembled in a wrong way?		
6. Is it easy to ensure that a part is correctly assembled?		
7. Can parts be handled easily during assembly?		
8. Are cables used in the product easy to identify while assembling?		
9. Are the parts of the product easy to grip while assembling?		

Risks/Ergonomics		
10. Is the risk for fragile items being damaged eliminated while assembling or storing?		
11. Is the risk of cables being clamped eliminated while assembling or storing?		
Equipment		
12. Can the tool's performance (torque etc.) be easily verified with existing standard test equipment?		
13. Is the number of assembly fixtures reduced to its minimum?		
14. Is there enough accessibility to use standard tools (or existing special made tools) while assembling?		
Assembly sequence		
15. * Is the product designed so parallel operations when assembling can be done?		
16. Is the product designed with a base object for locating other components?		
17. Is the number of assembly directions reduced to its minimum?		
Miscellaneous		
18. Have you completely avoided any chain of tolerances in the product?		
19. * When a second generation product is under development, is its assembly efficiency improved compared to its previous generation?		
20. Is the design of the product suitable for disassembly and service?		
Checked by:	Date:	Project number:
* This question is mainly reserved to the designers from EBD (Engineering for Business Development).		

Appendix 2: Guidelines for the checklist

These guidelines are developed as a help to each checkpoint in the checklist. The guidelines are aimed to <u>increase the awareness</u> of the designers and think design for assembly.

1. Minimal amount of parts

This question is difficult to answer therefore we recommend to look at detailed parts within the product at least one time. Then answer as best as you can.

In order to give guidance to the designer in reducing the part count, the DFA methodology provides three criteria against which each part must be examined as it is added to the product during assembly (Boothroyd G et al, 2002).

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 elements, for example, are not sufficient for a positive answer.

2. Must the part be of a different material than 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?

It is of big importance to reduce the numbers of parts in a product without changing its functionality (Eskilander S, 2001). By using proper operating functions (e.g. those involving simple demands for mobility), suitable methods of manufacture (e.g. plastic processing for the production of complex shapes), and favorable product structures (e.g., fixing a number of parts by common connection), you can often keep the amount of parts low (Engerstam M et al., 1973). Note that each function in the product should be satisfied by the lowest possible number of parts (Engerstam M et al., 1973).

By using integrating production methods (e.g. casting or injection molding) the number of parts can be reduced, hence facilitating assembly. An economic evaluation has to decide whether the cost for developing a special tool for producing an integrated part is higher than the profit of reducing the number of parts (Eskilander S, 2001).

When minimizing the amount of parts or in general designing products take into account to design for an easy and low manufacturing cost.
Product cost may be increased if parts are integrated resulting in very complex parts. The costs for manufacturing a complex part may be higher than the costs for e.g. four simple parts that require assembly (Eskilander S, 2001).

2. Minimal amount of fasteners

The numbers of fastenings elements in a product usually determine the assembly time and should thereby be minimized (Eskilander S, 2001). Each fastener used is one more component to handle and there may be many more than one in the case of a bolt with its accompanying nut, flat washer, and lock washer. Each instance of the component handling takes time, typically 10 sec per fastener (Ullman D, 2010).

In the total cost of fasteners, besides the cost of the components themselves additional costs must be included, cost of purchasing, inventorying, accounting for, and quality-controlling them.

Fasteners are stress concentrators; they are points of potential structural failure in the design. For all these reasons it is best to eliminate as many fasteners from the design as possible (Ullman D, 2010). Another way to reduce the number of fasteners is to use only one fastener and either pins, hooks, or other interference to help connect the components (Ullman D, 2010).
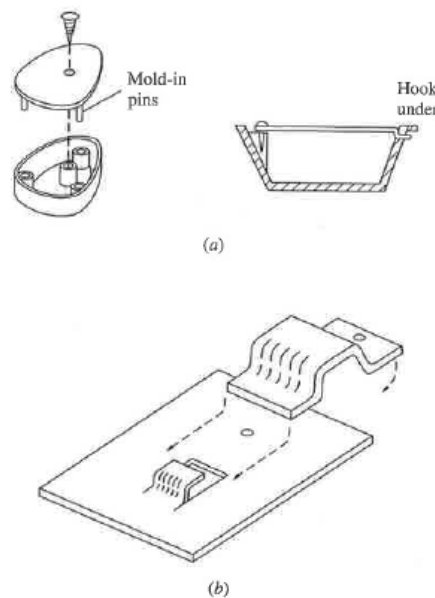
Fig 1: Examples of reducing fateners (Ullman D, 2010)

3. Standard size and/or type of fasteners

This guideline encourages the use of standard size and length of fasteners facilitating the usage of standard tools and the unification of torque forces. The standardization of fasteners can also contribute to the minimization of number of fasteners (Eskilander S, 2001).

The strive for using standard parts instead of using only unique parts throughout the whole product family has become common. There are several advantages with using standard parts; i.e. purchases of

scale, fewer parts to administrate, and existing equipment can handle all parts etc. (Eskilander S, 2001).

If standard sizes and/or types of fasteners are not used other solutions should be financially motivated. Finally, avoid the usage of slotted screws.
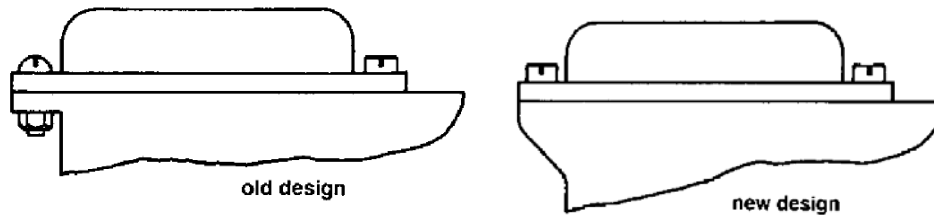
Fig 2: Example of using standard fateners (Eskilander S, 2001)

4. Parts already used in existing products

Use the database of existing products or contact the appropriate person from the production plant in Tierp to search and find items that can potentially be used in a new product.

If not already existing parts can be reused, then the approach is to design the new part or component for replacing existing parts or components in different variants of the product. This can lead to several variants being assembled in the same automatic assembly system with no need for new grippers, new fixtures or new feeders (Eskilander S, 2001).

If no standard fasteners can be used then reuse fasteners that are common in existing products, with the exception for slotted screw that have statistics that shows high injury during assembling.

5. Parts that cannot be assembled in a wrong way

It should be impossible to assemble a part in a wrong way (Eskilander S, 2001) hence the need to check or adjust will be minimized if not eliminated (Eskilander S, 2001). If a component can be installed in the assembly only in one way, then it must be oriented and inserted in just that way. The act of orienting an inserting the component takes time and either worker dexterity or assembly machine complexity (Ullman D, 2010).

There are two measures of symmetry: end- to end symmetry (symmetry about an axis perpendicular to the axis of insertion) and axis-of insertion symmetry. End-to end symmetry means that a component can be inserted in the assembly either end first. Before modifying a component to meet this or similar guidelines, it is important to check the value of the modification. The cost of adding a feature may not improve its functionality for the assembler sufficiently to warrant the modification. The designer should also strive for rotational symmetry so the components can be inserted in two directions, in that way achieving axis of insertion symmetry (Ullman D, 2010).

A component can be designed to be clearly asymmetric as well, in order to create a single way of insertion (Ullman D, 2010).

Design self-located parts that could be able to keep orientation and position after being assembled (Eskilander S, 2001).

6. Easy handling of a part while assembling

Manual assembly with one hand should be possible thus it implicates easy and simple assembly motions (Eskilander S, 2001).

Avoid, where possible, the necessity for holding parts down to maintain their orientation during handling of the subassembly or during the placement of another part. If holding down is required, then try to design so that the part is secured as soon as possible after it has been inserted (Boothroyd G et al, 2002).
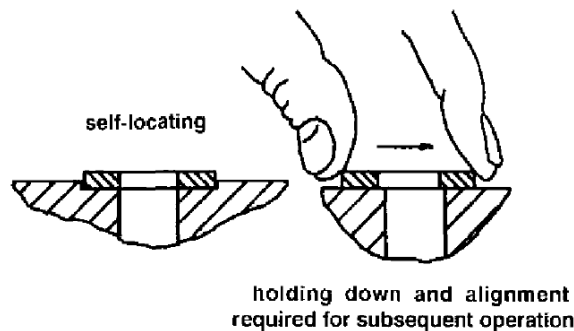
Fig 3: Example of self-locating (Boothroyd G et al, 2002)

Parts that are secured immediately, i.e. does not loose orientation or position if the assembly is turned upside down, ensures a more reliable assembly process (Eskilander S, 2001).

Finally, if the components fastened together must be taken apart for maintenance, use captured fasteners (fasteners that remain loosely attached to a component even when unfastened) (Ullman D, 2010).

To make the actual insertion or mating of a component as easy as possible, each component should guide itself into place. This can be accomplished making use of chamfers, leads and compliance (Ullman D, 2010).
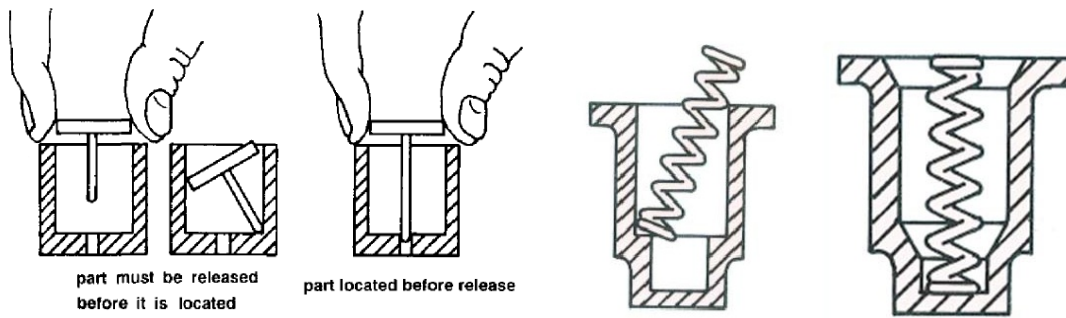
Fig 4: Examples of guided insertion and chamfers (Boothroyd G et al, 2002)

7. Control if the part is correctly assembled

A rule of thumb is to avoid any design that requires adjustments during assembly. Adjustment operations are difficult (Eskilander S, 2001).

If a part can be ensured visually that it is correctly assembled then it is favorable for the assembly time.

8. Identifying cables while assembling

Provide features that facilitate the identification of cables and its respective connectors in order to assemble them correctly.

Use connectors that are different from each other and may not fit in the wrong connector. I.e. when connecting two similar connectors with the same amount of poles change deliberately the female connector to one with a higher number of poles. All this in order to avoid incorrect assembly.

9. Parts that are easy to grip

Avoid parts that stick together or are slippery, delicate, flexible, very small, or very large or that are hazardous to the handler (Boothroyd G et al, 2002).
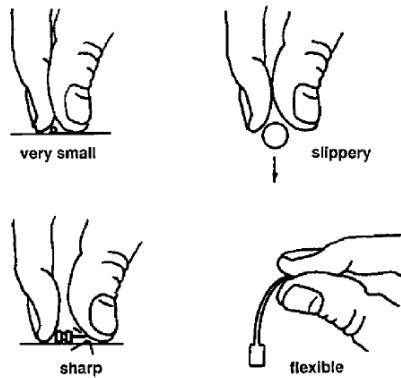
Fig 5: Examples of parts difficult to handle (Boothroyd G et al, 2002)

Provide features that will prevent jamming of parts that tend to nest or stack when stored in bulk (Boothroyd G et al, 2002).

Avoid features that will allow tangling of parts when stored in bulk (Boothroyd G et al, 2002).
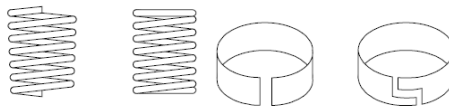
Fig 6: Examples of design features that help to avoid tangling (Boothroyd G et al, 2002)

10, 11. Avoid cables and fragile items to be damaged or clamped

Design features with enough space so the possibility for cables being clamped will be minimized.

Take also into account the risk for human injuries during assembling. Avoid sharp edges that may cause cuts on the operators (Lindqvist and Skogsberg, 2007). The operators' ergonomics is of big importance.

12. Use standard test equipment

When developing new products, it shouldn't be necessary to acquire or develop new test equipment. At the same time think about not having more than one setup in the test rig.

If a new-developed product has a different kind of functionality than previous tools then an appropriate test procedure should be developed.

13. Reduce the number of assembly fixtures

By reducing the number of assembly fixtures the assembly affords fewer steps in the assembly sequence (Ullman D, 2010).

14.   Accessibility for standard tools

Assembly can be difficult if components have no clearance for grasping. Assembly efficiency is also low if a component must be inserted in an awkward spot (Ullman D, 2010).

There must be space for grippers and assembly tools around the part to reach for insertion and any special operations. Consider having space especially for standard tools. Degrees of freedom in movements and assembly area should also be considered. Obstacles for insertion are to be avoided since they only cause complex movements or tools, which take time and can be difficult to program (Eskilander S, 2001). Besides concerns for assembly, there is also maintenance to consider. In both assembly and maintenance, tools are necessary and room must be allowed for the tools to mate with the components and to be manipulated (Ullman D, 2010).
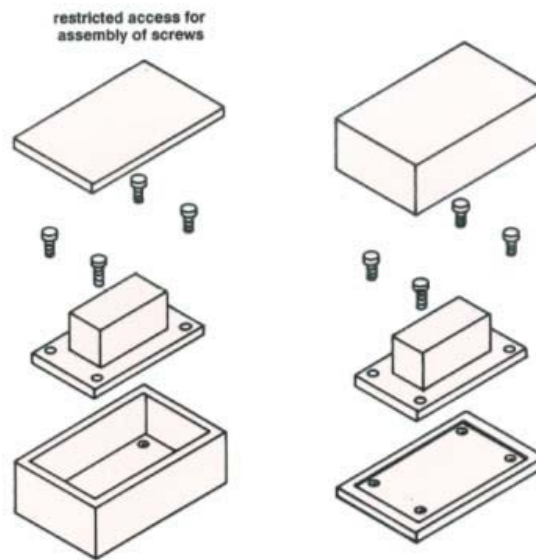
Fig 7: Examples of restricted access for assembly of screws (Ullman D, 2010)

15.   Parallel operations when assembling

If components can be assembled in parallel, the total lead-time in the assembly shop can be reduced drastically compared to ordinary sequential assembly. A change in any component will result in a significantly limited change in the assembly system if it is being assembled in parallel. The total lead time can be reduced by having parallel operations during assembly (Eskilander S, 2001).

A parallel assembly process and a standardized set of parts may ensure that all the variants of the product can be produced in the final assembly. This can result in simplified logistics, less work in progress, less storage, less buffers and so on (Eskilander S, 2001).

A sub-module or component should not be designed as an emergency solution for an assembly problem. There should be straight assembly sequence that does not require sub-assemblies, but gives the possibility to assemble in parallel, which in turn can shorten the lead-time (Eskilander S, 2001).

When developing products make sure that a subassembly in a CAD-model corresponds to the same subassembly when assembling.

16.   Base object

A base object is a single base on which all the other components are assembled, providing a foundation for consistent component location, fixturing, transport, orientation, and strength. The ideal design would be built like a sandwich, with each component or subassembly stacking on top of another one (Ullman D, 2010).

A base object should be designed with a stable center of gravity considering:

- Center of gravity as low as possible.
- Support points as far apart as possible from one another.
- Possible holes for guiding the insertion and/or stripping elements.

Furthermore, the base object should not exhibit a larger number of composition points than what may be simultaneously assembled. The motions required should, ideally, be vertical or horizontal and no flipping or turning the base object should occur during assembly. Turning the assembly requires extra equipment. Furthermore, the fixture becomes more complicated since it has to be adjusted to new surfaces for location. There is also risk that already assembled parts can lose orientation if assembly is turned (Eskilander S, 2001).
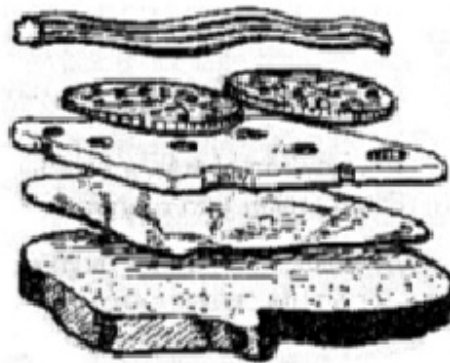
Fig 8: Illustration of "sandwich" assembly. (Eskilander S, 2001)

17.   Reduce assembly directions

The components should mate through straight-line motion, and this motion should always be in the same direction. If both of these corollaries are met, the assembly will then fall together from above.

x

Thus, the assembly process will never require reorientation of the base nor any other assembly notion other than straight down. (Down is the preferred single direction, because gravity aids the assembly process.) (Boothroyd G et al, 2002).

18.   Chain of tolerances

Chain of tolerances should be avoided. In case of having one or more chain of tolerance(s) calculates its value and ensures that it works when assembling the parts together. Thereafter make tolerance changes and re-dimensioning if necessary. Avoid tolerances that can give interference fit (e.g. H and h tolerances).

19.   Improvement of the assembly efficiency on former generations

In order to get an improved efficient assembly process, follow up on notable problems from former product generations, by consulting the concerning assembly staff. A second generation product should have an improved assembly process than its previous generation.

20.   Designing for service/maintenance

Few parts and simple fastening methods result in easier, and thereby cheaper, disassembly. Snap fits can be disadvantageous for disassembly if they are not designed to simplify disassembly, service and maintenance. Standardization of fastening elements is important since e.g. fewer types off screws require fewer types of tools, which simplifies disassembly and service (Eskilander S, 2001).

Liquids that are hazardous for health or pollution should be avoided. Any hazardous substances in a product lead to difficulties in disassembly and re-use of the product (Eskilander S, 2001).

Valuable parts must be designed to be easily removed. These parts can then be recycled or re-used in another product (Eskilander S, 2001).

If a product is easy to disassemble, it will also be easy to adjust (Eskilander S, 2001).

Also take into consideration the risk of injuries and damages on items, when the product has to be maintained or disassembled.

Appendix 3: Benchmarking interviews

3.1. Intervju med Mikael Hultqvist från DeLaval

1. Hur ser er produktutvecklingsprocess ut? Kan du beskriva den?
   Svar: Generera idéer > Koncept > Develop Solution > Launch > Post Launch
2. Hur lång tid tar det att få ut en produkt på marknaden?
   Svar: Beror på produkten. En utveckling av produkten VMS och AMR tar flera år. Men minst 6 månader för en ny produkt.
3. Hur följer ni upp en produkt? Hur mäter ni resultat? Har ni interna mätvärden?
   Svar: Funderat på att ha en procentsats för monteringsvänligheten som mål i ett projekt. Men när man räknar fram monteringsvänligheteten med sådana metoder kan man få olika resultat beroende på kunskap hos utföraren. Vi mäter monteringtider, räknar kostnader. Man balanserar tider för att undvika förluster.
4. Hur mycket tillverkar ni själva? Hur mycket köper ni in färdigt?
   Svar: Här i Tumba gör man slutmonteringen så vi köper in mycket färdigt.
5. Hur sker samarbetet mellan konstruktion - och produktionsavdelningarna?
   Svar: Man vill göra en provmontering där konstruktörer är med, ingen riktig line. Man har ett modul-möte per vecka med konstruktörer, produktionstekniker, inköp representanter och planerare.
6. Använder ni andra metoder än DFA för att förbättra monteringsvänligheten av era produkter? I så fall vilka?
   Svar: Nej. Men tänker på DFM och försöker utnyttja underleverantörernas kunskap.
7. Hur länge har ni jobbat med DFA?
   Svar: Knappt ett år. Implementerat sedan december 2011.
8. Hur kom ni i kontakt med DFA?
   Svar: Via exjobbare som föreslog metoden.
9. Hur jobbar ni med DFA? Är det ett standardiserat arbete?
   Svar: DFA-riktlinjer när man utvecklar produkter. Implementerat sedan december 2011. Testar på en nollserie. I ett miniprojekt togs en kokbok fram. Frivillig process i produktutvecklingen. Finns ingen uppföljning på det.
10. I vilken fas av produktutvecklingsprocessen använder ni DFA?
    Svar: I develop solution, prototyp stadiet.
11. Vem eller vilka är ansvariga för att DFA används?
    Svar: Konstruktören själv. Checklistan används som hjälpmedel, är inget krav.
12. Hur fungerade implementeringen av DFA? Stötte ni på några hinder?
    Svar: Rätt bra. Tog lite tid att komma överens men inga större hinder.
13. Vad var svårt med implementeringen av DFA? Vad var lätt med implementeringen av DFA?
    Svar: Bra stöd från supplay chain.
14. Använder ni DFA- checklistor?
    Svar: Ja.

15. Använder ni DFA-software?
    Svar: Nej inte ännu.
16. Hur fungerar upprätthållande/revisionen av DFA?
    Svar: Det är inte svårt att införa ändringar.
17. Hur mäter ni monteringsvänligheten hos era produkter?
    Svar: Vi gör inte det.
18. Har det skett någon ändring i användandet av DFA sedan ni började med det?
    Svar: Man stödjer utvärderingsprocessen med att göra provmonteringar.
19. Ser ni eller har ni sett några nackdelar med användandet av DFA?
    Svar: Det blir ett extra steg men en vinst i längden.
20. Tänker ni även på att produkterna ska vara lätt att demontera vid exempelvis service?
    Svar: Service är viktigt. Är det lätt att demontera så är det lätt att montera.
21. Använder ni er av andra aktörer som granskar monteringsvänligheten hos era produkter?
    Svar: Ingen tredje part/aktör. I sådana fall fungerar provmonteringen som en sådan.

3.2. Intervju med Dick Bergman och Erik Jaenssen från Scania

1. Hur ser er produktutvecklingsprocess ut? Kan du beskriva den?
   Svar: Indelad i tre under-processer: konceptutveckling (gul); produktutveckling (grön) och produktuppföljning (röd). Under konceptutvecklingen sker en del forskning och ett uppdragsdirektiv tas fram. Produktutvecklingen är indelat i fyra faser/generationer: funktionsgeneration I, funktionsgeneration II, verifikationsgeneration och valideringsgeneration.
2. Hur lång tid tar det att få ut en produkt på marknaden?
   Svar: Runt sex år. Det skiljer sig mellan projekt men upp till sex år.
3. Hur följer ni upp en produkt? Hur mäter ni resultat? Har ni interna mätvärden?
   Svar: Inga siffror som mätvärde. Produktionstekniker lämnar synpunkter på konstruktion som sedan kan åtgärdas. Man mäter monteringstid, och hur en produkt går felfri igenom monteringslinan, detta blir något slags av nyckeltal. Det viktiga är att tro på metodiken för att fysiska resultat kommer fram ändå.
4. Hur mycket tillverkar ni själva? Hur mycket köper ni in färdigt?
   Svar: Standardkomponenter köps in färdiga. Det är ett tiotal komponenter som vi gör själva resten köps in. Det ingår även en del förmontering.
5. Hur sker samarbetet mellan konstruktion och produktions avdelningar?
   Svar: Det är ett dagligt arbete. Vi är länken mellan konstruktion och produktion. Vi är med i så kallade layout-möte under konceptutveckling-fasen och ger synpunkter på konstruktionslayouten det vill säga saker som kan påverka utseendet av en produkt (motor). Här är det mycket fokus på hur monteringslinan ser ut så at man inte behöver göra radikala ändringar. Man följer upp sedan konstruktionen genom att träffa konstruktörer minst en gång i veckan. Relationsbyggandet är viktigt vid kontakt med konstruktörerna. Verifiering av konstruktionen sker genom att konstruktören

lämnar en prototyp för provmontering på en så kallad utvecklingslinje. På utvecklingslinjen testas bara nya produkter. Även verifiering av CAD-modeller förekommer då kollar man t.ex. om man får plats för standard verktyg. Det är viktigt att påminna konstruktörerna om att rätt monteringssekvens ska följas.

6. Använder ni andra metoder än DFA för att förbättra monteringsvänligheten av produkter? I så fall vilka?
Svar: SES (Scanias Ergonomi Standard) är ett annat verktyg som är kopplat till DFA där man kollar på konstruktionen och ser till att ergonomiska krav uppfylls. Man ser till att produkten är monteringsvänlig ur ergonomi synpunkt.

7. Hur länge har ni jobbat med DFA?
Svar: Sedan 1990 började Dick Bergman jobba med DFA.

8. Hur kom ni i kontakt med DFA?
Svar: Dick Bergman gick på en DFA-kurs.

9. Hur jobbar ni med DFA? Är det ett standardiserat arbete?
Svar: Ja. Vi har styrande dokument. Vi har en checklista som konstruktörer kan gå igenom, den ligger upplagd på deras hemsida. Konstruktörerna kan använda den som hjälpmedel. Men det är vi som driver frågan. checklistan består av 130 frågor och är uppdelat i kategorier beroende på vad det är som påverkas t.ex. logistik, montering m.m. Produktionsteknikern tar upp ur checklistan de frågor som är relevanta vid varje respektive verifiering/möte med konstruktörer. Checklistan är inte någonting man tar upp dagligen, den är mer som ett stöd. I verkligheten är det inte många konstruktörer som använder checklistan. Det finns även lite skillnad på nyexaminerade och mer erfarna konstruktörer där erfarna konstruktörer erhåller stor kunskap om hur montering och tillverkning går till. Men nyexaminerade är öppnare för konsultation och rådgivning från produktionsteknikerna. Det blir en vinst i det långa loppet.

10. I vilken fas av produktutvecklingsprocessen använder ni DFA?
Svar: Redan vid konceptutvecklingsstadiet. Och sedan uppstyrd vid varje fas/generations övergång.

11. Vem eller vilka är ansvariga för att DFA används?
Svar: Det är egentligen våra chefer som är ansvariga. Men det är vi som utför arbetet.

12. Hur fungerade implementeringen av DFA? Stötte ni på några hinder?
Svar: Det fungerade bra. Kommer inte ihåg att vi stött på några hinder. Chefer som kanske inte förstår tänket med DFA vill se till att det är lönsamt.

13. Vad var svårt med implementeringen av DFA? Vad var lätt med implementeringen av DFA?
Svar: Det var lätt att man fick stöd från ledningen.

14. Använder ni DFA- checklistor?
Svar: Ja, men checklistan används mer som upplagsverk.

15. Använder ni DFA-software?
Svar: Nej. Men det finns kunskapsbank där man ta till vara på alla bra konstruktionslösningar som föds inom företaget. Men man vill köpa en mjukvara där

man simulerar hur man monterar detaljer och även kolla ergonomin. Man har samarbete med Solme som ska ta fram en DFA-modul baserad på DFA2-metoden.

16. Hur fungerar upprätthållande/revisionen av DFA?
    Svar: Vi stämmer av med konstruktörerna checklistan vid behov.

17. Hur mäter ni monteringsvänligheten hos era produkter?
    Svar: Via synpunkter mäter man något slag monteringsvänlighet.

18. Har det skett någon ändring i användandet av DFA sedan ni började med det?
    Svar: Det har gjorts så mycket förarbete med checklistan så man känner inte att det är så mycket man ska ändra. Genom enkla lösningar har man kunnat minska monteringtiden drastiskt och vi har ett flertal exempel på detta.

19. Ser ni eller har ni sett några nackdelar med användandet av DFA?
    Svar: Nackdelarna är inte så många. Kanske är det tidsödande men är det verkligen en nackdel? Det är en investering, det blir en vinst i längden. Det är ingen mirakel medicin, om du köper den utan att förstå så ger den ingen effekt.

20. Tänker ni även på att produkterna ska vara lätt att demontera vid exempelvis service?
    Svar: Vi har en egen avdelningen som tar hand om demontering och de kan komma med viktiga synpunkter då får man kompromissa. Är det lätt att montera är det inte alltid lätt att demontera.

21. Använder ni er av andra aktörer som granskar monteringsvänligheten hos era produkter?
    Svar: Ingen tredje part/aktör. I sådana fall fungerar provmonteringen som en sådant.

3.3. Intervju med Mattias Bognäs från Sony Mobile Communications

1. Hur ser er produktutvecklingsprocess ut? Kan du beskriva den?
   Svar: Industridesign tar fram en design. Den skickas till konceptteamet som försöker få in tekniken som krävs, sen tar projektdelen över och tar fram telefonen.
   Under produktutvecklingsprocessen bygger vi ungefär 3 versioner av telefonen som vi kallar prototypbyggen. Mellan de byggena har vi möjlighet att göra designändringar för att förbättra DFA.
   Vi har produktutveckling i Lund, Peking och Tokyo och sen har vi våra monteringsfabriker i Kina.

2. Hur lång tid tar det att få ut en produkt på marknaden?
   Svar: Ca 1 år

3. Hur följer ni upp en produkt? Hur mäter ni resultat? Har ni interna mätvärden?
   Svar: Vi mäter Yield i produktionen under prototypbyggena.
   Vi har en issue lista där vi tar upp problem relaterade till DFA.
   Vi kallar vårt arbetssätt för DFM, Design For Manufacturing. En del av det vi tittar på i DFM bygger på DFA. Vi rankar issues och mäter vid olika tillfällen hur många issues som är öppna.

Sen har vi även en generell kravlista där vi mäter hur många av kraven som är uppfyllda.

4. Hur mycket tillverkar ni själva? Hur mycket köper ni in färdigt?

    Svar: Generellt kan man säga att vi monterar alla komponenter som går att montera för hand utan att använda några komplicerade utrustningar, som "heat stake" och svetsning. Vi köper t ex in kameror och LCDer som behöver specialutrustning och testas. Ibland väljer vi att låta underlevernatörer montera delar som vi bedömer att de kan montera säkrare än vår fabrik.

    Något som vi däremot har inom Sony är montering av kretskort i ytmonteringsmaskiner.

5. Hur sker samarbetet mellan konstruktion och produktions avdelningar?

    Svar: Vi som arbetar med DFM jobbar inom Industrialisering vilket är mellan konstruktion och produktion. Vi tar kontinuerligt in krav och förslag från produktion som vi försöker implementera i konstruktionen. Vi har daglig kontakt med båda parter för att få fram en kompromiss på designen.

6. Använder ni andra metoder än DFA för att förbättra monteringsvänligheten av era produkter? I så fall vilka?

    Svar: Våra krav och guidelines bygger på DFA men vi kallar det för DFM.

    Vi har en databas med "Lessons learned" från tidigare telefoner där vi kan gå in och hitta bra lösningar.

7. Hur länge har ni jobbat med DFA?

    Svar: Åtminstone 10 år. Innan dess var vi Ericsson med fabriker i Sverige och vet ej hur det gick till i detalj på den tiden.

8. Hur kom ni i kontakt med DFA?

    Svar: Hur det startade har jag inget svar på. Det fanns redan när jag började på Sony.

9. Hur jobbar ni med DFA? Är det ett standardiserat arbete?

    Svar: Vi börjar med att titta på ett utkast av en design i 3D CAD som vi försöker påverka för att göra den mer producerbar. Konstruktören ansvar för hela designen men fokuserar mest på tillverkningsprocessen av de enskilda komponenterna och sen även hållfasthetskrav för telefonen.

    Vi har en väl etablerad process för detta arbete och det sker kontinuerligt förbättringar.

10. I vilken fas av produktutvecklingsprocessen använder ni DFA?

    Svar: Från tidigt i koncept när vi har någon design att titta på och ända fram tills telefonen lanseras på marknaden. Mest påverkan har vi i den tidiga fasen som vi kallar koncept. Sen kan man i stort sätt bara göra små justeringar i designen.

11. Vem eller vilka är ansvariga för att DFA används?

    Svar: Inte helt enkelt att svara på. Men i telefonprojekten så är det Industrialiseringsobjektet som ser till att DFA utförs. I det objektet finns det en enskild person som utför arbetet.

12. Hur fungerade implementeringen av DFA? Stötte ni på några hinder?

Svar: Vi har länge haft funderingar på att börja använda ett verktyg som heter DFA2 men det har inte riktigt kommit på plats. Något vi känner att vi saknar just nu är ett mätvärde som visar producerbarheten av en telefon. Som vi sen kan använda för att besluta om vi ska fortsätta projektet eller det behövs göras mer förbättringar i designen.

13. Vad var svårt med implementeringen av DFA? Vad var lätt med implementeringen av DFA?
Svar: Om vi tar DFA2 igen så känner vi att det inte riktigt går att använda rakt av utan vi behöver anpassa frågorna i verktyget för att passa mobiltelefoner.
När vi tittade på Boothroyd-Dewhurst DFA verktyg så kände vi att det var väldigt tidskrävande att bygga upp byggstrukturen. En telefon design ändras väldigt fort i det tidiga skedet av utvecklingsfasen och då behöver vi ett verktyg som är snabbt och enkelt att använda. Sen när en ny telefon tas fram så brukar den alltid vara uppbyggd på ett nytt sätt så det är svårt att återanvända strukturen från en tidigare modell.

14. Använder ni DFA- checklistor?
Svar: Vi använder en DFM checklista med ungefär 60 generella krav och 200 guidelines. Sen skapar vi en lista där vi noterar alla DFM issues som behöver jobbas med för att få till en designändring.

15. Använder ni DFA-software?
Svar: Nej, inte för tillfället. Vi har tittat på DFA och DFA2.

16. Hur fungerar upprätthållande/revisionen av DFA?
Svar: Månadsvis uppdaterar vi kravlistan för att vara "alignade" med produktionen.

17. Hur mäter ni monteringsvänligheten hos era produkter?
Svar: Det är inget vi gör för tillfället men det har länge funnits en önskan inom företaget att kunna mäta det.

18. Har det skett någon ändring i användandet av DFA sedan ni började med det?
Svar: Det har ständigt varit förbättringar och DFM har fått mer och mer uppmärksamhet inom företaget.

19. Ser ni eller har ni sett några nackdelar med användandet av DFA?
Svar: Nej, bara vår arbetstid.
DFA verktygen som vi har tittat på har inte riktigt passat det vi har varit ute efter.

20. Tänker ni även på att produkterna ska vara lätt att demontera vid exempelvis service?
Svar: Vi som jobbar med DFM tittar på hur telefonen demonteras i produktion. Eftersom en del telefoner faller ut i våra tester och måste repareras. Sen har vi en avdelning som jobbar med fältreturer och de är med i utvecklingsprocessen och fokuserar på dessa frågor. De har ett liknande arbetssätt som oss.

21. Använder ni er av andra aktörer som granskar monteringsvänligheten hos era produkter?
Svar: Det sker inte kontinuerligt med det har skett att någon har jämför våra telefoner med konkurrenter.
Vi gör själva analyser av våra konkurrenter och jämför med våra projekt men den analysen sker i textform.

Appendix 4: Assembly efficiency calculation

4.1. Assembly efficiency calculation on product level

Objekt/Produkt/Modul	Reducera antal detaljer	Unika detaljer	Basobjekt	Utforma basobjekt	Monterings-riktningar	Parallella operationer	Toleranskedjor	SUMMA
PRODUKTNIVÅ	1	3	9	1	1	9	1	25

Monteringsvänlighet, M, beräknas: Total summa/ Maximalt möjliga poäng

$$M = 25/(7*9) = 0,396825... \approx 40\ \%$$

4.2. Assembly efficiency calculation on part level

Detaljnivå (final assembly)

Lista på detaljer	På varandra följande likadana detaljer	Måste detaljen monteras?	Orientering	Oömma detaljer	Fasthållning	Tyngdpunkt	Form	Vikt	Längd	Gripning	Monteringsrörelser	Åtkomst	Inpassning	Toleranser	Hålla fast monterade detaljer	Fästmetod	Sammanfogning	Kontroll/justering	SUMMA
1. Nedre lock(m. skruv)	0	9	1	9	1	3	1	9	9	3	9	9	1	1	3	3	3	9	83
2. Triggerknapp	0	9	1	3	9	3	1	9	9	3	9	3	3	1	3	9	9	3	87
3. Rev trigger	0	9	1	9	9	3	1	9	9	3	9	3	1	1	3	9	9	1	89
4. Display	0	9	3	3	9	3	1	9	3	3	3	3	9	1	3	3	3	9	77
5. Ledkort	0	9	1	3	9	1	1	9	9	1	3	3	9	3	9	9	9	1	89
6. Bajonett	0	9	3	9	9	9	1	9	3	3	3	9	1	1	3	3	3	9	87
7. Högtalare	0	9	3	3	1	9	1	9	9	1	9	9	9	1	1	3	3	9	97
8. Avkännare	0	9	3	3	9	9	1	9	9	3	9	3	9	3	3	3	3	9	97
9. Komuteringsgivare	0	9	3	3	9	3	1	9	9	1	9	9	3	1	9	9	9	3	99
10. Undre lock	0	9	3	3	9	3	1	9	3	9	9	9	3	1	3	3	3	9	89
11. Gängad skiva	0	9	3	9	9	3	3	9	9	3	3	3	9	1	9	3	3	9	97
12. Gängad splines	0	9	3	9	9	1	3	9	9	3	3	9	9	1	9	3	9	3	101
13. Låsning i plast	0	9	3	9	9	3	3	9	9	3	9	3	9	1	9	3	9	3	103
14. Liten låsring	0	9	9	9	1	9	9	9	9	9	3	3	1	1	9	3	3	9	105
15. Axel	0	9	3	9	9	9	3	9	3	1	9	9	1	1	9	9	9	9	111
16. Yttre lock	0	9	1	9	9	3	1	9	9	3	9	9	9	1	3	3	9	9	105
17. Handtag vä	0	9	3	3	9	3	1	9	3	3	9	3	3	3	3	3	3	9	79
18. Svart liten knapp	0	1	1	9	9	3	3	9	9	1	9	9	3	3	3	9	9	9	99
19. Enkel platt bricka	0	1	3	9	9	3	1	9	9	9	9	9	9	1	3	9	9	3	105
20. Huvudkabel	0	9	1	9	1	1	1	9	1	1	3	1	1	3	3	9	9	3	65
21. Mainboard	0	9	9	3	9	9	1	9	3	1	1	3	3	1	3	3	3	3	73
22. Växeln	0	9	3	9	9	1	1	9	3	1	9	9	9	1	3	9	9	9	103
23. Kort m. kabel	0	9	3	9	9	1	1	9	9	1	9	9	3	3	3	9	9	3	99
24. Kort under lock	0	9	9	3	9	3	1	9	9	3	9	9	9	3	3	3	3	9	97
25. Fjäderbricka(växel)	0	9	3	9	9	3	9	9	9	3	9	9	1	1	3	9	9	3	107
26. Kabel/jord	0	9	3	9	9	1	3	9	9	1	9	9	1	3	3	3	3	3	87
27. Ståldetalj(under mo)	0	9	3	9	9	3	1	9	9	3	9	9	9	1	9	9	9	9	119
28. O-ring	0	9	3	9	9	3	9	9	9	1	9	9	3	3	3	9	9	9	115
29. Plastring	0	9	3	9	9	3	1	9	9	3	9	9	3	3	9	9	9	9	115
30. Fjäderbricka(vid mo)	0	9	3	9	1	3	9	9	3	3	9	9	3	1	3	9	9	9	107
31. Låsring på axel	0	9	3	9	1	3	9	9	9	1	3	9	1	1	9	9	3	9	97
32. Packning/tätning	0	9	3	9	9	3	3	9	9	3	9	9	9	3	3	9	9	3	111
33. Fjäder	0	9	3	9	1	3	9	9	9	1	9	9	3	3	3	9	9	9	107
																	TOTAL SUMMA:		3201

Monteringsvänlighet, M, beräknas: Total summa/(maximalt möjliga poäng*antal detaljer)

M= 3201/(17*9*33)= 0,6339869281... ≈ 63 %

xx

Appendix 5: FMEA

FMEA	Issued by: Alexander Anturi & Jenny Tiger							Date: 2012-04-03	
Process	Type of failure	causes of failure	failure effects	O	S	D	RPN	recommended action	Responsible person
perceive different objectives between "customer" (AC) and "supplier" (KTH)	communication	misunderstanding, two different mentors	different result	3	6	4	72	Check with both mentors preferably simultaneously.	Alexander and Jenny
the checklist is poorly performed	administrative	lack of time, lack of commitment and/or poor planning, poorly defined	the company is not satisfied with the work, not representative as a working template	4	7	4	112	plan more hours, start earlier, clarify what should be expected from a checklist, more research	Alexander
Receive very different outcome from the interviews	not enough elaborated work	wrong formulated questions or not clear enough	False/untrue picture of the real situation, inadequate result	2	4	2	16	Evaluate/test the questions first, be more accurate while preparing questions	Jenny
Issues with the technics (such as internet, computers etc.)	technical problem	old equipment, not fully working or verified	time delay in our working process	5	3	8	120	Verify that the technics is working in advance	Atlas Copco
rescheduling in the project's plan	process problem	delays, project is poorly planned, the pan of the project is not followed as expected, difficulty in matching peoples agenda	lower quality of the performance, delays when delivering results, less time for reporting	7	5	6	210	Evaluate the impact on the projects result and replan. Set deadlines	Alexander and Jenny

The collaboration between the students doesn't work as expected	collaboration	Incompatibility of personalities. Different working approach.	decreased performance of each student, communication difficulties	7	6	7	294	communicate and agree in the best possible working approach	Alexander and Jenny
too little time for reporting	planning	Too much spend on analysis, procedures and results. Delays during the project	lower quality of the report, time budget will be exceed	7	6	5	210	inform the supervisors, increase the time set for reporting	Alexander and Jenny
too little time for preparation of the presentation	planning	Too much spend on reporting. Delays	poorly performed presentation	5	5	7	175	inform the supervisors, if possible postpone the presentation	Alexander and Jenny